MACHINERY SELECTION BASED ON MACHINE COSTS

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Abstract

Some of the principles that influence machine costs are discussed with the aim of improving the selection of optimum machinery complements. Emphasis is laid on the costs of untimely execution of operations and of under-utilization of power resources. A computer programme to analyse the mechanised requirements of a farm is discussed.

Introduction

In this paper some of the aspects that need consideration when selecting the optimum machinery complements for a farm are discussed. The increase in cost of energy as a result of not fully utilizing the available power of a tractor is subject for discussion as is the effect of tractor size on the hourly utilization factor. The concept of a timeliness penalty is introduced and it is shown how this penalty can influence the choice of machinery. Finally a computer programme that has been developed to evaluate the optimum machinery complement as an aid to mechanization planning is discussed.

Under-utilization of power resources

It is a costly practice not to fully utilize the potential power available from agricultural machinery. Each tillage task scheduled by a farmer may be measured in terms of the energy required to complete that task. The amount of energy required per operation per unit area is not a fixed quantity, but does vary somewhat with the speed of operation, although as shown by Zoz[7] (see Fig 1) and Grecenko[3] the variation in energy requirements for variation in speed is fairly small.

The energy requirement for any task may be expressed in terms of kilowatt hours. It is the product of the power available and the time for which that power is required to achieve an end result. As an example, consider a 43 kW tractor working at 50, 70 and 30 percent of maximum power. The cost per unit of energy is shown for each of the three conditions in Table 1, assuming that life expectancy increases in proportion to the decrease in average demand. The fuel consumption at the various power ratings was derived from Fig 2 on the assumption that operation was at the full govenor control lever position.

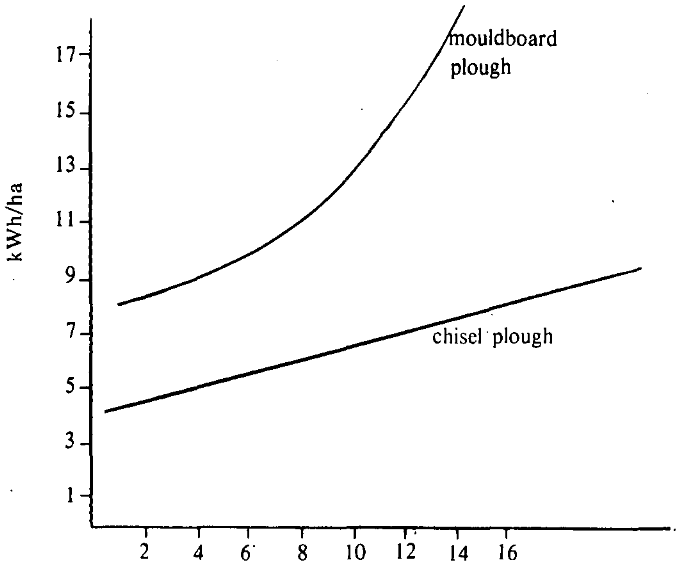

Figure 1. Energy per hour required vs speed of operation for chisel and mouldboard ploughing (after Zoz[7]).

TABLE 1
Calculation of cost per kWh

% Utilization of Power	70	50	30
Average power (kW)	30	21,5	12,7
Assumed life	5	6	7
TOTAL INVESTMENT (I)	10 000*	10 000	10 000
Tyre value	632	632	632
Resale value	3 500	3 000	2 500
Depreciable amount	5 868	6 368	6 868
FIXED COSTS			
Interest ($I(\frac{x+1}{2x}) \times .10$)	600	583	571
Licence, Insurance, 3rd party (.2xI)	200	200	200
Depreciation (Straight line)	1 174	1 061	981
TOTAL FIXED COSTS Per Annum	1 974	1 844	1 752
Specific fuel consumption (kWh/ℓ)	2,4	2,0	1,5
OPERATING COSTS			
Fuel (@ 15c/litre)	2 250	1 935	1 529
Oil and Grease (@ 10c/hr)	120	120	120
Tyres (pro-rata of 3 000 hr life)	252	252	252
Maintenance (0,75 x I/life yrs)	1 500	1 250	1 071
TOTAL OPERATING COSTS	4 122	3 557	3 043
TOTAL FIXED & OPERATING COSTS	6 096	5 401	4 795
Cost per hour	5.08	4.50	3.99
Cost per kilowatt hour	0,169	0,209	0,313

*** All costs expressed in Rand.**

Taking 50% of maximum power as the standard it can be seen from Table 1 that the cost is 20,9 c/kWh. By working at 70% of maximum power, this cost can be reduced by 19% to 16,9 c/kWh. Working at 30% of maximum power results in a cost of 31,3 c/kWh, which is 50% more expensive than the standard.

Some notes on the use of specific consumption as a tool for determining average utilization are given in Appendix I.

Matching of tractor to implement

An efficient tractor-implement match results in the tractor being fully utilized at acceptable speeds of operation and within acceptable limits of tractive efficiency. Fig. 3 illustrates the available output from a tractor in the various gear ratios. Superimposed thereon is the allowable implement input, the boundaries of which are determined by the allowable speed limits and expected draft variation as a result of different draft-speed relationships for the soils to be encountered. The measure of the degree of success of the tractor-implement match is the area of overlap between the available tractor output and allowable implement input.

In Fig. 3 Pd is the envelope of potential drawbar power, ie. (maximum axle power) x (tractive efficiency). Pdx and Pdy are the amounts of available drawbar power in gear ratios x and y respectively. B and C are the limits in drawbar pull expected due to variations in soil type, A represents the lower limit of tractive efficiency allowed, and V1 to V6 are rays of constant speed where V1 < V6. X is the increase in drawbar pull with respect to speed (after Grecenko[3]).

Under-utilization with respect to hourly use

Booysen and de Beer[1] illustrated the cost of under-utilization with respect to an hourly use factor. The hourly use factor is dependent on the match of the selected tractor-implement combination to the farming task at hand. The hourly productivity must be matched to the time available and the magnitude of the task. Obviously a large use factor is desirable, as has been shown by Booysen and de Beer[1] but extended use will result in less timely performance of operations. In choosing a machinery complement for a farming enterprise it is necessary to weigh the cost of a low use factor against the possibility of incurring a "timeliness penalty."

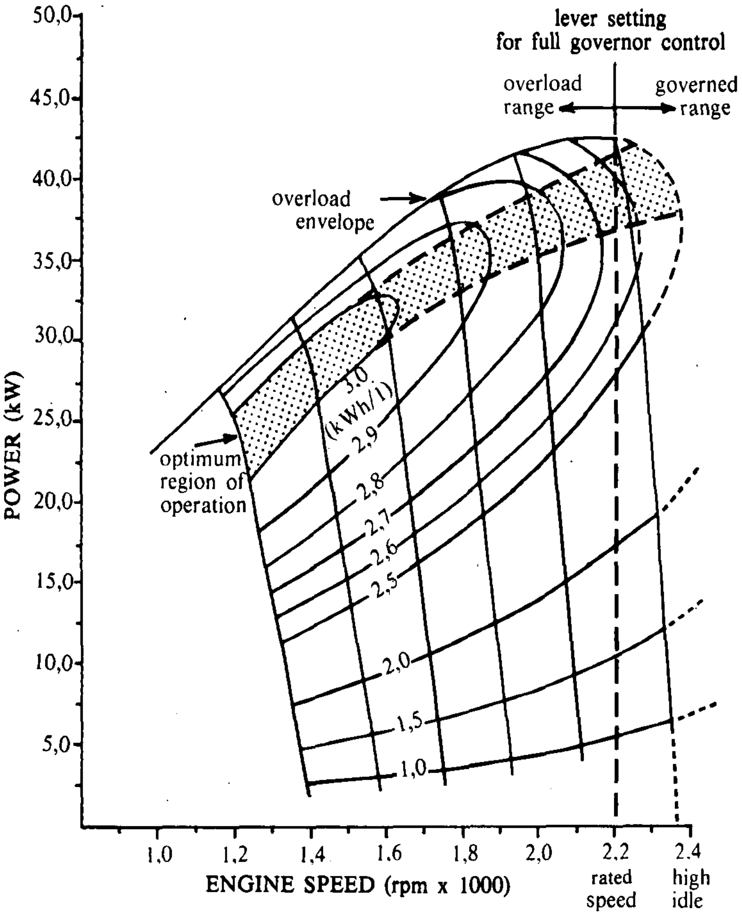

Figure 2. Engine power vs engine speed with lines of constant specific fuel consumption superimposed (Hansen[4]).

Timeliness

Timeliness penalties for the various operations that take place in the production of sugarcane are not easily quantified. However, using the planting operation as an example there are two instances in which a penalty might be encountered. Financial penalties may result due to prolonging the fallow period, and may also occur due to planting at a time of the year that is not optimal. Hoekstra[6] established a relationship for a North Coast estate in the form of:

$$y=A+B\,(\mathrm{Cos}\,(\tfrac{\pi}{6}(m-p))$$

where y is yield in tons cane per hectare at harvest (tch), A is the long term mean yield with respect to planting date (tch), and B is the amplitude of variation about the mean due to planting in month m (numeric representation of month, eg. January = 1 December = 12), as opposed to planting in optimum month p. It is interesting to note that for the particular estate in question the value of B was 8 tch, that is to say the best condition differs from the worst condition by 16 tch. Fig. 4 shows a diagramatic representation of the variation. It is evident that an optimum planting date exists and that deviation from that date can result in a penalty as great as 16 tch (for the case of the estate in question).

The loss in profitability due to the prolonging of the fallow period deserves consideration because the duration of the fallow period is dependent not only on agronomic factors, but also on the time that is required for the available machinery to complete land preparation. Discounting the expected profit from all subsequent crops to the date of harvest of the crop being ploughed out for different lengths of fallow period, indicates the decrease in profitability due to the duration of the fallow period. Fig. 5 shows the results of such an exercise. (The derivation of Fig. 5 is discussed in Appendix II). From this figure it appears that, within the bounds of the exercise, a decrease of ·2% in profitability per month of duration of fallow could be expected (although obviously a 50-month fallow does not have a profitability of zero).

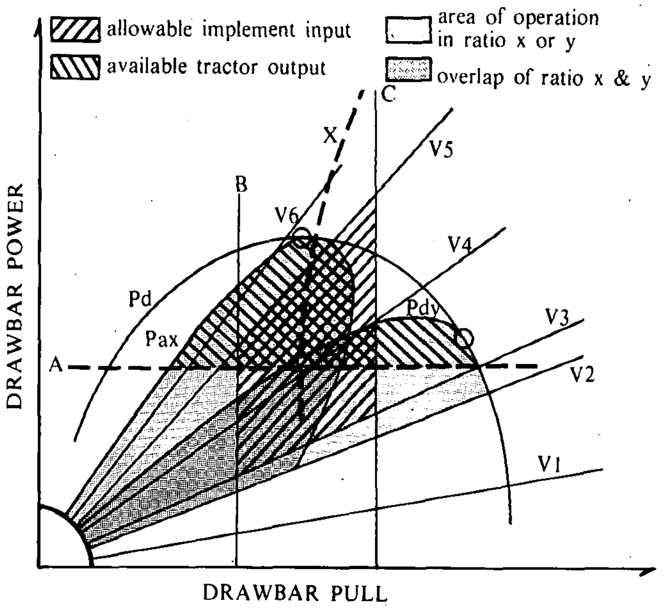

Figure 3. Traction characteristic for a tractor-implement combination.

From the preceding discussion it appears that a "timeliness penalty" does exist, relating to the time of planting and the duration of the fallow period. Should the availability of machinery being used in land preparation and associated activities be in any way responsible for delays in planting date or extension of the fallow period, then the penalty so incurred must be debited against that machinery. Such timeliness costs should be taken into account when selecting the optimum size and number of machines for a given farming enterprise. Fig. 6 illustrates the effect of timeliness on the total cost of production per unit of area.

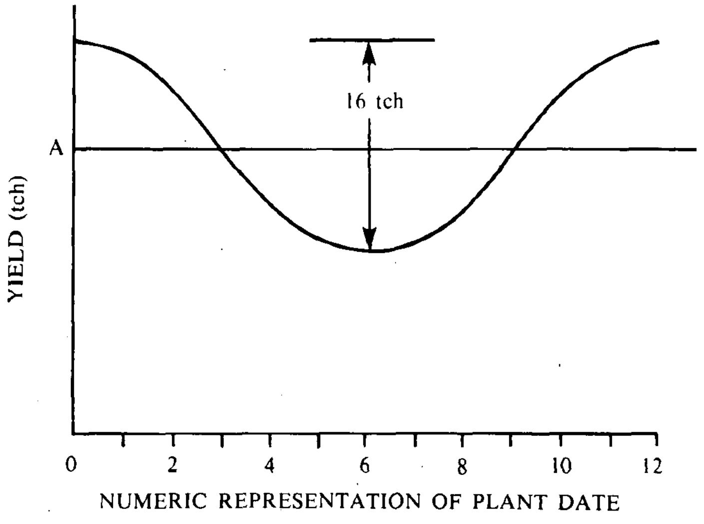

Figure 4. Diagramatic representation of yield at harvest with respect to planting date. (After Hoekstra[6]).

Other mechanized operations in the production of sugarcane obviously incur timeliness penalties, but are not easily quantified. Timeliness penalties need to be quantified to make mechanization planning more efficient.

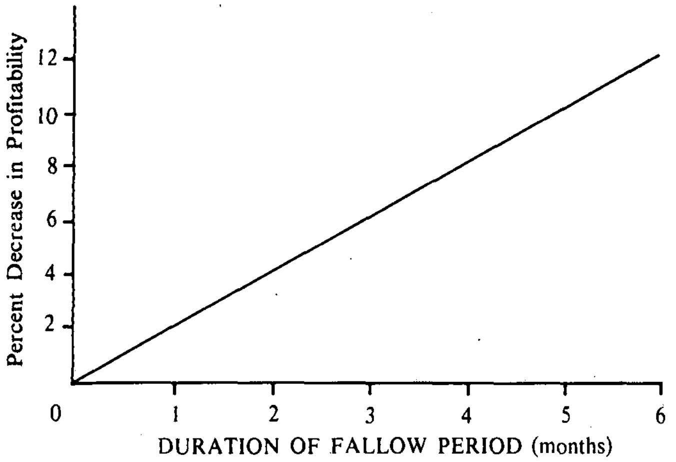

Figure 5. Percentage decrease in profitability vs duration of fallow period.

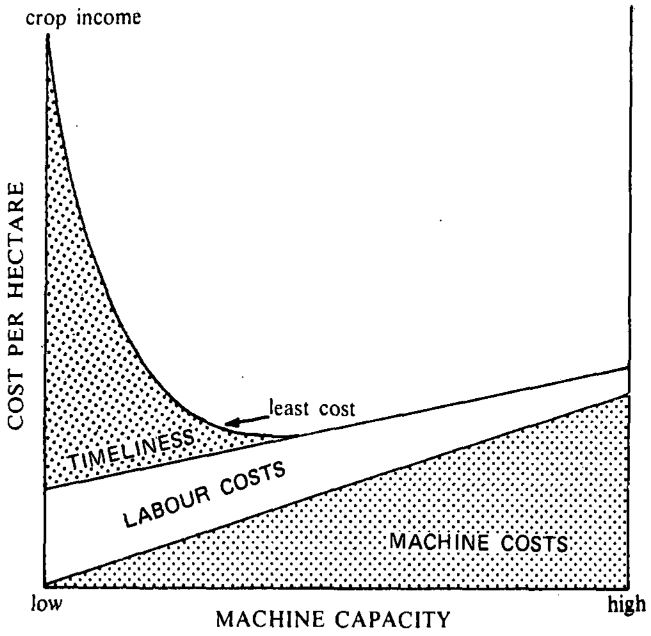

Figure 6. The relationship between timeliness, labour and machinery costs with respect to machine capacity. Labour costs are calculated on an hourly basis, hence the reduction in labour cost as machine capacity rises (after Burrows and Siemens[2]).

Mechanization planning

It is necessary to take all the aforementioned considerations into account when planning the mechanization needs of a particular farming enterprise. A computer programme has been developed that matches tractor to implement, and then on the basis of a given crop calendar, optimises the number and size of items required in terms of the total machinery costs per annum. The programme selects the machinery complement that is capable of completing the given schedule of operations at the least cost. This is achieved by scheduling each operation in the order of the desired operation starting date. Each operation schedule starts at the specified start date or the first day thereafter that the equipment necessary for the operation is available.

Once all operations have been scheduled, the total utilization of each implement and tractor is determined, from which information a detailed cost analysis for every tractor and implement is prepared. The sum of these costs, including the timeliness penalty if it is applicable, provides the total cost of the particular trial in progress (see Fig. 7 for a simplified flow chart of the computer programme).

To complete such an exercise it is necessary for the farmer to specify the programme of field events for at least one year ahead. The computer programme can accommodate data for 3 years in order to include all fields to be worked on in a given crop cycle, which period could exceed 26 months. Obviously it is not practical to programme so far ahead that planting programmes for all fields could be included. This is unfortunate, since at this stage it is only the planting operation for which a "timeliness penalty" has been evaluated.

Discussion

For effective mechanization planning it is necessary to take into account the factors, primarily economic, which affect the choice of tractors and implements. The tractor and implement cannot be considered separately, but must be chosen so that the tractor is fully utilized with respect to the power available, and so that the tractor-implement combination is matched to the size of the task in hand, in that any under-utilization in terms of the hourly use factor must be justified by a reduction in a "timeliness penalty."

Timeliness penalties for operations other than planting, and indirectly the land preparation preceding planting, have yet to be investigated. Once these penalties have been evaluated it will facilitate efficient machinery selection and evaluation of mechanized systems on a quantitative basis. The computer programme developed is primarily an extension aid to help with machinery management decisions. It has the facility that, as more machinery data become available, these can easily be incorporated into the analysis being carried out.

References

1. Booysen, S.S. and de Beer, A.G. (1977). Machinery selection by costing analysis. SASTA Proc 51: 12-15.
2. Burrows, W.C. and Siemens, J.C. (1974). Determination of optimum machinery for corn-soybean farms. Trans ASAE 17(6): 1130-1135.
3. Grecenko, A. (1968). Predicting the performance of wheel tractors in combination with implements. J Agric Engng Res 13(1): 49-63.
4. Hansen, A. (1977). Personal communication.
5. Hoekstra, R.G. (1976). Analysis of when to plough out a sugar cane field. SASTA Proc 50: 103-113.
6. Hoekstra, R.G. (1978). Personal communication.
7. Zoz, F.M. (1974). Optimum width and speed for least cost tillage. Trans ASAE 17(5): 845-850.

Appendix I

The use of specific fuel consumption as a measure of utilization

Fig. 2 relates engine power to engine speed with lines of constant specific fuel consumption superimposed. The optimum region for operation has been indicated and it lies specifically within the 3 kWh/litre contour. The tractor tested was in good mechanical condition, and the fuel pump had been correctly adjusted, hence one would expect most other tractors to have a performance worse than 3,0 kWh/litre. If 3,0 kWh/litre is considered to be the optimum, then estimates of optimum average power requirement can be made by multiplying fuel consumption in litres per clock hour by 3,0 kWh/litre, to give a result in kW.

An investigation into the relationships between clock hours and tractor hours produced the linear regression equations given in Table 2. There were no significant deviations from linearity.

TABLE 2

Regression equations representing tractor hours vs clock hours for various operations

Operation	Regression equation	Correlation Co-eff
Land planing	$y = 0,78 + 1,05\ h$	0,84
Ploughing	$y = 3,17 + 0,85\ h$	0,84
Ripping	$y = 1,47 + 0,70\ h$	0,72
Harrowing	$y = 1,73 + 0,71\ h$	0,54

y = tractor hours
h = clock hours

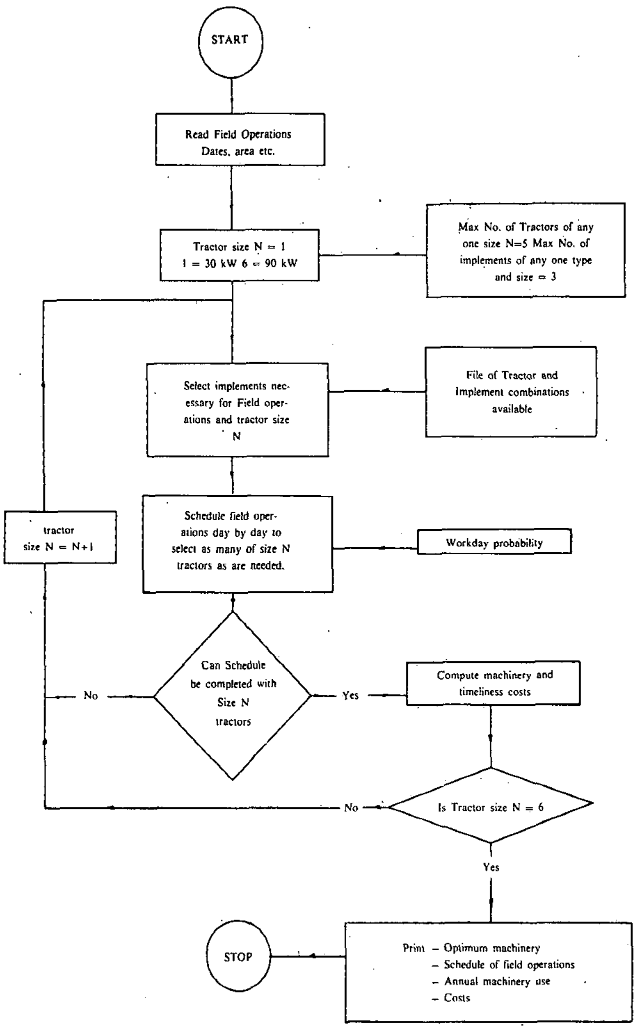

Figure 7. Simplified flow chart of the computer programme to optimise the size of a machinery complement.

Appendix II

Assume a crop yield Y(r) tons cane per hectare, obeying the equation $Y(8r) = 105 - 9r$, where r is the ratoon stage, $r = 0$ being a plant crop and $r = 1,2,\cdots n$, for n subsequent ratoon crops (Hoekstra[5]). Assume also that the age at harvest of a plant crop is 20 months and the age of ratoon crops is always 19 months.

The total future profit discounted to present value is given by

$$Z_n = \frac{U_n}{1 - d^{t_n}} \quad \text{(Hoekstra}^5\text{) where } U_n = \sum_{r=o}^{n} P_r d^{t_r}$$

P_r = marginal profit per hectare of crop at ratoon stage r.

d = discount factor where $d = \frac{1}{1+R}$ (When R = compound interest as a fraction for $R = .15$, $d = .87$).

t_r = life of crop stage r expressed as years (to include fallow period).

$P_r = (V - C)\,Y(r) - C_p$ for $r = o$, $P_r = (V - C)\,Y(r) - C_h$ for $r = 1,2,\cdots n$.

C = Cost of harvest per ton (R2).

V = value of crop per ton cane (R15).

Cp = Cost to establish plant crop (forward discounted to date of harvest of that crop) per hectare (R850).

Ch = Cost to establish ratoon crop (forward discounted to date of harvest of that crop) per hectare (R220).

The calculation of Z_n for fallow periods ranging from 0 to 6 months is shown in Table 3.

TABLE 3
Calculation of Zn for variation in fallow period

Duration of fallow period months	(Yrs.) t_o	d^{t_o}	(R) P_o	(Yrs.) t_1	d^{t_1}	(R) P_1*	(Yrs.) t_2	d^{t_2}	(R) P_2*	(Yrs.) t_3	d^{t_3}	(R) P^*_3	(R) Un	(R) Zn
0	1,67	,79	515	3,25	,64	1 130	4,85	,51	1 102	6,42	,41	1 056	2 123	3 599
2	1,83	,78	515	3,41	,62	1 130	5,00	,50	1 102	6,58	,40	1 056	2 073	3 456
4	2,00	,76	515	3,58	,61	1 130	5,79	,49	1 102	6,75	,39	1 056	2 025	3 319
6	2,17	,74	515	3,95	,58	1 130	5,34	,48	1 102	6,92	,38	1 056	1 959	3 160

***inflated at 10% per annum.**