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31 Potential change in animal output from grassland: production from fractionated forage

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INTRODUCTION

Ever since it was realised that the biological value of leaf protein was high – some of the earliest work was in the 18th century – efforts have been made to extract the protein for human consumption or for feeding to monogastric animals. The extraction process involves the separation of the protein from the cellulosic plant material. From the early days until the late '60s the objective of much of the work on forage fractionation was to obtain the highest possible yield of extracted protein, and the fibrous residue was considered to have little or no value as a feed for ruminants. More recently, following the establishment of protein requirements for ruminants (ARC, 1965) and in particular the work which followed on the utilisation of protein by beef cattle (Kay *et al.* 1968) it was realised that the protein content of very young green crops generally considerably exceeded the concentration of protein required in the diets of ruminants (Jones, 1977a), and attention was drawn to the possibility of partitioning the nutrients in green materials to provide a mainly cellulosic feed for ruminants and a juice, relatively rich in protein, for monogastric animals.

There are two types of machine currently available, which will extract plant juice; the pulper and belt press, and the screw press. In both, the amount of protein extracted depends on the degree of pulping and the pressure applied to the plant fibres. Both appear to have similar energy requirements of about 18–29 MJ/t and are capable of extracting 30–40% of the crude protein in the crop (Shepperson *et al.* 1977). The amount of protein extracted for a given setting in these machines varies, depending on the DM of the crop being processed (Jones & Houseman, 1975; Shepperson *et al.* 1977) and on the quantity of nitrogenous fertiliser applied to the crop. There is also some evidence that, independent of DM, the extractability of protein falls as the length of time between cutting and processing increases from 0–10 hours (A S Jones & R A Houseman – unpublished results).

In nutritional terms, three things are achieved by fractionation:

(i) The partitioning of the crop to provide a fibrous feed for ruminants and a protein feed, freed from cellulosic material, for non-ruminants.

(ii) The concentration of nutrients in the fibrous residue.

(iii) A change in the nature of the fibrous residue.

The protein extracted from the plant is carried in the juice, but although the juice contains up to 45% CP in DM, the DM content of the juice is low (average 8%). It is possible to concentrate the protein by centrifugation and to produce a dry product but the costs involved mean that the dry product is too costly to be included in pig and poultry rations (Wilkins *et al.* 1977) even when the extra value of the carotene is taken into account (Morris, 1977).

Significant reductions occur in the moisture content of the fibrous residue (Connell & Houseman, 1977). The moisture content of grass, for example, is reduced from 83 to 74%. In so far as the digestibility of the material is not significantly altered (Connell & Houseman, 1977; Jones & Houseman, 1975) the ME concentration should be greater. Since protein is in excess of the needs of the rumen microbes and the host animal, one would anticipate that intake and growth would increase in ruminants given the fibrous residue as compared with those given the unprocessed crop.

There is a change in the nature of the cellulosic material during processing; fibre length is shortened and the fibres and cells are torn. These changes should reduce the need for rumination and therefore the energy expenditure during digestion. They should also increase the rate of fermentation of the undigested fibres in the rumen, leading to improvements in digestibility and voluntary feed intake. There is evidence that this is so since Greenhalgh & Reid (1975) measured small improvements in digestibility and large and highly significant improvements in voluntary feed intake by sheep given processed rather than unprocessed grass; in their experiment, although the grass has been processed, the juice was not removed. Since processing grass probably increases the rate of fermentation in the rumen, increases in voluntary food intake are to be expected, but this appears to be the case only when the fibrous residue and juice are recombined. The explanation for this probably lies in the fact that juice contains highly degradable protein relative to the protein in the fibrous residue; the juice therefore supplies readily available nitrogen to enable the rumen bacteria to keep pace with the increased fermentability of the fibrous residue.

BIOLOGICAL VALUES OF THE FRACTIONS

Juice

The nutritive value of the juice is variable, reflecting differences in manurial treatment, season, and extraction rate. Experiments with young pigs have shown that fresh juice, produced in spring, has a high nutritive value and, in terms of supporting nitrogen retention in pigs, is equivalent to white fish meal (Jones & Houseman, 1975). The application of nitrogenous fertiliser decreases the true protein and the lysine in the juice, which also decline steadily as the growing season progresses. These differences in chemical composition are reflected in the nutritive value. Experiments undertaken at the Rowett Institute (Jones & Houseman, 1975) showed that pigs given protein extracted from spring grass grew faster than those given protein from autumn grass. The major problem with the juice is that it ferments rapidly, which results in a loss of all the soluble carbohydrate (≃40% of DM) and a portion of the protein. There is a concurrent loss of appetite in pigs and inferior growth (Braude *et al.* 1977; Jones, 1977b).

Fibrous residue

In experiments in which fresh fibrous residue from grass was compared with fresh grass, cattle given the former grew 15% faster (Houseman *et al.* 1975). Similar results were obtained for steers given clover residue (Mackie & Copeman, 1976) dried grass residue or a mixture of ensiled grass residue and barley (Houseman *et al.* 1975). Dairy cows, however, produced less milk on dried cobs made from lucerne fibrous residue than from dried lucerne (Connell & Houseman, 1977). There seems little doubt, therefore, that the fibrous residue is at least equivalent in nutritive value to the unprocessed green crop for growth in ruminants, although not for milk production.

THE APPLICATION OF GRASS FRACTIONATION

The fractionation of green crops leads to an improvement in carcase output per ha, firstly because it makes available protein for animal production which otherwise would have been wasted save for its residual manurial value, and secondly because this protein is utilised by pigs, which are much more efficient in utilising DM for carcase gain than cattle and sheep. Calculated values of the relative efficiency of land use for different systems of animal production between May and October are shown in Table 1, together with similar values calculated by Maguire (1977).

The question which has to be asked is whether it is better to allow the yield of CP and DM of a green crop to increase as the crop matures to the flowering stage, rather than to extract the protein at a younger stage and accept lower total yields. Even if the protein content of the crop at the mature

Table 1

The efficiency of land use for animal production

System	Carcase gain (kg/ha)	Relative efficiency
Grass fractionation (pig/cattle)	923 (853)	100 (172)
Zero-grazing (cattle)	575	62
Barley-beef (cattle)	373	40
Paddock grazing (cattle)	435 (495)	47 (100)
Conventional (pig/cattle) [1]	717	78

Figures in parentheses from Maguire (1977).
1 Allowing for the area required for soya bean production.

stage is in excess of the needs of the ruminant, it would seem more logical to match ruminant needs by judicious mixing at the steading, rather than to fractionate. The question is all the more important in view of the fact that 64% of the 2 M t of protein which are imported annually for animal feeding are used by ruminants.

An estimate of the potential benefit of fractionating grass at different stages of maturity can be derived from the data of Wilman (1970a; 1970b) relating to the cumulative yields of DM, digestible DM and CP of Italian ryegrass given 140 kg N/ha. Table 2 and Figure 1 show that, although yields of DM increased to week 10, there was little increase in digestible DM after the seventh week. Table 3, using slightly different base data and equations relating the extractability of DM and CP to crop DM (Shepperson *et al.* 1977) shows how yields of ME and CP vary with the age of the grass and how the partitioning of the DM and CP between juice and fibrous residue is affected. Yield of CP reached a peak at about six weeks. It follows that there is little point in leaving a crop to mature beyond the sixth to seventh week of growth.

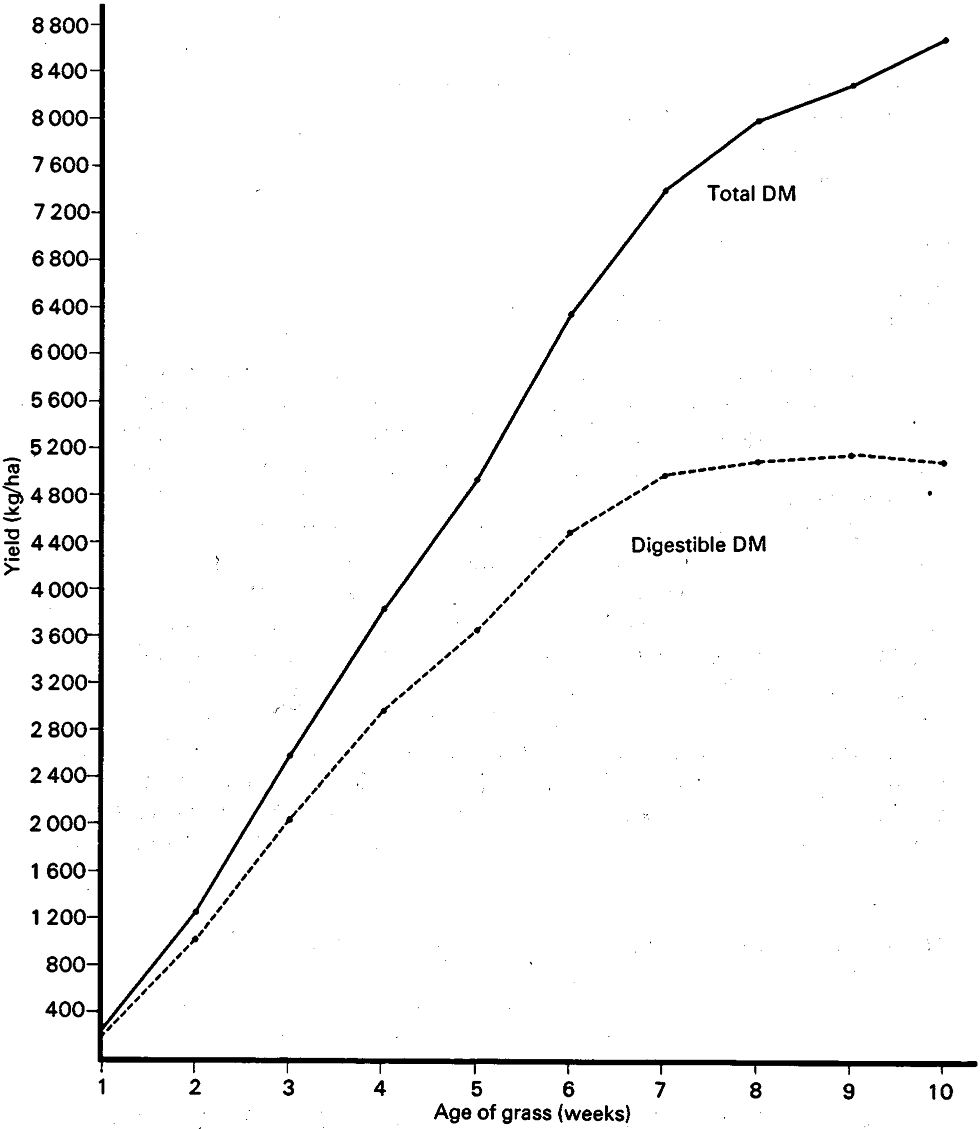
Table 2

The variation in yield and digestibility of grass DM with age

	Age of grass (weeks)									
	1	2	3	4	5	6	7	8	9	10
Yield of DM (kg/ha)	269	1 233	2 559	3 831	4 915	6 374	7 401	8 017	8 296	8 691
Digestibility of DM *in vitro* (%)	83.3	82.8	78.9	77.6	74.4	70.4	67.3	63.8	62.2	58.6
Yield of digestible DM (kg/ha)	224	1 021	2 019	2 973	3 657	4 487	4 981	5 115	5 160	5 093

Source: Calculated from Wilman (1970a).

Figure 1
The variation in yields of DM and digestible DM with age



The object of fractionation is to partition the crop to meet the protein needs of the ruminant more closely. The cumulative yield of protein and fractionated protein should therefore be considered in relation to the animal's requirements. Figure 2 gives the total yield of CP and the yields of

Table 3

The variation in yields of grass components with age, before and after fractionation

	Age of grass (weeks)									
	1	2	3	4	5	6	7	8	9	10
% N in DM of grass [1]	5.3	6.3	5.2	3.7	2.8	2.3	1.9	1.7	1.4	1.2
% DM in grass [1]	14.8	11.6	11.3	12.3	13.5	16.0	18.9	20.8	22.6	23.6
Calculated ME (MJ/kg)	11.69	11.62	11.08	10.89	10.45	9.60	9.45	8.96	8.73	8.23
Yield of CP (kg/ha) [1]	49	289	614	707	756	799	781	756	685	607
Yield of DM (kg/ha) [1]	1.5	7.9	19.4	31.3	43.0	57.8	66.6	73.9	76.3	79.7
Extractability of DM (%)	18.34	19.78	19.91	19.46	18.92	17.80	16.49	15.64	14.83	14.38
Extractability of CP (%)	32.68	34.69	34.88	34.25	33.5	31.92	30.09	28.90	27.76	27.11
Yield of DM in fibrous residue (kg/ha)	119	621	1 554	2 520	3 483	4 749	5 565	6 236	6 497	6 829
Yield of CP in fibrous residue (kg/ha)	33	189	399	465	503	544	548	549	495	442
Yield of DM in juice (kg/ha)	27	153	386	609	813	1 024	1 099	1 156	1 131	1 146
Yield of CP in juice (kg/ha)	16	100	214	242	253	255	236	223	190	165
Total ME (GJ/ha)	17	92	215	340	449	555	629	662	666	656
Protein requirement at 12 g CP/MJ ME (kg/ha)	20	110	258	409	539	666	755	795	799	788
Protein requirement at 10 g CP/MJ ME (kg/ha)	17	92	215	340	449	555	629	662	666	656

1 After Wilman (1970a; 1970b).

fractionated protein for ruminant and non-ruminant feeding. The calculated ME content of the grass, for each stage of growth, was used to estimate the cumulative yield of ME/ha and values were derived for the protein required to meet the needs of rumen micro-organisms, estimated at 10 g CP/MJ ME. For older beef cattle, it could be argued that the yield of microbial protein in the rumen is sufficient to satisfy the host animal's need for protein. For younger cattle, needs are more in the region of 12 g CP/MJ ME. Lines depicting cumulative animal needs for both ratios are plotted in Figure 2. The points, A and B, where these lines intersect the line of yield of protein in the residue, represent stages beyond which there is no case for fractionation – at least for the particular rate of nitrogenous fertiliser (140 kg/ha) and rate of extraction (approximately 30%) of CP. If only sufficient protein is left in the fibrous residue to meet the needs of the rumen microbes, then fractionation should not be carried beyond the sixth week – this roughly corresponds with the stage for the maximum yield of crop protein and digestible DM. As the protein needs of the host animal increases, the point of intersection moves nearer to the y axis and it is debatable whether crops should be fractionated when the feed is intended for lactating dairy cows. This protein partitioning may account for the lower milk yield, reported by Connell & Houseman (1977), for cows given pressed as compared with whole crops.

It is interesting to note that, by the end of the seventh week, the need for protein for young beef cattle (12 g CP/MJ ME) exceeds the total yield of protein in the unfractionated crop.

The general conclusion from these calculations is that there is no case for fractionating grass crops beyond the fourth to fifth week of growth. Even fractionation at younger stages may not be justified if the crop is to be consumed by very young growing ruminants or high yielding dairy cows.

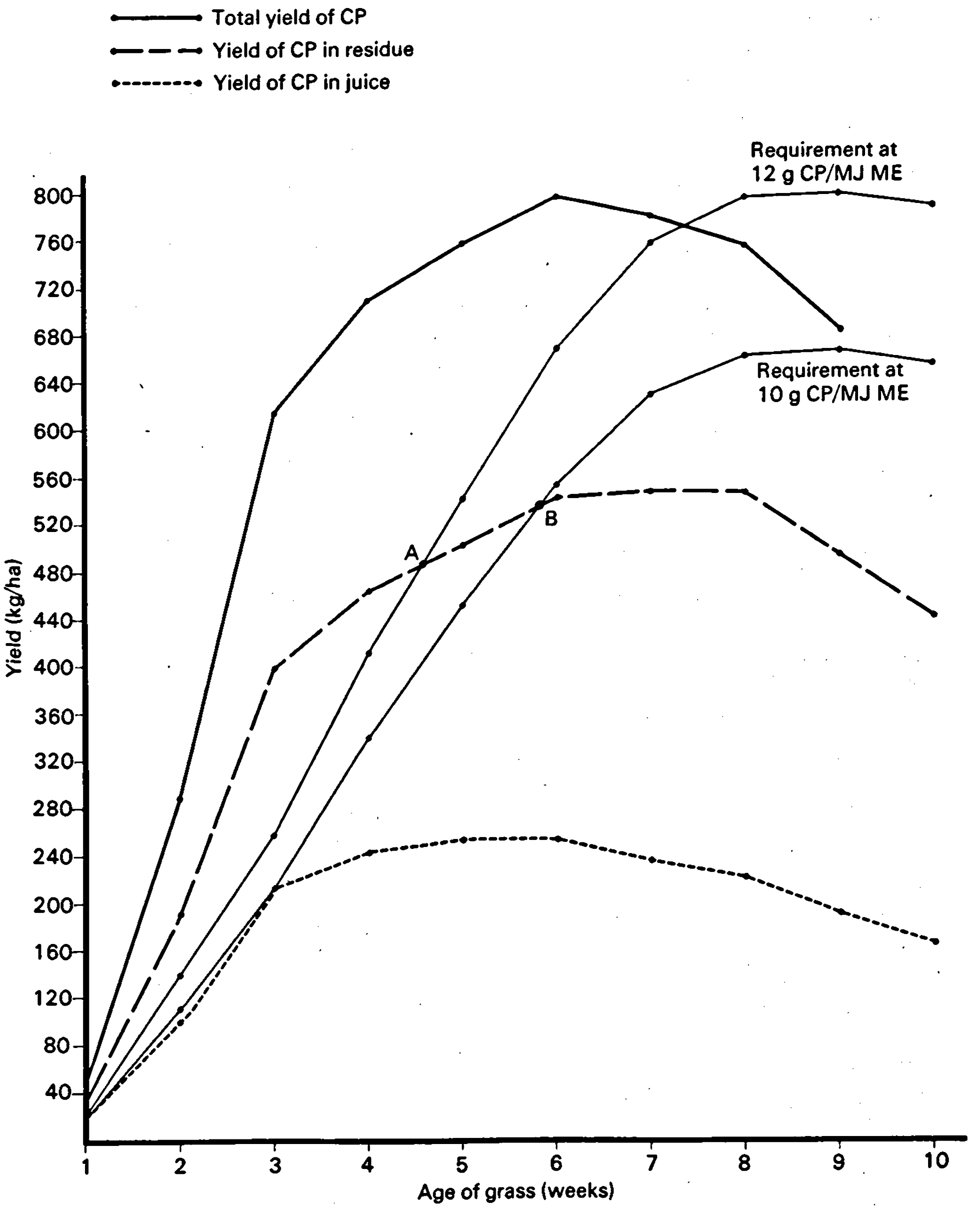
CHANGES IN RESOURCE

It is difficult to estimate the cost of fractionation and the benefits to be derived because the machinery available at present has a low capacity relative to that of farm machinery used, for example, in silage making. To date it has not been possible to derive costs relating to an ideal farm fractionation system. It does appear, however, that the energy cost of fractionation is low and, since there is little difference between the power consumption of machines currently available, even though these vary in principle and capacity (Shepperson *et al.* 1977), some calculations are feasible if the current estimates of energy cost/t are accepted.

There are several alternative ways of utilising the fractionation process. It may be used to produce dried leaf protein or, in its simplest form, to provide protein in dilute suspension. Since the cost of protein extraction increases as

Figure 2

Yield of crude protein in relation to requirements



the rate of protein extraction increases, because the throughput of grass falls, and since overextraction can reduce the protein content of the pressed residue below that required by the rumen micro-organisms for the maximum fermentation of the fibrous residue, it follows that the system with the most potential is one in which there is only a partial extraction of the plant protein. This will be examined further.

Change in fertiliser input

By far the most valuable fraction is the pressed residue. In one study (Jones, 1977b) the value of the pressed residue was nine times that of the juice. Increases in fertiliser increase yield and therefore the total value of the pressed residue. The important question is whether increases in nitrogenous fertiliser affect the fractionation process. Although increases in extractable protein accrue as a result of the application of nitrogenous fertiliser (Jones & Houseman, 1975), it is not known whether this increase is merely a result of an increase in moisture content of the grass. Furthermore, the increase in the extractability of the protein, as a result of applying more nitrogen, is accompanied by a reduction in the true protein and lysine content of the extracted protein, which could be expected to reduce the nutritive value of the protein extracted. In any event, the effect of a change in fertiliser input on protein extractability is a marginal one. In one experiment, increasing the fertiliser applied from 250 to 500 kg/ha increased the CP yield from 376 to 634 kg/ha, but only increased protein extractability from 22 to 26%, most of which can be accounted for by the change in the moisture content of the crop. The increased protein yield was associated with a reduction of 4% in the true protein content. The change in the weight of CP extracted, as a direct result of a change in the extractability, was 98 kg/ha, for which the soya bean equivalent would be worth approximately £30. The nitrogen required to produce this would, in the cheapest form, cost approximately £66. Clearly it is the effect of the fertiliser on the total yield of DM and protein which is important and the effect on the efficiency of the extraction process is marginal and certainly uneconomical.

There is obviously considerable variation in yield with respect to the rate of nitrogenous fertiliser applied, depending on the sward and climatic conditions. Estimates of the optimum level range from 100 to 200 kg/ha for grass to be cut after about five weeks of growth.

Change in fuel costs

There are two ways of examining the potential of forage fractionation in relation to the fuel costs of the system. Firstly, can the cost of the process be offset by the change in the value of the products produced? Certain assumptions have to be made about the value of the fractions. Here, it is assumed that the value of the protein extracted is equal to that of the protein of soya bean and that the value of the ME of the residue is equivalent to that of the unprocessed grass. When barley costs £93/t, the value of the ME is 0.79p/MJ. The ME in one tonne of fresh grass, of 13.5% DM, is worth £12.91. One tonne of fresh grass will yield 113.4 kg of fibrous residue worth £10.84 and the equivalent of 22 kg soya bean valued at £3.03. Thus the total value of the two fractions is £13.87 – an increase of £0.96/t or approximately £56/ha when compared with the value of unprocessed grass. Clearly this increase is sufficient to cover the energy cost of the process which, at 29 MJ/t, is in the region of 24p.

The calculations above are based on actual data obtained at the Rowett, where the extraction rate of protein was approximately 30%. It could be argued that the system would have its maximum potential when the amount of protein left in the fibrous residue was just sufficient to ensure maximum fermentation of the fibrous residue. There is, of course, the possibility of extracting more protein than this, if urea is used to ensure that microbial needs are met.

Figure 3, based on Rowett data, shows that there is a relationship between protein and dry matter extractabilities. This relationship was used to calculate the incremental return for different rates of protein extraction (Table 4). These data show that, as far as gross returns are concerned, there is little point in increasing the extraction rate above 25–30%. It must be remembered that as protein extraction rate is increased, so energy costs increase. However, preliminary data suggest that increasing the extraction rate of crude protein to 45% does not even halve the throughput so that the incremental increase in fuel costs would be met, although it is doubtful whether labour and capital costs would.

The second potential in fractionation is in the saving on the cost of winter forage production, and two aspects are worth consideration.

Improvement in drying capacity and reduction in drying costs

Figure 1 showed that maximum yield of digestible DM was attained after six to seven weeks of growth – a stage when the crop DM was approximately 20%. From data published by Shepperson & Bennett (1975) it appears that the drying load – that is the water which must be removed from the wet crop – of grass with a 20% dry matter content, would be reduced by about 40% by passing through a screw press. While it may be argued that drying load could be significantly reduced by wilting, this is not always feasible and is itself associated with considerable nutrient loss.

Low cost drying

The major drawbacks to grass drying are the high capital and fuel costs. It has been shown that it is feasible to dry the fibrous residue on low cost

Figure 3

The relationship between the extraction of dry matter and crude protein

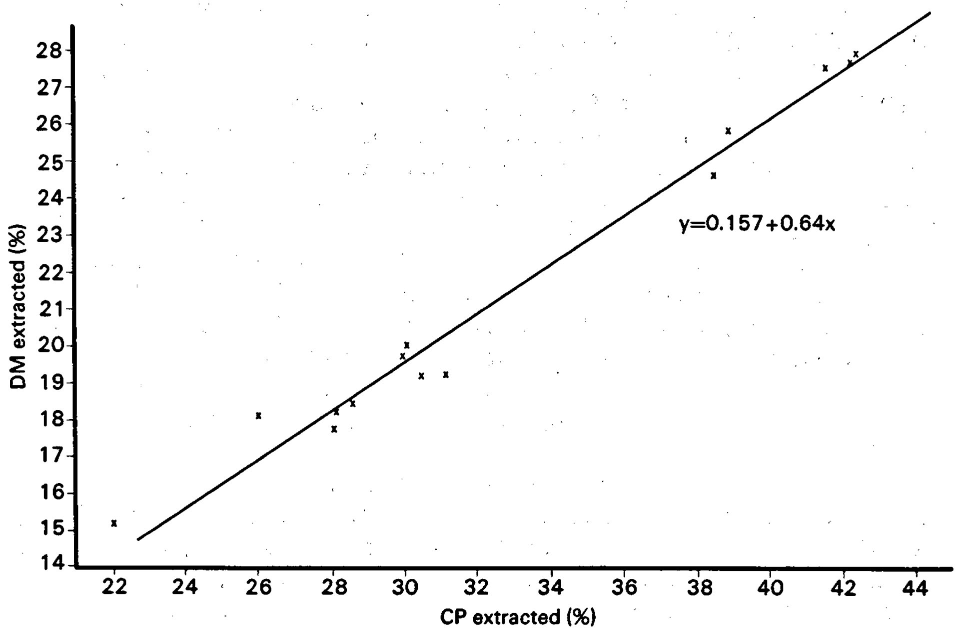


Table 4

The effect on the gross value of the products of fractionation of increasing the amount of protein extracted from one tonne of grass

Extractability		Protein extracted (kg)	Soya equivalent (kg)	Residue DM (kg)	Value of fractions (£)
CP (%)	DM (%)				
25	16.3	7.21	18.4	113	13.38
30	19.5	8.75	22.1	109	13.49
35	22.7	10.21	25.8	104	13.55
40	26.0	11.66	29.4	100	13.75
45	28.3	13.12	33.1	97	13.90

equipment by blowing air at near ambient temperatures through shallow layers of the material. Farm-scale work showed (Jones, 1977b) that it was possible to dry the residue to approximately 90% DM at an energy cost of approximately 10.5 GJ/t. This cost compares favourably with high cost driers with a fuel cost of around 16 GJ/t although the low cost process is a lengthy one.

Changes in capital costs

Estimates of the changes in capital input and returns on capital are difficult because the capacities of the machines currently available are too low to enable a fully integrated study of fractionation on a farm scale to be undertaken.

An economic analysis of work carried out using a single-screw press (maximum capacity 2 t/h) has been attempted (Sutherland, 1975). The analysis was based on the assumption that the capacity of the press was 1.25 t/hour although in practice it was difficult to achieve this and in very dry conditions the throughput fell to 50% of the assumed value. The other assumption made was that the feeding value of the protein in juice was equivalent to protein in soya bean. The estimated return on capital (Table 5) shows that the return reached a reasonable level only when the opportunity cost of land was low and when the machinery was depreciated over seven years. Sensitivity of these estimates, to changes in the basic assumptions, is examined in Table 6. The most important factor affecting return was the value of the fibrous residue; the value of the juice had little effect on return.

Table 5
Return on investment

Working life of equipment (years)	Opportunity cost of land	
	£100/ha	£200/ha
5	—	7%
7	6%	15%
10	12%	21%

Table 6
Sensitivity analysis: changes in projected return on capital with variation of some of the main assumptions and prices

Throughput of grass – initial assumption 1 250 kg grass/hour

	Alternative assumptions (kg grass/hour)					
	1 000		1 500		1 750	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	–%	–%	1%	12%	5%	16%
7 years	–%	9%	10%	20%	13%	24%
10 years	7%	15%	15%	25%	19%	28%

Capital cost of drying installation – initial assumption £22 500

	Alternative assumptions					
	£25 000		£20 000		£17 500	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	–%	4%	–%	10%	2%	14%
7 years	4%	13%	8%	18%	11%	22%
10 years	10%	18%	14%	23%	16%	26%

Electricity for drying pulp – initial assumption £10/t

	Alternative assumptions (£/t)					
	5		15		20	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	1%	11%	–%	2%	–%	–%
7 years	10%	19%	1%	11%	–%	7%
10 years	16%	24%	8%	17%	3%	13%

Yield of grass – initial assumption 10 000 kg DM/ha

	Alternative assumptions (kg DM/ha)					
	9 000		11 250		12 500	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	–%	4%	–%	9%	3%	11%
7 years	1%	13%	9%	17%	12%	19%
10 years	8%	18%	15%	22%	17%	24%

Value of fibrous residue – initial assumption £75/t

	Alternative assumptions (£/t)					
	70		80		85	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	–%	2%	1%	11%	6%	16%
7 years	1%	11%	10%	19%	15%	23%
10 years	8%	17%	16%	24%	20%	28%

Value of juice – initial assumption £3.6/t

	Alternative assumptions (£/t)					
	2.8		3.2		4.0	
Opportunity cost of land (£/ha)	100	200	100	200	100	200
Working life of machinery and equipment:						
5 years	–%	4%	–%	6%	–%	8%
7 years	3%	13%	5%	14%	7%	16%
10 years	10%	19%	11%	20%	13%	22%

Source: Calculated from Sutherland (1975).

In this analysis, considerable capital investment was allowed for drying and obviously a fractionation system based on feeding fresh fibrous residue, or ensiled residue, would show greater returns.

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