Effect of seasonal variation on optimal selection of seeding machinery

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Introduction

Selection of optimally sized cropping gear is an important financial decision for farmers. The cost of machinery relative to other cropping costs is large and delayed sowing of crop can lead to large losses in yield. In the eastern wheatbelt of Western Australia depreciation on machinery, ownership costs and repairs and maintenance are over 40% of total cropping costs (Pannell and Bathgate, 1990). Yield losses can be as high as 15 kg/ha for every day sowing of cereal is delayed (Perry, 1990). Losses can be up to 30 kg/ha/day for crop legumes; lupins and field peas.

A number studies have been conducted which determined optimal sets of machinery. Most have used mathematical programming (MP) to simultaneously determine optimal machinery complements and cropping strategies. For example, Lone at al (1986) used mixed integer programming to model a number of farms in Southern Dakota to 'determine optimal machinery complements for farms of different size and crop enterprise combinations'. Earlier work by Danok et al (1978) used a similar approach for a State farm in Iraq. Both studies developed a single period model, with annualised machinery costs.

In many farming systems the uncertainty of weather is important factor in influencing machinery selection. Danok et al (1980) allowed for the uncertainty of field time by using chance constrained programming and concluded that it was important to consider the stochastic nature of weather in machinery selection. Wetzstein (1986) used simulation modelling and stochastic dominance to determine the optimal machinery selection in a double cropping system and concluded that it was necessary to detail the 'interactions between the environment' and 'production to adequately model machinery selection'. Both studies emphasised the importance of determining machinery selection and crop area simultaneously.

This study uses a discrete stochastic programming model which allows for seasonal uncertainty to determine the optimal size of machinery in the eastern wheatbelt of Western to Australia. Unlike other studies of the problem which have used MP, this approach allows for uncertainty in many production variables, the most important of which, to this problem, is crop yields and losses associated with the timeliness of sowing. The results are compared to those for a single period equilibrium model of the same region. The effect of changing the input of casual labour from season to season on the optimal size of seeding gear is also examined.

Model Description

MIDAS: Model of an Integrated Dryland Agricultural System

A detailed description of MIDAS can be found in Kingwell and Pannell (1986). Details of further developments of the model can be found in Pannell and Bathgate (1990) and Morrison and Young (1991).

It describes a representative dryland farm in the eastern wheatbelt region of Western Australia, using a MP framework. It is a single year, equilibrium model which represents an average season. The model differs from other MP models by describing the biology of the system in greater detail. Particular attention has been paid to interactions between the cropping and livestock enterprises.

Seven soil types are described in the current version of the model with up to twenty six rotation options on each soil class. Factors considered in each rotation are: the effect of cropping on pasture growth, disease carryover, nitrogen fixation and weed burden. Crop options include; wheat, barley, oats, triticale, lupins and field peas.

Thirty classes of sheep represent different ages, selling times, sex and pregnancy status. These combine to describe a self-replacing sheep flock.

Pasture growth during winter and spring, and deterioration of crop residues and pasture over the dry months of the year are divided into twelve monthly periods. Stubbles are available for grazing from November onwards.

The machinery complement for seeding and harvesting is fixed. Machinery work rates and labour input combine to determine the rate of sowing. Del:vs in sowing of cereals and grain legumes lead to a reduction in final crop yields.

Commodity prices used are those expected in the medium term. For the most part the model is used for exante, static analyses of medium term strategies. The objective is to maximise whole-farm profit before tax.

MUDAS: Model of an Uncertain Dryland Agricultural System

A detailed description oı MUDAS can be found in Kingwell et al (1991).

MUDAS is a discrete stochastic programming model (DSP) which describes the same representative farm as MIDAS. The main difference is that nine different season types are described, along with associated yields and pasture growth. Within each season tactical adjustments can be made to farm plans in response to conditions as the season unfolds. Decisions are made on the basis of the season to date, with knowledge of the final outcome only of a probabilistic nature.

Adjustments which may be made to the farm strategy include; increasing or decreasing the area of crop, altering the level of supplementary feeding, agistment of sheep, pasture deferment, fertiliser rates and casual labour input.

Price risk is represented by a set of historical prices. In this study prices between 1986 and 1991 are used. Assumptions concerning risk attitudes of farmers can be varied within the DSP framework, however risk neutrality is assumed for the purposes of this analysis. As with MIDAS the objective is to maximise whole-farm profit before tax.

Analysis of optimal machinery complements

This study concentrates on the analysis of optimal size of seeding gear. As the risk of crop damage during harvest in the eastern wheatbelt is very low, the period of harvest is not critical.

On the other hand, results of trials conducted by the Department of Agriculture in Western Australia consistently show a strong relationship between crop yield and time of sowing. Depending on the time of the break of season, it is assumed in MUDAS that yield losses are between 7 and 30 kg/ha for every day sowing is delayed beyond the opening rains. Size of seeding gear affects the rate of sowing and hence the total yield loss resulting from delayed sowing.

Defining machinery sets

Complements of machinery defined for this analysis are described by the width the cultivator bar. Tractors and seeding implements were matched according to the draft requirement of the implement, as per Reithmuller (1988).

The draft requirement for an implement is dependent largely on the soil type being worked. Given the soil type differences that exist between farms draft requirement was determined for a heavy and a light soil for the same speed of working and sowing depth. The greater draft requirement of the heavy soil meant a larger tractor was required, which has a higher total value. Hence depreciation and ownership costs are higher.

The main factor affecting depreciation and ownership costs is machinery value (or price). An examination of sale figures reveal that the value of second hand machinery is extremely variable, so a sensitivity analysis of value was conducted for machinery with the larger draft. This means that the analysis was repeated three times at different assumed values of seeding machinery.

Depreciation

Anecdotal evidence suggests depreciation is partly dependent on the use of the machinery. ie. it will depreciate faster the more it is used. Therefore depreciation was separated into fixed and usage components.

To the knowledge of the author there has been no analysis of farm machinery which attempts to quantify the proportions of fixed and usage depreciation. Consequently the analysis was repeated for two rates of fixed and usage depreciation, to examine the importance of these factors on machinery selection.

Hansen and Lee (1991) determined rates of depreciation of farm tractors in Canada and showed that annual depreciation was not affected by new technology (tractor vintages) and did not vary over time. However no attempt was made to separate fixed and usage depreciation. Given that larger machinery is usually associated with a greater area of crop it is reasonable to suspect that depreciation would be constant across tractor models only when machinery size is matched to area of crop. In other words, depreciation would be lower when machinery is underutilised in a technical sense.

In this study annual depreciation is assumed constant across different sizes of machinery, only when the area of crop and machinery size are appropriately matched. Results of a survey of farmers in the eastern wheatbelt were used to determine the average crop area associated with different sizes of seeding gear. Depreciation was calculated for each complement of seeding machinery and then divided proportionally into fixed and usage components. The per hectare cost of depreciation was then calculated using the area of crop previously matched to each size of seeding gear.

Optimal machinery complements were determined for both MUDAS (DSP) and MIDAS models. The analysis was then repeated using MUDAS, altering assumptions regarding the input of casual labour during seeding. Labour input was altered so more labour was hired during seasons when yield losses from delayed sowing were potentially highest. This allows an increase in the rate of sowing without increasing the capacity of machinery.

Initially it was assumed that usage and fixed depreciation are 75% and 25% respectively of total depreciation. The model was rerun assuming that usage and fixed depreciation were 25% and 75% respectively of the total.

Sensitivity analyses were also conducted to examine the impact of different annual depreciation rates and discount rates on machinery selection by the two models

The results of the analyses are presented below.

Results and discussion

Initial runs showed that the optimal area of crop and hence machinery size is smaller when seasonal variation in production parameters is not considered. These results are consistent with Kingwell at al (1990) who found that when tactical adjustments are not made to farm strategy, the optimal crop area is more sensitive to changes in commodity prices. The expected wool price over the period 1986–90 was high relative to expected wheat price. The much higher relative profitability of wool led to an optimal area of crop 13% less than the optimal area selected by MUDAS.

Also, when wheat prices are high relative to wool prices the optimal area of crop selected by MIDAS is larger than is the case if seasonality was taken into account. Markedly different areas of crop means that the optimal size of seeding machinery would also be different for the two models.

Because the optimal areas of crop selected by the two models were different, a constraint was included in MIDAS so that the area of crop was equal to the area selected by MUDAS, for a given width of seeding gear.

Optimal size of seeding gear

Figures 1a. and 1b. show the increase in profit resulting from a change in the width of seeding gear for both models, assuming the value of machinery is $19500 for each additional metre of seeding width above the standard width of 7.5 metres. In Figure 1a the optimal width of seeding gear according to MUDAS is 12 metres but this is only is marginally more profitable than 10 metres ($100/annum) and 14 metres ($500/annum). The opportunity cost of selecting these sub-optimal sets of machinery is not significant.

Where no allowance is made for seasonal uncertainty, as in MIDAS, the optimal width is 10 metres. This is $1500 less profitable than a seeding width of 12 metres.

Figure 1b shows the change in profit for different seeding widths assuming fixed depreciation is 75% of the total. Although smaller machinery is optimal in Figure 1b the results are generally consistent with those in Figure 1a. That is, when seasonal uncertainty is not taken into account the optimal width of seeding gear is underestimated.

A narrower width of gear is optimal in Figure 1b because higher fixed depreciation effectively increases the cost of machinery to the farmer. Wide seeding gear is not utilised to capacity on farms of the size assumed in the models. This is reflected in lower depreciation costs when the major component of depreciation is variable (ie a result of use). However under utilisation has little impact on depreciation costs when the major component is fixed because the cost is incurred regardless of the area cropped.

Figure 1b differs to Figure 1a in that the cost to the farmer of selecting sub-optimal machinery, 2 metres narrower, may be significant. In this case the loss in whole farm profit is greater than $600 per year. The opportunity cost of smaller machinery may be much less however, depending upon the marginal tax rate of the farm business. However at current commodity prices the marginal tax rate would be very low for most businesses of the size assumed in the model.

Figure 1a. Change in whole-farm profit for different widths of seeding gear (Value of machinery, $19500/ additional metre. Fixed depreciation 25% of total)

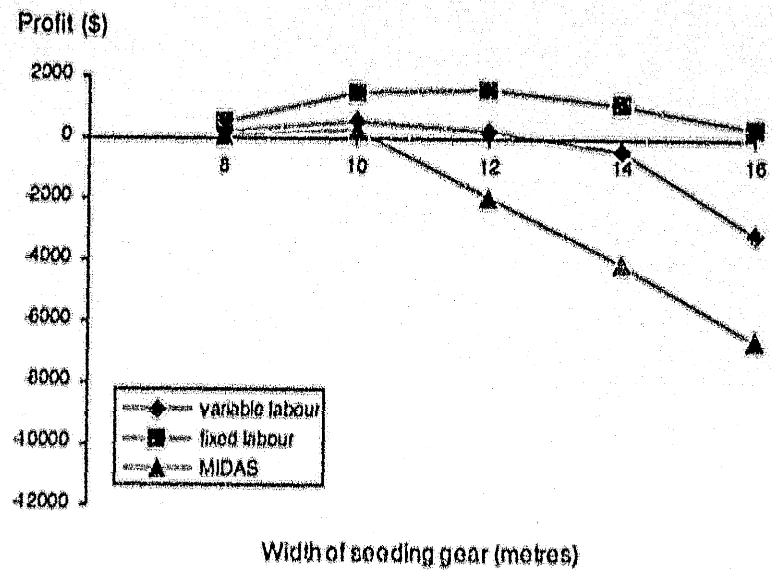
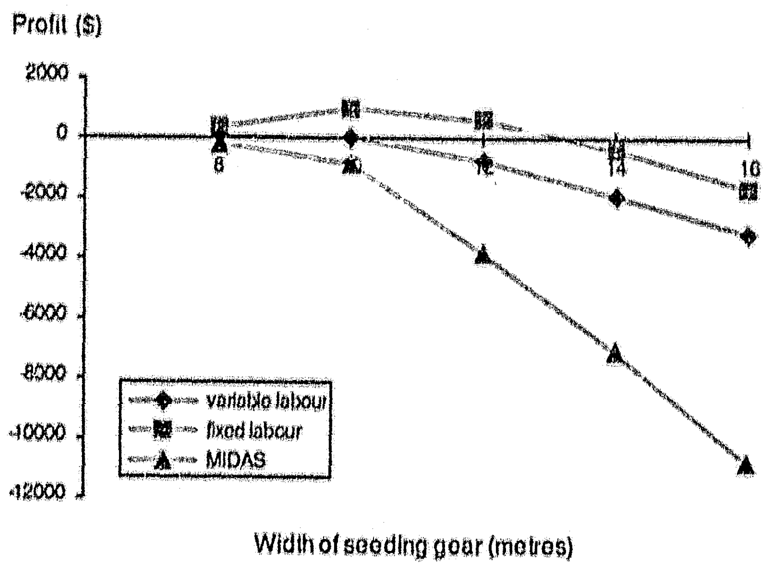


Figure 1b. Change in whole-farm profit for different widths of seeding gear (Value of machinery, $19500/ additional metre. Fixed depreciation 75% of total)



Effect of increased machinery size on farm strategy

Despite a doubling of the width of seeding gear there was no marked changes in the optimal farm strategy. The expected area of crop changed by only 6% over the range of machinery sets defined in the analysis. The area of cereal on two of the heavier soil types was increased by shifting away from continuous annual pasture to a pasture cereal rotation, and by altering the area adjusted in and out of crop according to season type.

This result is unexpected as an increase in the work rate at seeding time provides the ability to substantially increase the area of crop without increasing the yield penalty due to delayed sowing. Previous analysis using MIDAS (Bathgate, unpublished) led to the conclusion that the area of crop was quite sensitive to changes in the work rate at seeding time, as well as the mix of soil types on farm.

This indicates that the main benefit of increasing size of seeding gear is a reduction in the yield penalty by the timely sowing of crops.

Effect of tactical adjustments on machinery selection

The differences in the selection of optimal machinery is a consequence of the ability within the DSP framework to make adjustments to the strategic (or planned) area of crop according to the break of season. An increase in the area of crop in seasons with a good start results in a higher potential loss in yield. This is because sowing takes a longer period of time. The potential loss in yield in MIDAS is less than in MUDAS, because losses in an average year (as in MIDAS) are less than expected losses (as in MUDAS). Therefore the marginal revenue gained by reducing yield losses in MIDAS is less than the marginal revenue gained in MUDAS, and not sufficient to cover the marginal cost of 2 metres of additional width.

Yield losses from delayed sowing are dependent on: 1) the rate of loss each day sowing is delayed, 2) the area of crop (and hence the time taken to sow the crop) and 3) the length of the period, after the break of season, which is not subject to a yield penalty. These three factors, and the probability of a season occurrence determine the expected loss in yield from delayed sowing. The expected yield loss can be computed by weighting the yield losses in each season type by the probability of the season occurring and the area of crop in that season. The yield loss described in MIDAS is not weighted by the crop area because the adjustment to crop area in each season cannot be determined.

The importance of yield losses from delayed sowing in calculating the marginal value of seeding gear and the marginal value of cropping means that it is necessary to determine machinery size in conjunction with crop area and best rotations in each season. This is true even though the expected area of crop is relatively insensitive to width of seeding gear. If sowing is extended or reduced by just one day the marginal returns to crop are significantly altered.

Different values of seeding gear

Figures 2a and 2b show changes in profit from increasing the width of seeding gear, assuming a lower purchase price of machinery. The value of seeding machinery per additional metre in this case was $16000. This led to an increase in the profitability of larger seeding machinery, but not sufficiently to alter the optimal width.

Decreasing the draft requirement, and hence further reducing the value ($14150/ additional metre) and depreciation costs of machinery, the optimal width increased to 14 metres (Figure 3a).. When higher fixed depreciation was assumed the optimal width was 12 metres but the opportunity cost of adopting 10 metres (the MIDAS optimum width) was not significant (Figure 3b). The reduction in depreciation costs was not enough to alter the optimal size gear selected by MIDAS

When considering the often suggested notion that farmers are over-capitalised with cropping machinery, it is interesting to note that the opportunity cost of seeding gear 2 metres wider than the optimum is not significant n Figures 2a and 3a. In both cases the opportunity cost is less than $300 annually, pre-tax.

In Figures 2b and 3b the opportunity cost of over-capitalisation is higher but is still less than $600 per annum, pre-tax.

Effect of varying the input of casual labour between seasons

Results discussed above were based on the assumption that the input of labour, and hence the daily work rates, were constant across all season types. Figures 1 to 3 (a and b) show the optimal width of seeding gear when daily work rates are adjusted by changing the input of casual labour.

In seasons where there is likely to be more area sown to crop the number of seeding hours per day was increased by hiring more casual labour. More labour is also hired in seasons where yield penalties associated with late sowing are potentially large.

Not surprisingly, it was found that varying the labour input between seasons generally resulted in smaller width of seeding gear, coincidently the same width as was selected by MIDAS.

Increasing the input of labour in some seasons increases the efficiency of the seeding machinery so the same daily work rate can be achieved with smaller gear. Consistent with results above, the opportunity cost of selecting a sub-optimal set of machinery, 2 metres larger or smaller than the optimum, are insignificant in most cases. Another important feature is that varying the input of labour between seasons increased whole farm profit by between 2 and 3%.

Figure 2a. Change in whole-farm profit for different widths of seeding gear
(Value of machinery, $16000/ additional metre. Fixed depreciation 25% of total)

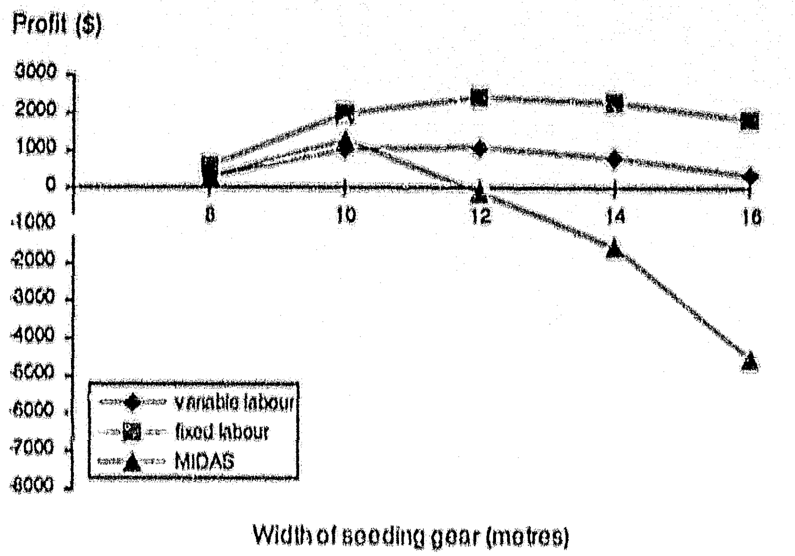


Figure 2b. Change in whole-farm profit for different widths of seeding gear
(Value of machinery, $16000/ additional metre. Fixed depreciation 75% of total)

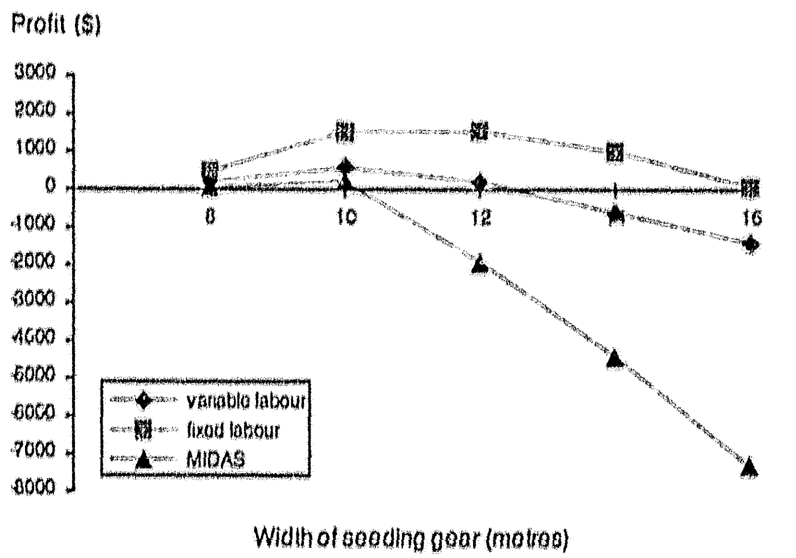


Figure 3a. Change in whole-farm profit for different widths of seeding gear
(Value of machinery, $14500/ additional metre. Fixed depreciation 25% of total)

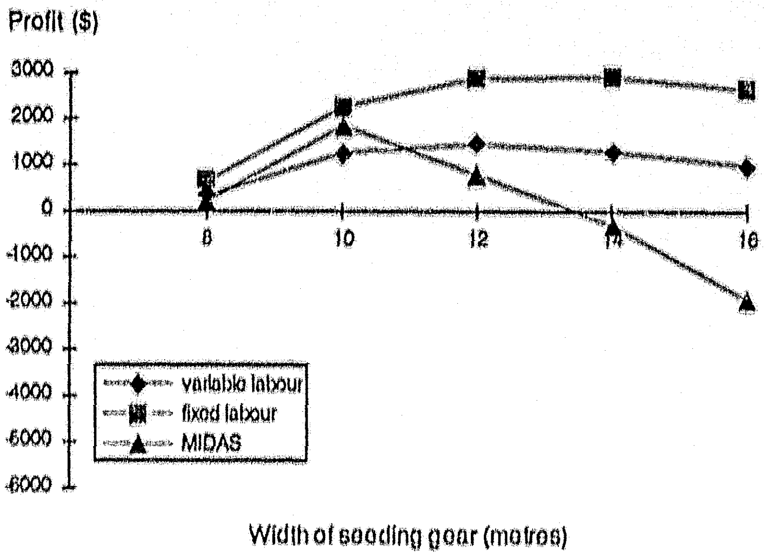
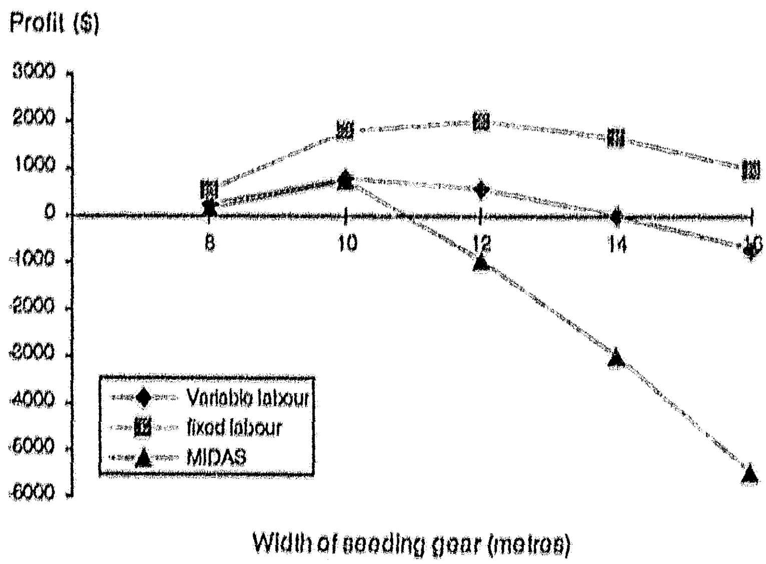


Figure 3b. Change in whole-farm profit for different widths of seeding gear
(Value of machinery, $14500/ additional metre. Fixed depreciation 75% of total)



Whilst increasing the labour input reduces t. ...d for wider gear, and increases farm profit, it is often argued by farmers in the eastern wheatbelt that it can be difficult to hire competent labour at seedi... ...e. Mistakes often decrease crop yield potential or further delay sowing. This could lead to costs greater than the savings associated with smaller machinery.

Conclusions

A comparison of the optimal size of seeding gear selected by the two different models showed that analyses based on 'average' production assumptions could lead to the optimal size being underestimated.

Machinery selection needs to be done in conjunction with the selection of optimal crop plans. This includes adjustments to cropping areas from year to year, according to seasonal conditions. This means seasonality is an important consideration in machinery selection. This conclusion is consistent with other studies of the problem.

The main benefit of larger machinery is the timeliness of sowing, avoiding costly yield penalties associated with a delay in sowing. This is evident as machinery size had very little impact on the optimal farm strategy.

However, while seasonality does affect the selection of optimal cropping gear, in many instances the opportunity cost of selecting sub-optimal gear is not significant. On the other hand, analysis using MIDAS is unlikely to lead to the adoption of machinery larger than its optimum due to the apparently large opportunity cost of selecting wider gear.

Analyses not including seasonality aspects of production could lead to the conclusion that farmers are over-capitalised in seeding machinery. Results in this study indicate that this may not be the case, however. Also, where there is over-capitalisation that the opportunity cost may be small, depending on the marginal tax rate faced by the farmer.

Arguments regarding over-capitalisation appear to be supported however, where the quantity of labour can be altered according to seasons, to increase daily work rates without increasing the width of seeding gear. Selecting gear up to 2 metres wider than the optimum has a low opportunity cost, consistent with results derived under the assumptions of fixed labour between seasons. Therefore objectives other than profit maximisation can often be met at little cost to the farmer.

A better understanding of how use of machinery affects the decline in value through time is important to the determination of optimal machinery size. If fixed depreciation is the major component of the decline in value, optimal machinery size will be smaller compared to the optimum where usage depreciation is the major component. An econometric analysis of machinery sales data to determine the factors affecting depreciation rate may be useful in the resolution of this issue.

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