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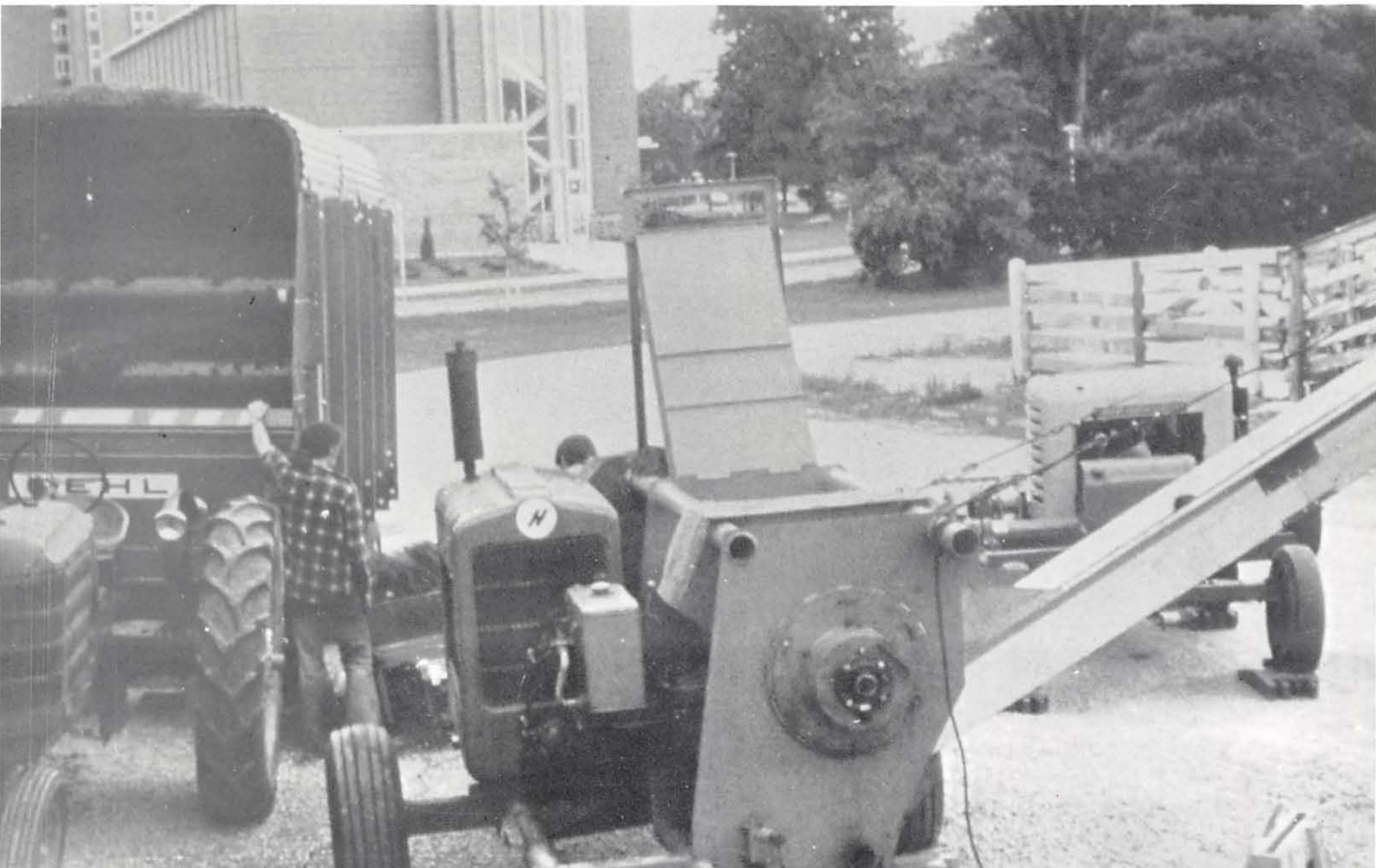

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Tel: Silsoe 61096

Advertisement Manager:
LINDA PALMER

Production Manager:
NORMAN STUCKEY

Advertisement and Production Office:
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Tel: Rickmansworth 78877

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Protein production: Problems for the agricultural engineer

D S Boyce and R W Radley

D S Boyce

R W Radley

THE year 1973 will be remembered as that in which the vulnerability of the western world to fossil fuel energy supplies was dramatically exposed. The sharp oil price rises which were to follow were later to provide the stimulus for the technical content of the annual conference of IAgrE in 1975.

But, 1973 was also the year in which the dependence of Europe, and Britain in particular, upon external sources of vegetable protein was underlined – a worrying fact largely overshadowed at the time by the focus of attention upon energy. In the year previous to this, there was a shortfall in Peruvian fishmeal production (which was to be sustained); also a smaller than usual soya crop in the US coincided with a commitment by the US Government to sell 1 million tonnes of soya beans to the USSR. Further, competition for available supplies of soya and other oilseed residues was heightened by the entry of China into the world market for the first time as a purchaser. These events, and others, combined to push up the cost of some of the key vegetable proteins threefold in a comparatively short period and this was soon reflected in the price of animal foodstuffs and livestock products.

The aim of the 1977 annual conference, reported in this issue, was to establish the nature and magnitude of the so-called protein problem and to identify the role of the agricultural engineer in the future production of protein foods, be they of plant or animal origin, conventional or novel.

The subject matter of the conference introduced the application to more effective food production of two new areas of technology. One was the separation of biological materials into their more basic components, for example proteins and carbohydrates, and their reconstitution into new products with specified qualities. The other was the establishment of a much more fundamental knowledge of the biological requirements of plants, animals or organisms, for example single celled bacteria or fish, and the development of systems in which they can yield competitive commercial products. These new technologies have already resulted in many agricultural engineering departments in the USA and Canada re-describing their interests as "bio-engineering" or something similar and extending their areas of responsibility accordingly.

We would like members of the IAgrE to consider the role of the Institution in the new technologies of fractioning and reconstituting biological products and in the research, development and design of complex bio-engineering systems in non-traditional agricultural activities.

Also, in addition to the challenge of defining possible new boundaries for agricultural engineering, members are invited to reflect upon the contribution being made to engineering technology in its broadest sense by the comparatively new (post-war) analytical methods made possible by the use of computers. The last 25 years has seen the application and acceptance of mathematical modelling and computing as a powerful and integral part of engineering research, development and design.

It is suggested that the Institution of Agricultural Engineers should seek to increase its involvement in this field of endeavour – a field which is increasingly accepted by the world at large and which has already been applied usefully to a wide range of engineering problems. It might be speculated that such a development would increase the attractiveness of Institution membership to young graduates and to others already engaged in this work.

D S Boyce BSc MSc PhD MASAE FIAgrE is from the National Institute of Agricultural Engineering.
R W Radley BSc PhD is from the National College of Agricultural Engineering.

Protein production: Problems for

Dr K L Blaxter FRS

THIS conference, which I have been given the privilege to chair, is somewhat unique in that it has been designed to explore an area in which engineers can collaborate with biologists in an attempt to improve our supply of food. You will note that I use the word 'collaborate' to describe such an interdisciplinary undertaking; I do not use the word 'help' which infers a certain condescension on the part of one or other party. This is because I believe most sincerely that it is only through a close and equal association of those who have different skills, aptitudes and intellectual approaches, we can maintain and increase the productivity of our country. People can only co-operate in this effective way if they share a common purpose, have a high mutual respect for one another's separate disciplines and a willingness to share both in failure and success. Any other solutions to the wider problem of how best to harness our respective abilities, any suggestion that one partner has a subservient or secondary role to play, are not sufficient because they do not bring out the best in people and do not meet our modern needs.

The context in which we are to discuss collaboration between engineering sciences and the biological sciences concerns the production of protein. Without trespassing on what Professor Aylward and Dr Wilkins will say, I should like to remind you that our major requirement for import of protein stems from the need to provide protein for animal feed rather than for human food. Our animal populations in turn produce meat, milk and eggs which are highly relished by our own people and in high demand in the European Economic Community as a whole. The overall task of meeting these needs for feed protein is a considerable one and, because of our climate, somewhat daunting. It presents a challenge to all concerned with the agricultural industry, and there is no single simple solution to it. The objectives in the broad are simple enough; how can we incrase our own production of protein, save on an expensive importation, prevent an unacceptable depletion of fish stocks through industrial fishing, at a cost in terms of the resources we deploy which our economy can bear. Solutions are more difficult as we shall see.

In this respect, in the presentations which follow, most of the papers are being given by biologists rather than by engineers. Each will no doubt suggest facets of this wide area of protein production where an application of engineering prowess appears to him to offer possibility of reward, or where the next step demands skills not usual to biologists. Undoubtedly, in listening to their papers you, as engineers, approaching the central question of protein production with a different attitude of mind will discern other possibilities for the application of engineering knowledge which has escaped them entirely. If this happens, as I am sure it will, then the conference will have been in part successful. It will have been wholly successful if it leads to collaboration and an erosion of a somewhat artifical interface between engineering and other sciences as applied to agriculture and food provision.

K L Blaxter FRS FRSE NDA BSc DSc is Director of the Rowett Research Institute, Aberdeen.

Chairman's opening remarks made at the annual conference of the Institution of Agricultural Engineers, on 10 May 1977, at Bloomsbury Centre Hotel, London.

What protein will we be eating in 2001 AD?

Professor F Aylward PhD DSc FRIC and Dr B J F Hudson Dphil MA FRIC

Present sources of protein

The average daily per capita consumption of protein in the UK is currently about 70g, of which more than 60% is of animal origin. This has fallen over the course of the decade from around 75g but the animal protein component has hardly fallen at all, the drop in vegetable protein being due to a somewhat reduced consumption of cereals. As a percentage of the total energy derived from food, protein has risen from just under to just over 12% in the same period. This is a picture reflecting the increasing affluence of the people of Britain extending through the 1950's and 1960's up to the time of the oil crisis and the escalation of inflation in 1974.

If we are to be concerned with future protein supplies we must now ask if this level of protein consumption is adequate, quantitatively and qualitatively, for the maintenance of health? There is some dispute as to the precise needs of the human being in terms of protein, but the official view is that, on average, UK consumers are obtaining about 30% in excess of recommended intake and about 100% in excess of minimum requirements. This means that some fall in protein consumption could be tolerated without adverse nutritional consequences.

Against this background some changes in average dietary patterns can be discerned. The consumption of meat and dairy products is being well maintained, though with some interesting change of emphasis – pig and poultry products, for example, are increasing in popularity at the expense of beef and lamb. The consumption of cereal products, the main source of vegetable protein, shows a long-term decline. Fish, too, is becoming less important.

In terms of quality, meat, dairy products and eggs are good. Cereal protein is deficient in lysine but this can be offset by parallel consumption of pulses, usually themselves deficient in cysteine and methionine. The protein quality of baked beans on toast is therefore similar to that of steak. Furthermore, some of the minor sources of protein, such as potatoes, are of good quality. Generally, it is true that a normal mixed and well varied diet tends to eliminate effects due to low protein quality in individual items.

Projecting, as far as is possible, from today to an era still 24 years away, what trends can be foreseen, or perhaps even guessed at? We can divide these into three groups:

a) Economic and political factors.
b) The influence of the consumer.
c) The advance of agriculture and food technology.

Economic and political factors

Food habits and preferences are among the most basic of human characteristics. They therefore respond, except in situations of dire necessity, very slowly to external pressures. During the last decade the consumer in the UK has gradually become aware that the cheap food era was coming to an end, and that cash crops and similar commodities based on cheap overseas labour have now become subjects of competition from many other purchasers with dramatic effects on world prices. Some consumers have even realised that our heavy dependence on imported food and feeds, whether alone or within the EEC, can be extremely dangerous in the context of a weak economy.

Such factors, though expressed dramatically in coffee and cocoa prices, are fundamentally much more important in relation to imported meat, cereals, rice and fruit. Further, our heavy dependence on imported protein concentrates such as fish meal and soyabeans is fundamental, under present conditions, to the whole of our livestock, milk and egg production programmes. Unless, therefore, we can, through our economic strength, again assume a leading position as a buyer in world commodity markets, we shall be forced gradually into a "siege economy" position in which we shall have to provide our own food from our own resources. Whilst hoping for the best, we should be preparing for the worst in food terms.

Professor F Aylward was formerly Professor of Food Science, University of Reading, and Dr B J F Hudson is Reader in Food Science, University of Reading.

Paper presented at the annual conference of the Institution of Agricultural Engineers on 10 May 1977, at Bloomsbury Centre Hotel, London.

How do such considerations affect the UK consumers' protein supplies? Assuming, for the time being, that the present world market forces will continue to operate, we can foresee an increasing price differential between the foods which we are able to produce ourselves and those which are imported, including the raw materials for animal production. This affects directly the whole of our meat, dairy and poultry production. Though, in a sense, fish is also home-produced, increasing scarcity is leading to price escalation also in this area.

The conclusion is inescapable. We have an efficient agricultural industry but no ultimate control over raw material prices. We can produce our own cereals, pulses and vegetables, and protein from such sources can therefore play a larger relative part in our diet. Furthermore, we have a very restricted cultivable land area, so the output per annum per hectare becomes a crucial factor. Expressed in terms of protein, wheat can be roughly twice as productive as milk, which in turn is twice as productive as meat. Less conventional crops can be even more productive than wheat – rapeseed 50% greater and beans 100% greater.Even high productivity can be achieved with leafy material – the possible large-scale production of leaf protein concentrate is under active consideration.

The influence of the consumer

In attempting to forecast patterns of eating it is important to take into account trends in consumers' characteristics and attitudes. The average consumer is now almost certainly better educated and more adventurous in regard to food than were his parents and grandparents. The typical woman is much more likely to have a job outside the home. Class differences mean less, age differences more. The mystique of home cooking and ritual presentation means less, convenience means much more. All these factors combine to produce progressively changing purchase, preparation, cooking and eating patterns.

Such considerations are beginning to affect purchasing decisions in terms of "value for money", quality consciousness, convenience and even nutritional value. Food producers have recognised this and responded with more subtle advertising, better packaging, and meticulous attention to quality control. Legislation in terms of food orders and regulations regarding food additives and labelling have become more stringent. Nutritional advertising is making its appearance; not simply meaningless statements like "Product X is Good for You", but specific claims based on protein and vitamin contents, as in breakfast cereals, and even "contains natural ciscis-linoleic acid" in one highly successful product.

The consumer nowadays has a much clearer idea of the meaning of the word "protein". It carries for most of them an image of health, body building and goodness. However, they also know that protein is primarily associated, in food terms, with meat, milk, eggs and fish. They are less aware that protein is also a feature of cereals, pulses and vegetables generally. Parallel with more informed attitudes to nutrition, ethical standards are also changing, if very slowly. Interest in vegetarian foods, as well as in "health" foods is developing. This trend, together with revulsion towards "factory farming", will significantly hasten the advent of new plant protein foods, quite apart from economic factors.

Technological developments

Until comparatively recently, protein was available to the public only in the form of relatively straightforward commodities accepted traditionally for hundreds, indeed, thousands of years in much the same form. Often some processing had been undertaken, the milling of wheat, the freezing of fish, the bottling of milk – and so on, but nothing more elaborate in terms of sophistication than the baking of bread or the making of sausages or chocolate.

The position is now in a rapid state of change. Protein "concentrates" and "isolates" are becoming available from various sources and these can be built into fabricated foods by appropriate processing techniques. Fig 1 illustrates, in outline, the range of options available.

Processing of agricultural commodities for protein

For the food processer and manufacturer the mere knowledge that sources of protein, conventional, semi-conventional or unconventional are available or can be made available, is, however not enough. It is one thing to produce a powder with a 50% or even 75% protein

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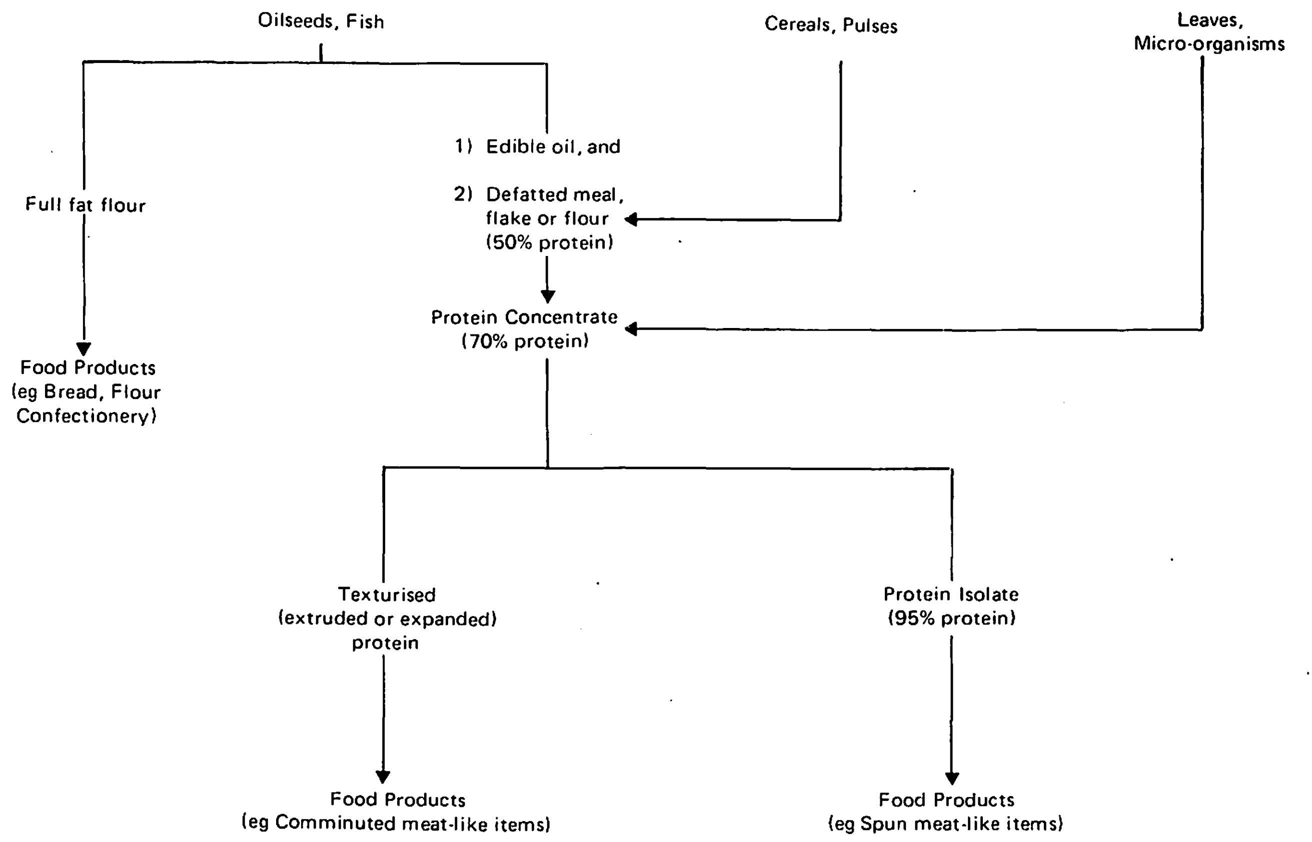
Fig 1 Processing of agricultural commodities for protein



content: it is quite another thing to use it effectively in a food product. On the one hand, it must be attractive to the consumer in terms of colour, odour and taste, and free from toxic substances or anti-nutrients. On the other hand, it must possess appropriate functional properties for the formulation contemplated. Usually, a bland white powder is required. It may be necessary that it should show good water solubility, some surface-active features, gelling properties and a capacity to bind water and fat. In order to achieve acceptability and functionality various processing operations involving separations, concentration and refining will become necessary.

Before passing to plant products, reference must be made to developments in animal products which are directed to the improved utilisation of such materials. In general such developments seek to maximise the use of all parts of a product. For example the rapidly rising price of meat has forced meat product producers to re-structure the traditionally less attractive cuts of meat, such as trimmings and offals. Comminution and milling, followed by moulding and extrusion leads to "reformed meat" a product with many possibilities including the potential for "extension" with other sources of protein. In the dairy field, the recovery and utilisation of whey, not so long ago a waste product from cheese making, is perhaps the most promising corresponding development. The processes of ultrafiltration and reverse osmosis, when widely operating, will add significantly to our supplies of protein and at the same time ease pollution problems.

Texturised plant protein

After all possible steps have been taken, however, to make full use of by-products and low grade protein of animal origin, it must be evident that a greater long-term opportunity is offered by exploiting vegetable and microbial protein. Rapid advances are being made in this field, pioneered mainly by US soyabean protein technology. Texturisation, which is necessary if consumer acceptability is to be achieved, can be performed in several ways, of which the chief are: extrusion of a suitable viscous mix, steam injection under pressure followed by expansion/drying, and spinning as in textile production. In all cases a friable dry "meat-like" material is achieved. In spinning, the "meat-like" attributes are reinforced by the alignment of fibrous material into a structure similar to that of meat muscle. Suitably formulated, coloured and flavoured it is not easy to distinguish such material from real meat. The other processes lead to particulate material which is less like meat in structure, but which possesses many useful functional properties shared by a corresponding dry meat preparation, for example the ability to absorb three times its weight of water and a useful amount of fat.

Texturised plant protein is at present seen mainly as a meat "extender", providing a means whereby limited and expensive meat supplies can be stretched to meet consumers' needs. Production in the UK is at present very limited – spun protein costs nearly as much as meat, though material processed directly from concentrates by other means is already much cheaper. It is only a matter of time, however, before production capacity will increase and prices fall further relative to meat.

New analogue foods

An analogue food is one which is produced so as to simulate, in composition and in consumer use pattern, a familiar food in widespread use. The classical example is margarine. This product has been available for more than 100 years, though familiar to UK consumers for only about 70 years. Designed originally to replace butter it could be described as a **substitute**. Gradually, through scientific developments in chemistry and nutrition, and through engineering developments in the design and operation of heat exchangers, it came to be regarded in all essentials as an **equivalent**. Perhaps some housewives could still tell the difference, but such differences as there were became unimportant.

Finally, it became clear that margarine had a number of advantages, price apart, over the product it was originally made to imitate, such as greater flexibility in composition, improved softness at low temperatures, better baking performance and, according to many experts, better nutritional value. Brands embodying these various advantages were marketed. Margarine had now become an **alternative**, or rather a range of alternatives, to butter.

This classical food case history now seems to be about to repeat itself. In terms of raw material, an analogue food can adapt to any one of a number of sources of supply. The manufacturer of margarine could once make use of whale oil, tallow, lard and cottonseed oil, but now he uses fish oil, palm oil, soyabean oil and rapeseed oil. The texturised protein manufacturer is restricted now largely to soyabean products, but there is no reason why, in the near future, he should not include protein concentrates from field beans, groundnut meal, rapeseed meal, fish meal, or sunflowerseed meal. Later, the range of raw materials may well increase – lupinseed, linseed, leaf protein concentrate and protein of microbiological origin may all become realistic – and available from UK production. Ideally, once the functional properties of these proteins have been documented, "tailor made" protein blends appropriate to particular uses will become available.

The popular idea that "soya steaks" will eventually emerge is probably a fantasy. Though in time such an objective may become technically possible, it seems unlikely that, at that time, the consumer will be familiar with meat in that form. The texturised proteins will be marketed, mainly in the early days as extenders, in a great variety of different forms – as canned, dried and frozen products, as snacks, as complete meals and as meal supplements. They will have important advantages over the "real thing", ease of storage, ease of preparation, no waste. The "real thing" will continue to tempt the consumer, but mainly as a luxury food.

Though meat-like food products represent a fascinating prospect it must not be forgotten that other possibilities exist. What are the possibilities for milk and egg protein, for example? The cow produces protein more efficiently through its milk than as a meat-producer. Furthermore, milk offers more versatility to the food technologist than does meat. It has a unique combination of protein components, not so far successfully imitated by proteins from other sources. The energy component of feeds requirements, in the case of ruminants, is substantially home-produced: the protein component mainly imported. Since there should, with increased UK oilseed production, be no insuperable barrier to provision of ruminant feeds from our own resources, it can be foreseen that milk production will continue on a similar scale to present levels. It may well be, however, that milk quality will tend to be judged on protein content rather than on fat content, as at present. Hence milk will probably tend to become richer in protein and lower in fat. For all these reasons plant products will be much less likely to penetrate the milk market than the meat market.

Some conclusions

Clearly it is not possible to predict a precise situation in 2001 from available evidence, but we can identify some likely trends.

(1) Through general pressure on world supplies and competition between the stronger economies, the UK consumer will eat less protein than at present but his supplies from all sources will be well above the essential minimum.

(2) It seems likely that much less meat and fish will be available and meat may be regarded as a luxury food. Probably a high proportion of meat will be "extended" with texturised plant protein, or will be "re-formed" from cheaper material. Such a movement is already evident in the catering business. Milk will probably retain its popularity, though there may be an increasing demand for skim or other low-fat milks and for powdered milk products. Cheese will still be an important item.

(3) Plant protein concentrates may be produced on a large scale from home-produced pulses and oilseed crops. These can be expected to find their way into most formulated foods and "meat-like" products, with a strong bias towards convenience.

(4) Single-cell protein concentrates, such as those from yeasts or bacteria, will probably be in widespread use for animal feeds. Direct use in human food will almost certainly have to await some years of experience in animal feeds – apart, perhaps, from some specific products, such as those based on fungi.

(5) In the developing plant protein technology, as well as in dairy and cereal technology the contribution of the engineer will be vital. New methods for effecting the unit operations involved will be eagerly sought because food, even in 2001, will continue to be one of the main pleasures of life.

Increasing crop protein production for animal feeding in the UK

Dr R J Wilkins BSc PhD MIBiol

Summary

THIS paper details the supply of protein to farm livestock and then discusses the possibilities for reducing feed protein imports through the application of current knowledge and, in the longer term, by exploiting the results of current research. Attention is centred on the supply of protein in cereals, oilseeds, legume grains and forage crops.

Introduction

The availability and price of concentrated protein feeds on world markets has been subject to wild fluctuation in the last six years. The cost of imports of these feeds into the UK in 1976 was over £200m and most projections indicate that the pressure on supplies of protein feeds will increase in the coming years (eg Hulse, Fawcett and Daniels, 1975). Not surprisingly much attention has been given to the ways in which home production could be increased.

Supply of protein to farm livestock

Table 1 shows the total supply of crude protein (CP) (this includes non-protein nitrogen as well as true protein) to farm livestock in the UK for 1973–74 and is taken from the Joint Consultative Organisation (JCO) (1976).

The largest quantities of CP came from grassland herbage (51% of the total) and from cereals and other high-energy feeds (25%); oil cakes and meals and animal protein supplied only 15% of the total.

Imported protein and protein from imported raw materials amounted to 20% of the total: For feeds with high protein concentration this figure was a massive 73% whereas imports represented only 8% for other feeds. Our dependence on imports is restricted to the feeds which are used to increase CP content of concentrate feeds given to productive pigs, poultry and ruminants. The JCO estimated that 51% of the imported high-protein feeds were given to ruminant animals, 35% to poultry and 14% to pigs. These must however be regarded as approximate values as other studies have calculated ruminants to consume from 30% (Wilkins, unpublished) to 64% (Jones, 1977) of the total. It is clear, however, that there is scope for substantial import saving with all these classes of livestock.

Figures for protein imports and for livestock numbers do not indicate any major change since the analysis made for 1973–74. Over the last ten years total CP imports have varied from 675 to 898 kt CP, but there has been no obvious time trend either up or down. There have, however, been changes in the feeds that make up these imports with the percentage coming from soyabean increasing from 19% in 1967 to 51% in 1976 largely at the expense of groundnut, cotton seed and fishmeal (fig 1). Most of these imports are from developed rather than developing countries.

Fig 1 Imports of crude protein in oil cake and meal and animal protein (1967–76).

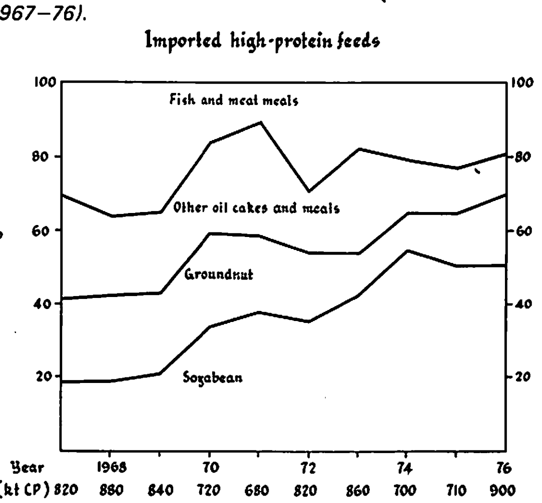


Table 1 The supply of crude protein, (kt CP) to farm livestock in the UK (July 1973 – June 1974).

	Home produced				*Fed to:*		
from:	*Home-grown*	*Imported*	*Imported*	*Total*	*Pigs*	*Poultry*	*Ruminants*
High-energy feeds							
Cereals							
Barley	611	–	55	666			
Wheat	240	–	33	273			
Oats	79	–	1	80	356	303	544
Maize and sorghum	–	–	164	164			
Other	20	–	–	20			
Cereal offals	93	111	24	228	76	53	99
Miscellaneous energy feeds	91	4	22	117	19	77	21
Total	1134	115	299	1548	451	433	664
High-protein feeds							
Oil cakes and meals	3	281	316	600	65	172	363
Animal protein							
Fish meal	47	–	111	158			
Meat and bone meal	95	–	24	119	85	179	26
Milk derivatives	6	–	–	6			
Feathermeal	7	–	–	7			
Other protein							
Maize gluten	–	57	–	57			
Distillers' by-products	25	30	–	55			
Field beans	24	–	–	24			
Dried grass	25	–	–	25	–	54	179
Dried poultry manure	30	–	–	30			
Urea	40	–	–	40			
Others	2	–	–	2			
Total	304	368	451	1123	150	405	568
Bulk feeds							
Turnips, swedes, mangolds and fodder-beet	73	–	–	73	–	–	73
Kale and cabbage	58	–	–	58	–	–	58
Rape	21	–	–	21	–	–	21
Sugar-beet tops	29	–	–	29	–	–	29
Potatoes	15	–	–	15	4	–	11
Wet brewers grains	34	–	–	34	–	–	34
Arable silage	15	–	–	15	–	–	15
Straw	32	–	–	32	–	–	32
Other bulk feeds†	11	–	–	11	–	–	11
Grassland herbage	3138	–	–	3138	–	–	3138
Total	3426	–	–	3426	4	–	3422
Overall total	4864	483	750	6097	605	838	4654

Possibilities for import saving

One possible scheme for complete replacement of imported proteins using existing knowledge and technology was outlined by the JCO (1976). Of course protein imports could be reduced if the proportion of plant products in the human diet were increased, but this possibility is not considered here. →page 60

R J Wilkins BSc PhD MIBiol is Head of the Agronomy Department, Grassland Research Institute, Hurley, Maidenhead SL6 5LR.

Paper presented at annual conference of the Institution of Agricultural Engineers, on 10 May 1977, at Bloomsbury Centre Hotel, London.

Increased protein production would have important effects on the use of resources, with different options for increasing protein supply requiring, for instance, different inputs of land, support energy and capital. Also different co-products – feed energy and edible oil – would be produced. Comparison between the different possibilities is, therefore, difficult. Table 2 gives an indication of potential production, potential utilisation and the efficiency with which resources would be used for increased supply of CP in oilseeds, grain legumes, crop by-products, improved hay and silage, dried grass, leaf-protein concentrate, non-protein nitrogen and microbial protein.

Table 2 Potential production and utilisation of different crude protein sources and the efficiency with which they use land, support energy and capital

	Potential:		*Efficiency of use of:*		
	Utilis-ation	*Prod-uction*	*Land*	*Support energy*	*Capital*
Rape and oilseed flax	***	***	**	***	****
Field beans and peas	***	***	**	****	****
Non-protein nitrogen	*	****	****	***	***
Improved hay and silage	**	****	***	**	***
Crop by-products	*	*	****	****	**
Dried grass	**	****	***	*	*
Leaf-protein concentrate and forage juice	****	****	***	**	*
Microbial protein	****	****	****	**	*

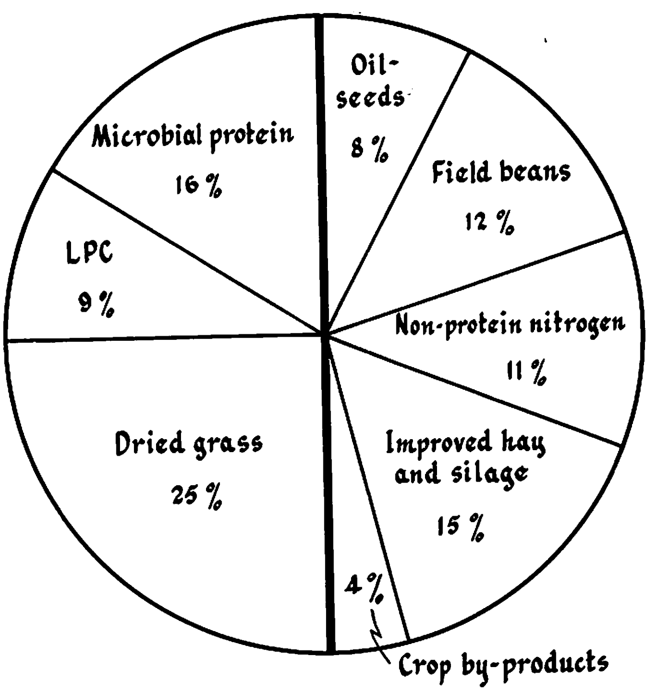
Assessments made on an arbitrary scale with a maximum of four asterisks for the highest potential or most efficient resource use.

Particular features include (i) the high rating for non-protein nitrogen on all scores other than potential utilisation (which is restricted to only some dietary situations for ruminants), (ii) attraction for the use of crop by-products within the constraints of limited availability and utilisation only by ruminants, (iii) the relatively inefficient use of land in oilseed and grain legume production – outputs of feed energy are much lower than with cereals or forages and (iv) the relatively inefficient use of support energy and capital in the production of dried grass, leaf-protein concentrate and microbial protein.

It is hardly surprising that this analysis did not identify an individual source of protein that could be produced with efficient use of all the major resource inputs and could be widely used. If such a resource had existed then our current heavy reliance on imported high-protein feeds would probably not have arisen!

There are, however, opportunities for substantial import saving. Fig 2 illustrates a slightly modified version of the scheme discussed by the JCO (1976) for achieving complete import saving. To attain this objective some contribution from all of the protein sources listed earlier was envisaged. However the saving of 50% of current imports was considered more feasible. This involved increased production of rape, oilseed flax and field beans, improvements in hay and silage quality, increased use of crop by-products and non-protein nitrogen. Inputs of capital and support energy are estimated at only 30 and 36% respectively of those for complete import saving, but 67% (168 kha) of the extra land for complete replacement would be needed.

Fig 2 One possible scheme for replacing the total imports of crude protein into the UK in 1973 (adapted from JCO, 1976).



Crop protein production

Although microbial protein and industrial sources of non-protein nitrogen may make substantial contributions to feed protein supplies in the future it is likely that the major contribution will be from crop protein. This section discusses the prospects for increased protein production from cereals, oilseeds, legume grains and grass and forage crops, considering the possibilities with current technology and with that which may develop from research.

Cereals

The large contribution made by cereals to CP supply has already been noted, as has the requirement by most farm livestock for CP concentrations in their diets that are higher than those contained in cereal grain. It follows that the production of a higher yield of CP per unit area of land would not lead directly to any reduction in the need for supplementary protein. The CP concentration in the grain would need to be increased or the amino-acid balance improved for savings in CP to result. A negative correlation between protein content and yield has been commonly reported (eg Jenkins, 1969). This is particularly obvious when only a limited quantity of nitrogenous fertiliser is used, restricting the total quantity of nitrogen available for uptake and elaboration to protein in the crop. One approach to obtaining high yield and high CP content is to identify genotypes that are responsive to high rates of nitrogenous fertiliser. However, the energy (fixed in photosynthesis) required for the production of grain with high CP content is greater than that for normal grain (Bhatia and Rabson, 1976). This factor contributes to the negative correlation between CP and yield. Genotypes of wheat, oats, maize and rice with adequate yields and higher protein contents than normal have however recently been produced (see Rhodes and Jenkins, 1975). Study in the UK has been concentrated on wheat, but it will be some years before suitable new high-protein varieties are developed.

Barley genotypes with high lysine (the first-limiting amino acid in cereal grains) content were identified by Munck (1972) and Doll (1973). Work at the Plant Breeding Institute on Risö 1508 material from Doll has unfortunately shown that the high lysine character is closely associated with a shrunken endosperm which limits yield potential (Rhodes and Jenkins, 1977). Further breeding is required, but the proved existence of genetic variability gives encouragement that in the long term varieties of grain with improved amino-acid balance will be produced.

Oilseeds

These crops are, of course, grown for two products – the extracted oil and the protein-rich residual meal. However the UK is highly dependent on imports of both edible oils and protein-rich feeds so increased cultivation of oilseed crops would lead to reduced imports on both counts.

The production of oilseed crops in UK was at a trivial level until five years ago when a rapid increase in rape production started together with some commercial production of oilseed flax. The prospects for rape, soyabean and sunflower are considered here.

Rape It was suggested (JCO, 1976) that 125 kha (309 000 acres) of rape would need to be grown to replace the then imports of 48 kt of CP in rapeseed meal. By 1976 the area of rape grown was 48 kha (119 000 acres) and imports of CP in rapeseed meal had fallen to 26 kt.

There has been considerable resistance to the use of rapeseed meal in compound feeds largely because of high contents of glucosinolates which may be broken down by the enzyme myrosinase to give toxic goitrogenic compounds. The enzyme can be de-activated during processing of the meal, but, because there may be other sources of myrosinase in the diet or in the gut of the animal, removal of the glucosinolates by breeding or by other means is needed for the greater acceptance of rapeseed meal. Sources of rape with low glucosinolate content have been located: the spring rape varieties Tower in Canada (Stefansson and Kondra, 1975) and Erglu in Germany, which contain only two to three per cent of the normal glucosinolate content and also have very low contents of erucic acid (which when present in large quantities reduces the acceptability of the oil for human use), are now in commercial use. It is anticipated that varieties of spring and winter rape with low glucosinolate content and adapted to the UK should be available in the early 1980's (Thompson, personal communication). Other problems have been associated with the use of rapeseed meal – fatty liver syndrome in poultry and taint of eggs (see Livingston, 1977). It is not clear to what extent these problems will be avoided with glucosinolate-free material, but the availability of such material will facilitate a marked increase in the use of rapeseed meal in feeds for both ruminant and non-ruminant animals.

Rape can be grown on all free-draining soils in the midlands and southern part of the country and so act as a break crop over a substantial area. Insect pests and diseases make it likely that rape would not be grown more than one year in every five in a rotation. At 10% of the area of cereals, some 360 kha (889 000 acres) of rape would be grown. It must, however, be noted that rape does not produce more CP/hectare than cereals, but it does give CP in a more concentrated form.

The major mechanisation problem with rape is the harvest. The crop has a long flowering period with the result that seeds vary considerably in moisture content as the crop ripens; the ripe pods tend to shatter and considerable shedding of seed may occur. Swathing is commonly adopted for winter rape prior to combining. An alternative is the use of diquat as a pre-harvest desiccant (Sanderson, 1976).

Soyabean The soyabean has never been established as a commercial crop in the UK. Low night temperatures particularly at flowering time provide a major limitation to soyabean in western and central Europe and DM yield levels in the UK are only around 1.3 t/ha (0.5 t/acre). There has however been considerable breeding effort, particularly in Sweden, and this resulted in the production of the Fiskeby varieties (see Bunting, 1969, 1974; Radley, 1974). These materials are extremely determinant in habit; this limits total yield and results in many of the pods being below normal cutting height. Considerable increases in yield would be needed for the soyabean to be attractive in the UK and there is little immediate prospect of any breakthrough in this respect (Bunting, personal communication). Work to modify equipment to harvest the present varieties more effectively would not be worthwhile.

Sunflower The world production of sunflower is increasing rapidly. The oil is of particularly high quality and there are no major problems in the use of the meal. There has been much progress in breeding hybrid sunflowers with high yield potential that are earlier maturing than previous varieties. Production in France is increasing and good results have been obtained in recent experiments at the Plant Breeding Institute with seed yields higher than those for rape (Bunting, personal communication). It is probable that varieties which produce commercial yields in favoured sites in the south and east of England will be available within the next decade.

The site and soil characteristics needed for high yields of maize will also be required for sunflower. It is likely that techniques such as bitumen mulching that contribute to warming the soil early in the year will lead to increases in yield. Harvest will be a problem. Seeds in different parts of the capitulum ripen at different rates and there may be variation in ripeness in different parts of the field and a considerable quantity of green foliage present at the time of harvest. Also consumption of seeds by birds may be substantial and this loss increases with delay in harvest. Earlier harvest and significant increases in harvested yield have resulted from pre-harvest desiccation of the crop with diquat (Hill, Knight and Ogilvy, 1974). Application by air is attractive; ground application would present major difficulties. Adjustments to the pick-up reel of the combine are needed for effective harvesting, but specific attachments for sunflowers have been developed in Europe and North America and could, presumably, be used in the UK.

Legume grains

Field beans have been the traditional protein crop of the UK; other legume grains considered here are peas and lupins. These crops are characterised by efficient use of support energy, because no nitrogenous fertiliser is needed, and higher yields of CP/hectare than can be obtained from oilseeds or cereal grains. Yields of feed energy per hectare are, however, markedly below those for cereals or forages.

Field beans The area of field beans grown in the UK was around 200 kha (494 000 acres) in the 19th century but has fallen to only 40 kha (99 000 acres) in 1976. Beans are now grown mainly as a break crop from cereals on heavy soils in England.

Little of the crop is used in compound feeds – there are substantial exports and sales for pigeon feed, in addition to direct on-farm feeding to cattle. High contents of tannin may reduce digestibility of the bean (Jones, 1976), and adverse effects on animal growth and egg production have resulted from the inclusion of high concentrations in the diet. However, it is now generally agreed that beans can be included in the diets of pigs, poultry and ruminant animals at up to 20% without adversely affecting performance. Certainly improvements in nutritive value would result from breeding for higher protein content and for lower tannins (low tannin is associated with white flowers; an attribute that can be easily used in a breeding programme), but much greater uptake of beans as a feed could occur without this development.

The limitations are more concerned with crop yield than nutritive value. Yield levels of existing varieties vary greatly from year to year, with yield liable to be reduced by extremes in either dry or wet weather, low effectiveness of insect pollination and the depradations of pests and diseases. A large proportion of the potential grains fail to develop and the crop has a low harvest index (proportion of the total crop yield in the harvested fraction). Considerable plant breeding effort is needed to circumvent these problems.

The potential of the field bean is recognised by the EEC with support given to bean seed production and to a co-ordinated research programme with the crop. In the UK research to improve yield is along two main lines. Firstly, the breeding of auto-fertile varieties which are not dependent on bees for pollination (Lawes, 1973; Bond, Toynbee-Clarke and Pope, 1976) and, secondly, the production of a more determinant plant type (with a fixed number of leaves and pods per stem) (Bond, 1977). This would give a ceiling to total yield but it should reduce vegetative growth, particularly in the late season, and increase harvest index, yield reliability and uniformity of pod maturity. It does not however appear that markedly improved varieties will be available in the short-term and it is unlikely that a major change in the area of beans grown will take place until such improved varieties are available.

Peas Peas are grown at present mainly for human consumption but they can be used in animal feed to at least the same dietary concentrations as field beans. One of the main problems with the pea crop has been that of efficient harvesting. When the seed is mature the crop is normally prostrate and some 20–30% may be lost at harvest (Snoad, 1975).

There has however been a major breakthrough in this respect. Naturally occurring mutants which have either the leaflets modified into tendrils or the stipules reduced to a vestigial size have been used in work at the John Innes Institute by Snoad (1974, 1975). Although these materials have reduced photosynthetic area, seed yields have been similar to those of existing varieties. Advantages of these new materials listed by Snoad include (i) improved standing ability, (ii) greater uniformity of ripening, associated with better distribution of light through the canopy, (iii) less pathogen attack, because of a less humid microclimate in the crop and (iv) easier seed drying.

Genotypes incorporating these characteristics have not yet been adequately evaluated on a field scale, but the potential for improved production of peas both for human food and for animal feed is exciting. Substantial increases in yield may well occur if varieties are bred specifically for animal feeding because attributes particularly relevant to market acceptability for humans would not need to be satisfied.

Lupins Lupins have never been widely grown as a seed crop in the UK, but there is now research in progress at several centres. This interest has been stimulated by the successful introduction of alkaloid-free lupins in West Australia in the late 1960's and the sustained quest for alternative protein feeds (although alkaloid-free materials had been bred over 30 years earlier in Germany) (Gladstones, 1970, 1974). A further interest has been in the possibility of using lupin as an oilseed crop. Up to 14% oil content has been found in lupins (Hudson, Fleetwood and Zand-Moghaddam, 1976) and one of the main objectives of research at Reading University is to produce materials with oil contents similar to those in soyabeans (*c* 16%), sufficient to justify extraction.

Lupins are probably of greater interest as a protein crop *per se*. Seed yields of over 3 t/ha (1.2 t/acre) have been reported for strains of pearl lupin (*Lupinus mutabilis*) grown at Oxford (Masefield, 1976) and over 2 t/ha (0.8 t/acre with both the white and blue lupin (*L albus* and *L angustifolius* respectively) at Reading (Tayler, personal communication). There are problems of sensitivity to

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drought and high temperatures at flowering and of susceptibility to fungal disease in autumn-sown crops, but the yields that have been obtained are sufficient to encourage further effort with the crop. The lupin is traditionally a crop of light acid soils and although cultivation need not be confined to such soils it appears that yields on heavy clays and on calcareous soils will not be high.

As with other "new" protein crops there are likely to be harvesting problems. The white lupin is slow to dry and has a fleshy pod. In all species pods are formed on both the main stem and on secondary stems, with those on the main stem being more mature. Desiccants may make some contribution, but attention to harvesting and drying procedures will be important.

Grass and forage crops

Only the use of the whole crop as feed for ruminants will be discussed. Green crop fractionation, in which a feed is prepared for non-ruminant animals, is discussed by Bruhn, Straub and Koegel (1977) and was the subject of a recent symposium (Wilkins, 1977).

Grass supplies 67% of the CP consumed by ruminant animals. It is quite possible to produce more CP from the existing grassland area. The average application of nitrogenous fertiliser to grass is about 100 kg N/ha (89 lb/acre). If this application is increased to 300 kg N/ha (267 lb/acre) some 65% of the extra nitrogen is recovered in the crop (Williams and Jackson, 1976). There is also a substantial increase in dry matter yield (*c* 25 kg DM/kg fertiliser N) over this range of application. Increase in the national average application to grassland to 300 kg N/ha (267 lb/acre) would give an extra 7 Mt of CP – compared with our current CP imports of only 0.8 Mt.

It is doubtful, however, whether this extra production of CP in grass and forage crops would directly lead to any savings in protein imports. Increased production of CP would have to be allied to, particularly, improved grass conservation. Substantial losses of CP and other nutrients occur during conservation as hay or silage. Also, the quantities of DM (and energy) that are consumed as hay and silage are often below the requirements of the animal, thus necessitating the input of concentrate feeds.

Since the nutritive value of grazed grass is normally higher than that of conserved grass and the use of high-protein feed supplements at grazing is small, attention is focussed on conserved grass. Conservation by dehydration is not discussed although pelleted dehydrated forage can replace imported high-protein feeds in concentrates given to supplement hay or silage (Tayler and Wilkins, 1976). The requirements for capital and for support energy will probably preclude any major expansion of grass dehydration.

Hay Hay is still the main conserved forage in the UK, but the CP content is, on average, about ten per cent – lower than that in cereal grains and lower than that required by productive ruminants. The low CP content arises mainly from the grass being at a mature stage of growth when cut for hay and, in part, from losses of CP, mainly in the leaf fraction, during field curing. Hay with higher contents of CP (and energy) can be made by cutting at an early growth stage. This practice has not been widely adopted. The moisture content of the standing crop is lower when it is cut at a mature stage of growth and also weather for drying is generally better in the middle of the summer than earlier in the year. There are, however, advantages for the haymaking process in using less mature crops – total water to be evaporated per hectare is lower and the resistance to drying of leaves is less than that of stems.

Tetlow (unpublished data) cut grass for hay three times at 6-weekly intervals to give an annual yield of 7.4 t hay DM/ha (3 t DM/acre) with a CP content of 17% and *in vitro* D value of 65. Subsequent calculations showed this strategy to be economically attractive in relation to more traditional management for hay. The problems of making hay from leafy crops differ from those with stemmy crops. Dry matter yields per hectare at any cut are less and any loss in the field through inefficiency of pick up is likely to be a larger proportion of the total crop than when yields are higher. The structural strength of the leaf is less than that of the stem, so that it is difficult to construct swaths with good architecture for rapid drying (Klinner, 1975, 76). The crop has a higher value/tonne than normal hay so that greater expenditure to prevent losses and reductions in feed value can be justified. The use of either barn drying or the chemical preservation of moist hay is, I believe, an essential part of making high-quality hay. The development of a rapid and effective moisture meter would be a major step forward in facilitating the effective harvesting of material for barn drying or chemical conservation.

A marked improvement in the average CP content of hay could be achieved by greater adoption of current technology, but further attention by engineers and biologists to making hay from high quality crops is required to facilitate the complete replacement of high-protein concentrates in feeding highly productive livestock on hay-based rations.

Silage The average CP content of silage at 14% is much higher than that of hay and at a level that should be adequate for most productive ruminants. However, the voluntary intake of silage may be low and the efficiency of utilisation of CP is reduced by changes arising during ensiling (Wilkinson, Wilson and Barry, 1976). Responses in milk yield to high-protein content in supplements have been reported in several experiments even when the basic rations had apparently adequate CP contents (eg Castle and Watson, 1976). During ensiling much of the true protein in the crop is broken down to amino acids and simpler nitrogenous compounds such as amides, amines and ammonia. A large proportion of the CP in silage may be lost from the rumen as ammonia. Only small quantities of feed protein reach the small intestine undigested and this factor, coupled with possibly reduced microbial protein production in the rumen, will lead to reduced amino-acid absorption by the animal. It is likely that the introduction of a new system for protein evaluation and calculating protein requirements (Roy, Balch, Miller, Ørskov and Smith, 1977) will lead to the ascription of a lower value to the CP in silage than in hay or dried grass.

The solution to this lies not so much in cutting grass at earlier stages of growth to increase CP content, but more in improving the value of the CP contained in silages. We have found that the efficiency with which the CP in silage is utilised decreases with increase in the contents of volatile acids and ammonia in the silage (Barry, Cook and Wilkins, 1977).

The adoption of techniques such as wilting and the use of formic acid as an additive will improve the value of CP in silage by suppressing clostridia but the CP will still be in a highly soluble form. There is greater scope for improvement of protein in silage by the application of formaldehyde. This will chemically react with the protein so that its breakdown in the silo and in the rumen is restricted, although the protein is still digested (with greater efficiency) in the small intestine (Barry, 1976). Application to silage will increase the total absorption of amino acids compared with that from untreated silage (Beever, Thomson, Cammell and Harrison, 1977). With formaldehyde treatment there is the potential of making the value of the CP in silage higher than that of the fresh grass prior to ensiling.

However, the dose rate of formaldehyde in relation to the CP content of the grass is quite critical wih an optimum rate of 3 to 5 g HCHO/100 g CP. Thus for the successful exploitation of additives containing formaldehyde more precise control of application rate than can be obtained with the present simple applicators may be needed. Alternatively, chemicals which protect protein in the rumen but have a wider range of safe application rates should be sought.

Conclusions

There are prospects for considerable saving in protein imports by greater production and more efficient utilisation of crop proteins. Improved conservation as hay and silage could replace much of the CP currently given to ruminant animals. The area of oilseed rape could be increased markedly with existing varieties and the availability within a few years of varieties low in glucosinolates and erucic acid would facilitate further increase in production and utilisation. The prospects for the eventual successful introduction of sunflowers and lupins are good. Increased use of peas as animal feed may result from the development of varieties with reduced leaves and/or stipules, but marked improvements in the efficiency of field bean production appear likely only in the long term. Engineering developments which could contribute to this increase in protein production and utilisation include:

1 Techniques for the efficient harvesting of seed crops which may have a high leaf content at harvest and have seeds at varying moisture contents and stages of maturity.
2 Techniques for increasing soil temperature in spring for crops with requirements for high temperature for germination and growth.
3 Better machinery for making hay of high quality.
4 Silage additive applicators with more precise control of application rate.

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Lightweight land drains

A new lightweight material – glass reinforced cement (GRC) – is being used for the first time in the production of inspection chambers and junction boxes for agricultural land drainage. And the manufacturers, H H Robertson (UK) Limited, claim that the installed cost of their GRC components – which have MAFF approval for grant-aided field drainage schemes – can be substantially less than the conventional brick or concrete counterparts.

The 10 mm thick GRC used in the inspection chambers weighs only 20 kg/m^2 as opposed to the 150 kg/m^2 of pre-cast concrete for a similar application. This means that the slot-together components in the new inspection chambers and junction boxes can easily be manhandled with obvious savings in installation time and cost.

Inspection chambers include a sump diameter of 900 mm, with side wall sections available in either 600 or 900 mm lengths. Covers are reinforced to withstand a top pressure of 3½ tonnes (as required by BS556/Part 2 1972) – ample to support the weight of a tractor. Galvanised steel ladders are available when necessary. Junction boxes are tapered from 500 mm at base to 600 mm at the top and are 400 mm deep with an easily placed on lid.

The components are produced under licence at Robertson's Welshpool factory from a material developed and patented by Pilkington Brothers.

H H Robertson (UK) Ltd, Ellesmere Port, Wirral, Cheshire L65 4DS (tel 051-355 3622)

Protein production: Problems for the agricultural engineer

A comment on single cell protein in the next decade

C A J Pritchard (BP Nutrition [UK] Ltd)

SINGLE cell protein represents a net input to agriculture because it can use non-agricultural raw materials such as oil, gas and waste streams from paper production. These substrates are used to yield a product suitable for animal feeds of approximately 60% to 70% crude protein.

Over the years, extensive testing programmes have been undertaken to demonstrate the safety and nutritional value of single cell proteins: BP's test programme has extended over 15 years and I think it is true to say that Toprina has been more thoroughly tested than any other new food product over this period.

Within th EEC, capacity already exists in Italy for the production of 200 000 t/a of SCP in two 100 000 tonne plants owned by Italproteine (BP and ENI) and Liquichimica. A very complicated political situation has so far prevented the sale of either product and today these plants stand idle. In the UK ICI have announced the construction of a plant at Billingham whose capacity is 40 000 – 70 000 t/a, depending on the grade of product produced. The construction of these plants demonstrates that SCP production on a vast scale is technically feasible, even though the industry is still in its infancy – for example, little work has been done on mixed cultures and substrates.

Much less certain is the economic feasibility of these processes, at least in the short term. Development of SCP began in the era of cheap energy: the escalation in energy prices since 1973 and the effect of inflation on capital costs has had a serious effect on the economics of SCP production. It seems likely that it will be some years before there is any significant expansion in the capacity for SCP production in Western Europe beyond the 300 000 tonnes already installed or under construction.

Taking a long term view, however, it seems likely that a further expansion of SCP production will eventually be necessary if Europe is to continue to satisfy its growing demand for high quality protein. The enormous expansion of animal feed production which has taken place over the last ten to fifteen years was made possible by the rapid growth of fishmeal and soya production. The expansion of fishmeal production has now come to an end and there are signs of the US production of soya nearing its limit also: very few commentators are now talking about the crops of two billion bushels which were commonly predicted two or three years ago. The only major source of further expansion is, therefore, Brazil. What is certain is that protein supplies can only be increased at a higher price level in real terms. The market is now feeling the effect of a 17% drop in US soya production last year, the main cause of which was the low price of soya last spring. The lesson is clear: if we in Europe want soya protein we must be prepared to pay a decent price for it. Given todays' prices, single cell protein can be produced competitively in Europe. Prices will of course fall back from todays levels but if they were to regain current price levels by the early 1980's SCP could then make a contribution to the overall protein supply. That is not to say that they will offer serious direct competition to soya: we are talking of some hundreds of thousands of tonnes of SCP against some 60 million tonnes of soya produced in the World. What SCP can offer, however, is a stable source of supply of high quality protein within Europe to supplement the supply of fishmeal and at prices comparable with those of high quality fishmeal.

Edited summary of morning discussion

Discussion of the morning session was led by J L Shiach BSc(Agr) BSc(Eng)

"I FEEL that the two papers we have had this morning have been comforting; I say this because the conclusions reached by both speakers were predicting evolutionary rather than revolutionary changes and since farming is essentially a long term business, then gradual change is more easily prepared for and absorbed.

"We are all in the business of providing food for our human population and with ever rising (or mostly ever rising) living standards and fewer and fewer jobs demanding large physical inputs, it is natural that the pattern of eating will change. Modern society, however, makes different demands on individuals and food is often used to fulfil a social role that has nothing to do with refuelling a working machine.

"One phrase used by Professor Aylward made me shudder a little – "fabricated foods". These must lower the quality of life. Texturised plant protein also sounds nasty, but we probably all eat it without realising. Coming as it does mainly from soyabean must be a worry for our home agriculture although its cost may well keep it at bay in the time span we are considering today.

"As agricultural engineers, I think it is fair to say that we have had considerable success over the last forty years at responding to the demands made upon us by our colleagues in other disciplines, be they agronomists, nutritionists or whatever. An example of success has been in the harvesting and storage of cereals where there is a high level of efficiency in the machinery used. Where the remit has been less clear, (an example which springs to mind is in the feeding of dairy cows in the milking parlour) there has been less success. In this case we have evolved more and more sophisticated equipment to measure out something which the pundits are now telling us is the wrong amount of the wrong material in the wrong place.

"Consequently, I feel we should approach Dr Wilkins' list of alternative protein sources with great caution and, to take one example, before we devote large resources to solving the problem of harvesting rape, we must be free from the anxiety of promoting fatty livers in hens or goitre in cows or humans.

Mr J G Shiach BSc(Agr) BSc(Eng) FIAgrE JP is Head of Engineering Division, School of Agriculture, University of Aberdeen.

"From the paper, some of the mechanisation problems for these alternative crops seem insuperable but my own favourite group for exploitation would be the turnips, swedes and mangolds. Aberdeenshire built its reputation for quality beef by feeding these with either hay or oat straw and bruised oats. Most of the mechanisation problems are solved and these crops yield well and consistently.

"However, without any doubt the greatest contribution will continue to come from our grasslands where, as Dr Wilkins showed, technology is well ahead of general practice. I would ask him what he means when he requests "better machinery for making hay of high quality". Surely the range of field machinery available is adequate. In most parts of Britain air should be blown through the crop and we have the equipment to do it. I agree that moisture meters are open to improvement but are they critical if crops are to be blown by ambient air?

"Professor Aylward made the point that "the energy component of feed requirements, in the case of ruminants, is substantially home produced: the protein component mainly imported". Summer grass has the protein needed for most of our stock. Should not our greatest efforts go to conserving it for winter use.

"I trust that I have not sounded too complacent about the problems facing the agricultural engineering industry if it is to cope with the changes predicted in the two splendid papers we have just listened to. But we do have an enviable record for ingenuity backed by good research and development facilities. My sadness is that our manufacturing is becoming more international and less British and since we can probably never be really self-sufficient and at the same time retain an interesting and varied diet, then we have got to have genuine exports to pay our way."

Question 1

E J Mostyn (ADAS, Huntingdon), commented on the attention being paid to the ruminant animal and asked if this were the right source of protein food for the future. He referred to American data which suggested that the conversion efficiency of New Zealand beef was about five per cent. Was the direct use of protein as mentioned by Professor Aylward therefore right? Should we be thinking so heavily of putting everything into ruminants?

Professor Aylward felt that there would probably come a time when the animal protein component of food would give way to an increase in vegetable protein farming. However, unless a catastrophy occurred, any such swing in this country was likely to take place very slowly, in view of recent evidence which suggested that the British population would tend to become static in the years ahead.

Dr Wilkins observed that we consumed considerably more protein than was actually necessary but we had the financial facility to purchase this material which we enjoyed eating. The human could manage quite well without the high protein foods which had been referred to, but a modern high production domestic animal could not.

Question 2

P N Wilson (Unilever), noted an apparent contradiction between Professor Aylward and Dr Wilkins. The former had stated that home produced protein was a misnomer when used to describe food derived from animals. This was because the proteinacious foods had been mainly imported. Dr Wilkins, however, observed that although the term imported protein was largely interpreted as meaning soya and fish based nutrients, our stock were also fed on cereals, which are mainly home produced and green crops which were wholly home produced. It seemed, therefore, that the predominant amount of protein was not imported.

Professor Aylward agreed that a more satisfactory statement would be that if protein imports were to cease, there would have to be serious modifications to certain aspects of livestock investments.

Dr Wilson observed that the JCO had shown how 100% self-sufficiency could be achieved in stock feeding with more satisfactory application of existing crops and their conservation. This was particularly relevant to the present conference.

Question 3

Dr R Braude (NIRD, Shinfield) was perturbed by the "seige economy" which was being considered. If it were true that soya could be produced cheaper in both North and South America than anything we can produce here, and delivered here at a price which is more economical, should we encourage a development which was based on false economics? He feared that the figures given, particularly for soya, were misleading. Certainly at present, production of soya in USA, was levelling off but the potential there was vast and even bigger than in South America.

Engineers should not be mislead by being given a target to produce machinery which was expensive and in any case would not be able to compete, in terms of end product, with cheap soya protein.

Dr Wilkins believed that the future existence of cheap soya was an open question but he also was concerned that British agriculture used its efforts wisely. He referred to the £700m imports of sugar per annum and compared them with our £200m imports of protein. There were certainly other alternatives that we should be considering in terms of increasing our agricultural production — not necessarily simply increasing the production of protein.

Question 4

P Jackson (Beecham Animal Health, Brentford), referred to Dr Wilkin's examination of the potential for replacing imported proteins by home produced protein in terms of crude protein. It may not be a pertinent analysis: we imported proteins primarily for their amino acid pattern and for their density.

If we were to use optimum levels of nitrogen on grass we would have 7m tonnes production of protein but this would be of an entirely different quality from that imported and would need further processing. There was danger of misleading engineering colleagues if we concentrated too much on forage production. We must address ourselves primarily to energy nutrition.

Where proteins are fed, we were very dependent on the supply of cereals. We could ill afford to employ high nutrient density protein such as fishmeal and single cell protein if cheap cereals were available. If we had good supplies of low protein, high energy sources, we could use large quantities of non-protein nitrogen as is done in USA.

Dr Wilkins pointed out that crude protein was a restricted way of assessing our requirements. We must however recognise other aspects of the nutritive value of particular protein sources; perhaps however we should consider other facets than the amino acid balance. A number of combinations of possibilities existed and dictated the need for a broad approach to protein supply.

In ruminant feeding where there was a much greater production of maize silage now, a product with a basal level of ten per cent crude protein was typical, and gave rise to a situation where non-protein nitrogen could now be used.

Question 5

E N Griffith (Farming interests in Australia), referred to the much lower costs of producing beef cattle in Australia than in this country. Britain should not be paying high prices for beef when cheap meat was available from parts of the world where production is based entirely on grass.

Dr Wilkins, speaking against the clock, agreed but observed that beef could be produced entirely on grass in this country too.

Health and safety

Statistics recently published by the Health and Safety Executive show an increase in fatal accidents on British farms during 1976. Seven more people were killed than in the previous year and children accounted for more than 20% of the total.

The 108 fatal accidents involved 43 farmers, members of their families or self-employed, 41 farm workers, 21 children and three other adults.

The number of fatalities caused by tractors overturning was 23 compared with 25 in 1975 and 22 in 1974. Only three of the tractors involved had been fitted with safety cabs. In all three cases the driver was killed outside the protection of the cab. In one case the driver tried to jump clear and in the other two the doors of the cab had been removed. In no overturning accident did the protective frame of the cab collapse. Not all tractors are yet fitted with approved safety cabs or frames. This became a legal requirement for tractors driven by agricultural workers on 1 September 1977. Of the 23 people killed by overturning tractors, 16 were farmers or other self-employed who are not covered by this requirement of the regulations.

Tractors and other field machinery caused or contributed to 39 deaths in 1976, including 10 children. These figures compare with a total of 27 deaths in 1975, including the same number of children.

There was a sharp increase in fatal farm accidents involving electricity. In 1976, 11 people died compared with five in 1975 and one in 1974. In four cases, exposed metal parts of equipment were not properly connected to earth. In two of these cases the dangerous practice of using makeshift fuses was also evident. Electrocution resulting from accidental contact with 11 000 volt overhead power cables, caused the death of five people on farms during 1976. The Health and Safety Executive advise that it is a wise precaution to fit a notice to any tall mobile machinery or tipping vehicle warning the operator to "Beware of overhead electricity cables".

Eight adults were killed by falls in 1976 compared with 16 the previous year. In both years four children also died as a result of falling accidents.

Again no deaths were reported from poisoning by pesticides and other chemicals. The Executive has, however, recently drawn attention to the need for care when using pesticides in the leaflet series *Agricultural Health and Safety Topics*. The use of hand-held ultra-low volume spraying machines to apply organo-phosphorus insecticides to standing cereal crops is described as a particularly hazardous operation. Emphasis is placed on the importance, often forgotten, of taking the precautions recommended by the spray manufacturer — information which is found on the container labels.

The number of non-fatal accidents and diseases in agriculture is provisionally 5272 — one fewer than 1975. Three categories showed a marked increase on the previous year, Implements (trailed or mounted), hand tools (powered) and burns.

Traces of fertiliser left in tubular frames or other confined crevices may produce vapour rapidly when heated, building up sufficient pressure — particularly in hollow sections — to burst the equipment explosively with serious consequences. The Executive has issued a warning on this ammonium nitrate explosion hazard which could occur when welding equipment which has been used for handling fertiliser and which has not previously been thoroughly cleaned.

The Executive also warns that operators of certain types of tractor linkage — mounted diggers and loaders risk being crushed to death or suffering severe injury. In recent years four operators have been killed and four seriously injured when trapped and crushed between control panels and tractor cab frames. The digger/loaders involved fit on to the three point linkage at the rear of the tractor and a seat is provided for the operator on the equipment between the tractor and the control panel. The Executive points out that a simple modification eliminates the risk which occurs when the clearance between the control panel and the cab frame is less than 18 inches.

An *Agricultural Health and Safety Topics* leaflet is available on caustic soda treatment of straw on farms. The leaflet refers to the hazards when using caustic soda and makes recommendations on suitable protective clothing and safe working procedures.

BAM

Protein production: Problems for the agicultural engineer

On farm forage protein - the potential and the means

Professor H D Bruhn MS FASAE R J Straub and R G Koegel

Summary

The advantages of the extraction of plant juice, as a protein concentrate, and the combination of this process with other forage conservation techniques, are discussed. It is suggested that a de-watering machine having a capacity of 18 tonne per hour of green material would be a realistic minimum size. Power and fuel requirements are given and may be the factor limiting the on-farm development of concentrate dehydration.

THE production of plant juice protein concentrate poses no insurmountable problems either at the large farm level or at the processing plant level. In most steps of the process there are alternative procedures possible Koegel, *et al* (1973), Koegel, *et al* (1973), Koegel, *et al* (1972), Holdren, *et al* (1970), the choice being dictated not necessarily by design feasibility but rather by such factors as economics, energy utilisation, quality of product or disposal of by-product. It is in this area that the agricultural engineer must exercise his ingenuity to develop an acceptable and economically feasible system from all the alternatives.

Because of the relatively small portion of the total available protein removed, it is doubtful if, in either the USA or western Europe, the production of green plant juice protein concentrate from either legumes or grasses will be economically sound unless the fibrous portion of the plant with its retained nutrients is utilised for livestock feed Pirie (1942), Pirie (1952), Stahmann (1968). The dry protein concentrate yield from alfalfa (lucerne) is in the magnitude of 2% of the green material weight or 10% of the dry matter entering the process Koegel *et al* (1974). Thus, the de-watering and juice processing must in most cases be geared to synchronise with some other forage harvesting or processing activity if it is to be adaptable to any appreciable extent.

There are possible exceptions to the necessity for synchronising processing to a pre-established harvesting rate in cases where normal waste material such as pea vines, potato vines, or aquatic vegetation may be de-watered to provide the plant juice for processing, but even in these cases the "waste" material becomes available at some normal rate determined by a harvest rate.

To obtain high quality and yield from alfalfa fractionation, processing must be completed within a relatively short time after harvesting to prevent protein precipitation within the forage. High temperature and excessive cell damage prior to fractionation will accelerate protein precipitation within the material.

Combining the production of juice protein concentrate with normal livestock feed harvesting presents three possible avenues of approach:

- No 1 Combining juice protein production with the forage dehydration process.
- No 2 Combining juice production with the harvesting and storage of low-moisture alfalfa or grass silage.
- No 3 Combining juice protein production with a modified field-curing process for the production of a product similar to dry hay.

The feasibility of No 1 has already been established in one instance by commercial production by Batley-Janss of California, Kohler and Bickoff (1971). Research at Ohio and our own research at the University of Wisconsin has demonstrated the feasibility of No 2 by the filling of silos and subsequent feeding trials of the ensiled material, Russell, *et al* (1974), Hibbs, *et al* (1968).

When the over-all energy situation is assessed, serious consideration of No 3 may well be forced upon us in the production of high quality forage that is not utilised near its point of production.

While research at Wisconsin has not progressed far enough in the area of combining mechanical de-watering and field curing to provide definite conclusions, it does indicate that with major modification of our present machinery used in cell rupture and de-watering, the process does have considerable potential.

The potential lies not only in producing protein concentrate, but also in providing a livestock feed that is a higher quality, more palatable dry hay with less weather damage during field curing. Hundtoft and Winkelblech (1966). However, this phase apparently has not yet stimulated widespread research activity, and at present the No 1 process (followed by No 2) is receiving considerably more attention.

The apparent future availability of gaseous or liquid fuel for the dehydration of forage crops in the USA is very dubious, and the development and acceptance of solid fuels has not been proven. In the transition or phasing out period of dehydration with gaseous and liquid fuels, considerable fuel can be saved by mechanically de-watering the forage prior to dehydration.

This saving becomes quite apparent when analysis is made of the moisture content of the material at various stages as shown in fig 1 (see footnote). On the basis of 18 144 kg (20 tons USA) (40 000 lb) of fresh alfalfa harvested at 80% moisture W B, 14 112 kg (31 111 lb) of water would have to be evaporated to produce 4032 kg (8889 lb) of dehydrated alfalfa containing 3629 kg (8000 lb) of dry matter following the conventional dehydration procedure.

In the wet fractionation process, 467 kg (1029 lb) of steam are used for coagulation, 686 kg (1513 lb) of water are evaporated in drying the protein concentrate, and 4812 kg (10 609 lb) of water are evaporated from the fibrous residue to produce 3062 kg (6751 lb) of dehydrated alfalfa containing 2756 kg (6076 lb) of dry matter for a processing total of only 5965 kg (13 151 lb) of water evaporated.

Thus in the case of complete dehydration 3.9 kg of water are evaporated per kilogram of dry matter in the dehydrated product, while in the case of preliminary mechanical de-watering and juice processing, it is only necessary to evaporate 2.0 kg of water per kilogram of total dry matter in the dehydrated product and the protein concentrate.

If, instead of dehydrating the fibrous fraction, it is made into silage, then only 0.4 kg of water need to be evaporated per kilogram of dry matter in total usable product (namely, the silage and the dried protein concentrate).

The economic advantage or disadvantage of producing 332 kg (731 lb) of protein concentrate instead of 970 kg (2138 lb) of dehydrated alfalfa depends on market conditions. Admittedly, more heat may be required to form one kilogram of steam used for coagulation than to remove one kilogram of water from green forage, but the tremendous difference in the energy requirements of the two systems is readily apparent.

There is opportunity for considerably further fuel economy by utilising waste heat in the dehydrator exhaust to accomplish the entire juice coagulation process, thereby reducing to a limited extent the total heat input to the process when the fibrous fraction is dehydrated.

To a large degree the capacity of a dehydrator depends on its fuel burning capacity and the effectiveness in utilising the generated heat to vaporise water initially in the plant cells, Owens (1949).

De-watered fibrous material produced in the fractionation process has well over half of the initial water removed and has been shredded in the process thereby providing ideal heat and mass transfer conditions (fig 1). It seems reasonable to assume that the dry matter throughput of a conventional dehydrator can essentially be doubled by an intensive mechanical de-watering treatment of the plant material.

One large US manufacturer lists dehydrator water evaporating rates for various sizes of machines at 9000, 12 000, 18 000 and 34 000 lb/hour or the SI equivalent of approximately 4082, 5443,

H D Bruhn is Professor, Agricultural Engineering, R J Straub is Research Assistant, Agricultural Engineering, and R G Koegel is Associate Professor in the Departments of Mechanical Engineering and Agricultural Engineering, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA.

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Footnote: Numerical values quoted herein have, in many cases, been derived from calculations or as a result of unit conversion from reference data. Rounding-off can, in some cases, be misleading and has been avoided in this paper.

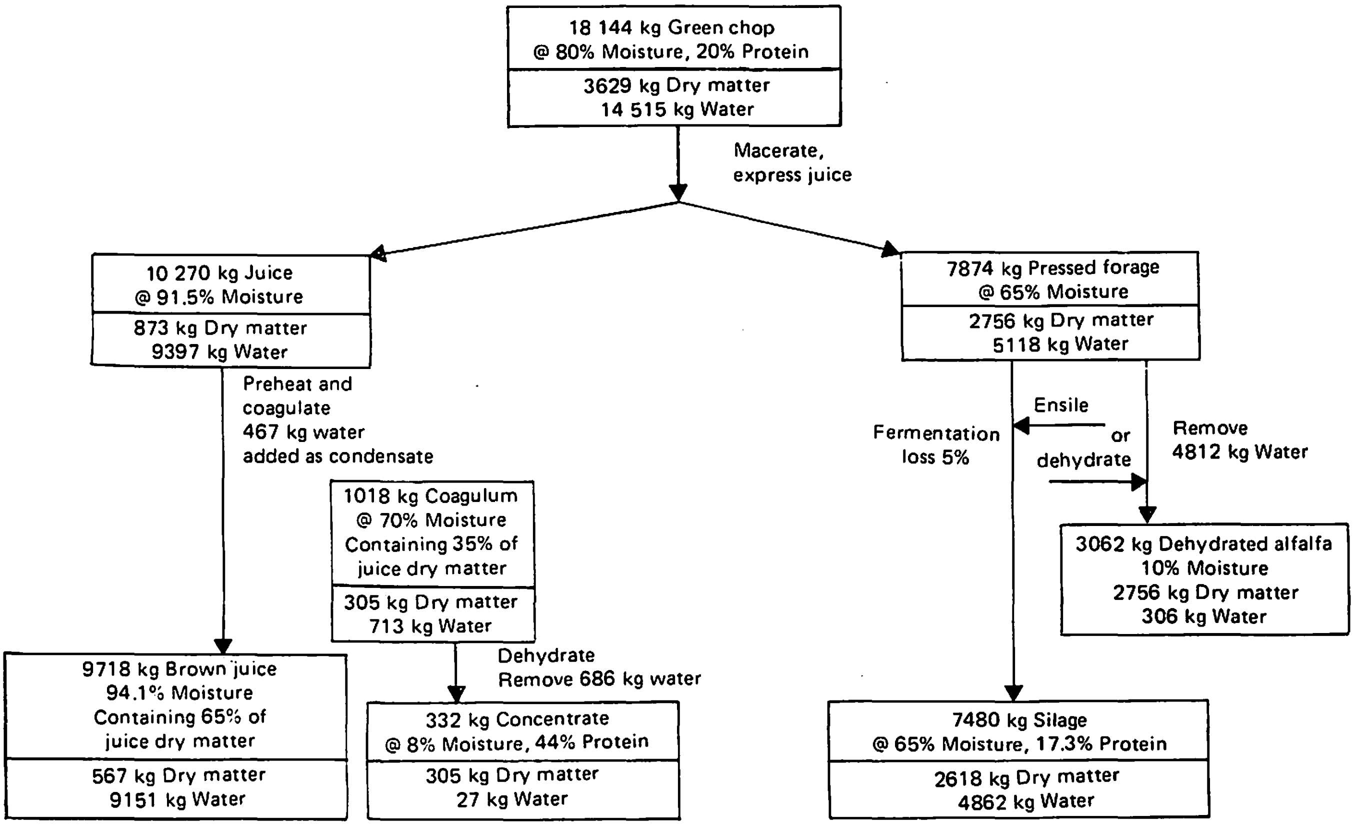

Figure 1 Quantities of products formed at various steps in the processing of 18 144 kg of alfalfa.

8165 and 15 422 kg/hour. Conservatively, this is the equivalent of a feeding rate of mechanically de-watered material of approximately 6, 8, 12 and 22 tonne/h or a field harvest rate of roughly 12, 16, 24 or 45 tonne/h of the crop as harvested. This then indicates the ultimate capacity required of mechanical de-watering equipment for installation on a dehydrator production line. Wide spread general acceptance of lower capacity equipment by the commercial dehydration industry is rather doubtful.

Each of the two smaller capacity dehydrators could be served by a single machine for juice extraction with a capacity of 18 144 kg (20 tons USA)/h of field chopped forage. The larger dehydrators could be served by a pair of these machines operating in parallel until larger equipment is developed.

This would also indicate that, to be practical in the dehydration field, the juice processing equipment should have a capacity approaching 10 tonne (11 tons) or 10 000 litres (2700 gal USA) of juice per hour resulting in the production of over 330 kg (700 lb) of dried protein concentrate per hour. See process flow diagram in fig 1 for the precise analysis.

The problem may be approached from another angle. The larger progressive farms in the north central dairy region of the USA that could reasonably be expected to operate fractionation equipment are approaching herd size of 100 or more dairy cattle. To provide dry hay and grass or legume silage for a herd of this size including young stock for replacement would require a minimum of 50 hectares (120 acres) of alfalfa yielding on the average five tonne (2 ton/acre) of dry matter or 25 tonne (10 ton/acre) of green material per hectare on the first cutting. To avoid losses from over-maturity the crop should be harvested within a 10 or 12 day time period or at the rate of 120 tonne of green forage per day or 12 to 20 tonne per hour.

Harvesters which normally would be used to cut and chop the forage prior to processing require 3 to 7.5 kilojoules per kilogram (1 to 2.5 hph/ton), *Agricultural Engineers Yearbook* (1976), and since the tractors being used on farms of this size are usually in the 45 to 150 kW (60 to 200 hp) class, the harvest rate is generally in the green crop equivalent range of 18 tonne (20 tons)/h or more. Crop blowers used for putting wilted alfalfa (low-moisture silage) into a silo require 3 to 6 kilojoules per kilogram (1 to 2 hph/ton) with a capacity of 18 to 27 tonne (20 to 30 tons)/h, *Agricultural Engineers Yearbook* (1976).

The above rate of harvesting and storing low-moisture material (de-watered) represents 36 to 54 tonne (40 to 60 tons) of material before de-watering. Thus a machine to carry out cell rupture and mechanical de-watering wiith a capacity of 18 tonne (20 tons)/h (green material) would probably be in the range of the minimum acceptable level.

A machine with lesser capacity would tend to slow the harvesting operation in an already busy season and simply would not be acceptable to enough farmers or dehydrator operators to establish a viable industry.

In a relatively small portion of the total crop growing areas of the world, forage crops can be grown 12 months out of the year with the aid of irrigation. However, in most of the world, temperature or rainfall conditions are such that forage crops reach maturity in rather well-defined short seasons two to four times per year and, with maturity, change rapidly in nutritive value and fibre content, Smith. High protein forage crops are subject to rapid deterioration if not dried or preserved in the harvesting operation.

Therefore, not only will equipment to produce plant juice protein need to be of a capacity suitable to synchronise with normal harvest rates but it must also be constructed to sell at modest cost.

The agricultural engineers in the farm equipment industry are accustomed to designing and producing machinery profitable to operate although, in the most part, it is used only a few weeks per year. In contrast, industrial equipment in many cases is in operation throughout the year, and the higher initial cost can be prorated over many hours of operation. For example, wheat harvesting is a seasonal farming operation, while the flour milling industry is a year around activity.

It is doubtful that much commercially available industrial food processing equipment can be justified for use in on-the-farm production, but rather it will be necessary to rely on equipment designed on farm machinery standards by engineers familiar with both food processing and agricultural equipment.

If we establish that a plant juice protein processing system should have a de-watering capacity of approximately 18 tonne (20 ton) of green material per hour, then the de-watering equipment and processing system can be designed within known parameters.

Direct-cut forage harvesters and hauling equipment have undergone many years of development both for use by the commercial dehydrator and for use by the individual farmer. These machines are now well designed, have adequate capacity, are available at acceptable prices, and are relatively trouble free. This portion of the harvesting equipment is satisfactory.

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The first link required in the new fractionation system needed to fit into either the farm silage system or the dehydration system is a portable but stationary operating machine to perform the maceration and juice separation, Koegel, *et al* (1973), Pirie (1971). This ultimately should be a single machine performing the two functions and should be readily movable from one location to another.

Power requirement for maceration and fractionation

Our research indicates that the power required for extrusion maceration on an operational basis is in the range of 4.5 to 12 kilojoules per kilogram (1.5 to 4.0 hph/ton), Schirer (1973), Basken (1975), Basken, *et al* (1975), and the power requirement for fractionation (pressing) is approximately 0.75 kilojoules per kilogram (1/4 hph/ton), Koegel (1971). Thus 6 to 13.5 kilojoules per kilogram (2 to 4 1/2 hph/ton) at 18 144 kg (20 tons)/h would require a power input in the range of 30 to 67 kilowatts (40 to 90 hp), well within the available tractor power commonly found on farms large enough to carry on this type of operation. Smaller farms would quite definitely be excluded except in cases of co-operatives, leased equipment, or custom operators.

Juice processing

With an hourly capacity of 18 144 kg (20 tons) of fresh cut forage at 80% moisture, the juice production on de-watering to 65% moisture is approximately 10 270 kg (22 640 lb)/h (fig 1).

In our climate in Wisconsin during alfalfa harvest we find that after the juice has been expressed and passed through at least one pump it is in the range of 27° to 30° C (80° to 85°F). If we assume an average of 52° C (93° F) temperature rise [28° to 80° C (82° to 175°F)], approximately 620 kW (2 105 000 btu/h) will be required for coagulation. However, 50% of this heat (or more if the green juice temperature happens to be low) can be reclaimed from the discarded, deproteinised brown juice through the use of a heat exchanger (see fig 2 and 3). Thus, roughly only one half or 310 kW (1 052 500 btu/h) will need to be supplied in the form of steam for coagulation of the protein in the green juice. This is equivalent to about 467 kg (1029 lb) of saturated steam per hour at 345 kPa (50 lbf/in^2). With a fairly efficient steam generating plant this can be accomplished with an oil burning capacity of 38 litres (10 gal USA) of fuel oil per hour.

Separation of protein concentrate and brown juice

The separation process may be carried on in any one of several procedures. At the present time we are skimming off the floating alfalfa protein immediately after coagulation. The power requirement is very low, and the equipment can readily be scaled up to any desired size. One thousand to 1500 kilograms (two to three thousand pounds) of coagulum per hour could be skimmed with an input of less than 0.5 kW (1/2 hp) (fig 3).

Straining devices to separate wet coagulum from brown juice may prove more practical particularly in processing plant juice from which the freshly coagulated protein has little tendency to float. A straining system may take more power than skimming equipment because it readily lends itself to greater mechanical de-watering of the protein concentrate. This would take slightly more power but could make a marked saving in total energy used in subsequent dehydration or other methods of preserving the protein concentrate.

We have partially completed research on mechanical de-watering of protein concentrate but have not translated research into pilot model equipment. Research indicates that straining and mechanical de-watering, within practical limits, can be carried on with less than 5 kW (7 hp) in the process described in fig 1.

It is entirely possible that a type of centrifuging equipment could be used to separate the wet protein concentrate from the brown juice. However, the class of construction normally associated with high-speed centrifuge equipment would not put it in a cost range competitive with skimming or straining equipment.

Protein concentrate preservation

While there is research in progress on the use of chemical preservatives for wet protein concentrate and also on the immediate mixing and pelleting of the wet protein with other dry feed concentrates, both of these systems restrict its use within relatively narrow limits. Drying remains a rather universal approach. In the 18 144 kg (20 ton) operation described in fig 1, it is indicated that 686 kg (1513 lb) of water need to be evaporated from the wet protein to produce 332 kg (731 lb) of stable protein concentrate per hour.

We have used four types of drying equipment, namely: oven, triple pass rotary, drum and spray. The characteristics and quality of the dried product vary widely as well as the initial and operating costs of the equipment. A discussion of drying would be far too involved to include in this paper.

Currently we are investigating steam heated drum drying and have found that with proper control a reasonably good product is obtained. On the average one kilogram of water can be evaporated from protein concentrate with 1.2 kg of saturated steam at 345 kPa (50 lb/in^2). With an 80% boiler efficiency, the 686 kg (1513 lb) of water could be evaporated by drums heated with steam by burning 72 litres (19 gal USA) of fuel oil per hour.

Processing de-watered fibrous fraction

The two alternatives in processing the fibrous fraction vary widely in energy consumption. If the de-watered fibrous fraction is used for silage, its well-shredded physical state is ideal for a desirable fermentation at 65% moisture, Russell, *et al* (1974). It requires less than 22 kW (30 hp) to blow the 7874 kg (17 360 lb)/h into a silo. *Agricultural Engineers Yearbook* (1976). In a "tight" silo a 5% fermentation loss can be anticipated, resulting in 7480 kg (16 492 lb) of silage with 2618 kg (5722 lb) dry matter.

If the fibrous fraction is dehydrated with care and no plant material is burned in the process, 3062 kg (6751 lb) of dehydrated alfalfa will be produced while burning approximately 416 litres (110 gal USA) of fuel oil, Owens (1949).

This operation is essentially the same as normal alfalfa dehydration except that the dry matter output capacity of the dehydrator should be about double of that attained when dehydrating fresh cut alfalfa.

Comparison of power and heat energy requirements

A summary of the power and heat requirements of the No 1 and No 2 process of producing protein concentrate and converting the fibrous fraction into either dehydrated forage or low-moisture silage is shown in table 1. The total power input when protein concentrate and dehydrated forage are the final product (No 1 process) is in the 125 to 129.5 kW (160.5 to 165 hp) range plus a total heating fuel requirement of 526 litres (139 gal USA)/h. While the power requirement is slightly higher [137.5 to 142 kW (183.5 to 188 hp)] for the No 2 process in making silage of the fibrous fraction, the heating fuel requirement is much lower [only 110 litres (29 gal USA)]. Considering that a diesel engine will convert one litre of fuel oil into 2.4 kW (12 hph/gallon) it can be seen that the overall energy requirement of the No 2 process is considerably lower, making this process much more desirable as an on-the-farm operation if the forage can be utilised in the immediate vicinity of its production.

As a matter of interest, the power and fuel requirements of the two conventional methods of harvesting forage crops are shown in table II.

Table I Power and heat energy requirements for de-watering alfalfa, producing protein concentrate, and processing of fibre at the rate of 18 144 kg (20 t)/hour by procedure No 1 or No 2

Operation	*Procedure No 1 Dehydrating fibrous fraction*	*Procedure No 2 Ensiling fibrous fraction*
Chopping green forage	30 kW	30 kW
Hauling chopped forage	15 kW	15 kW
Maceration and juice separation	60 kW	60 kW
Water supply total	0.8 kW	0.8 kW
Fuel to generate steam for coagulation	38 litre/h	38 litre/h
Skimming or straining	0.5 to 5 kW	0.5 to 5 kW
Blowing into silo		22 kW
Miscellaneous pumping	4 kW	4 kW
Miscellaneous conveyors		1.5 kW
Dehydration of protein concentrate	72 litre/h	72 litre/h
Protein concentrate dehydrator drive	3.7 kW	3.7 kW
Dehydrator mechanism drive	11 kW	
Dehydration of fibrous fraction	416 litre/h	
Totals	125 to 129.5 kW 526 litre fuel oil per hour	137.5 to 142 kW 110 litre fuel oil per hour

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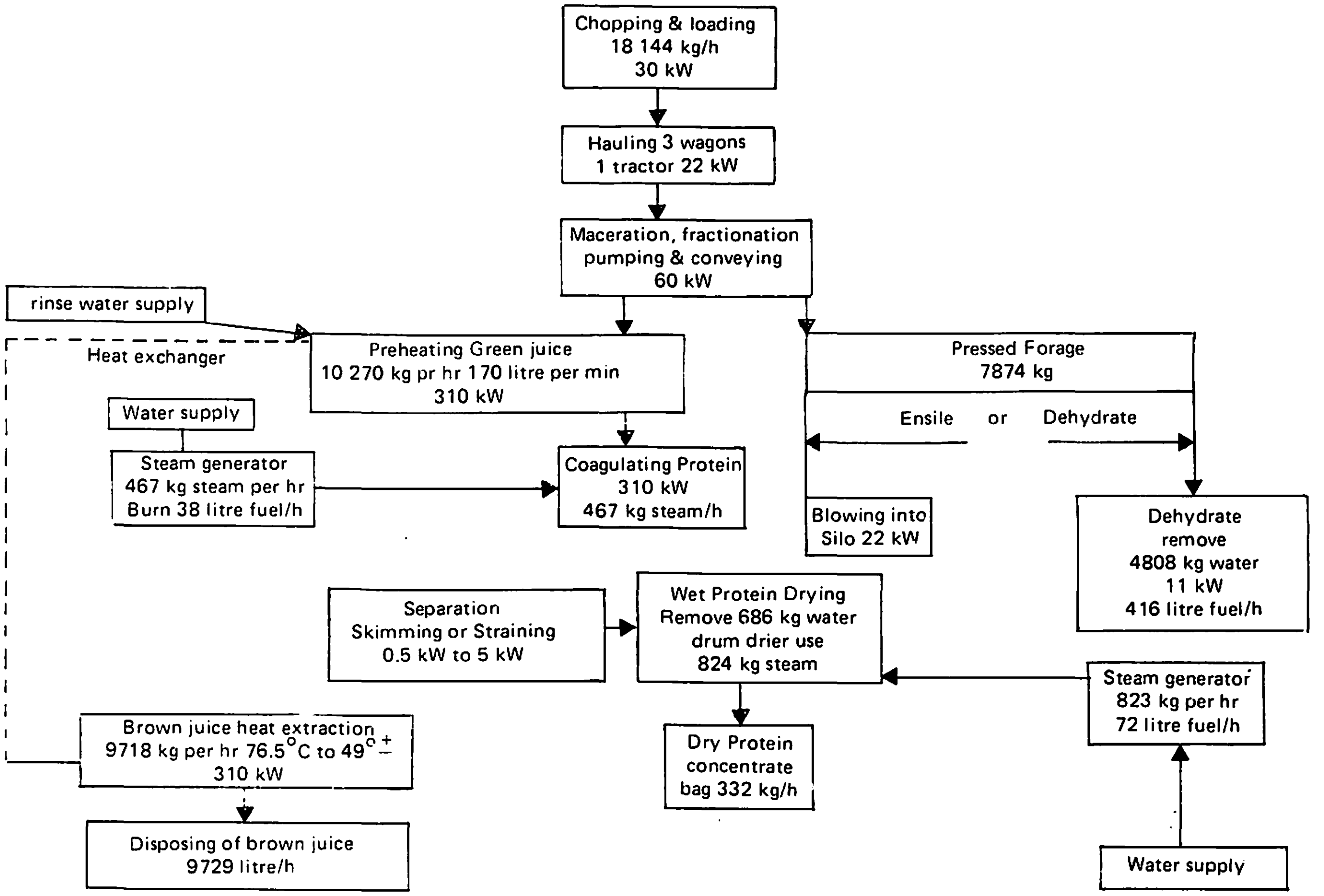
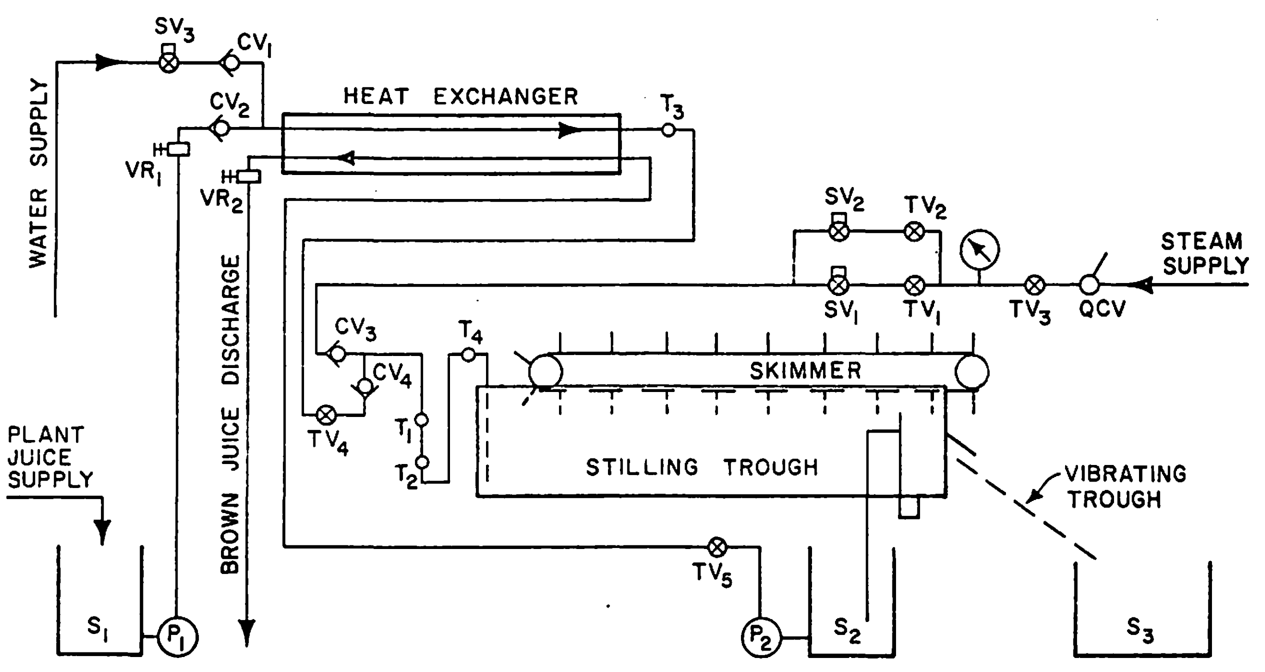


Figure 2 Energy requirements in wet fractionation and preserving alfalfa at the rate of 18 144 kg (20 t) per hour.

Fig 3 Plant juice protein processing system controls



Symbols:					
	CV	– Check valve		S	– Sump
	SV	– Solenoid valve		T	– Temperature sensor
	TV	– Throttling valve		VR	– Vacuum release valve
	P	– Centrifugal pump		QCV	– Quick closing valve

Table II Power and heat energy required to harvest and store 18 144 kg (20 ton) of alfalfa per hour by conventional methods

Operation	*Wilting, chopping and ensiling*	*Direct harvesting and dehydration*
Mower-conditioner windrower*	15 kW	
Chopping green forage	30 kW	30 kW
Hauling chopped forage	15 kW	15 kW
Blowing wilted crop into silo	22 kW	
Dehydrator mechanism drive		11 kW
Dehydration of entire crop		1287 litre fuel oil per hour
Totals	82 kW	56 kW 1287 litre/h

**Mower-conditioner operates less hours than balance of equipment*

Harvesting and storing a forage crop as a wilted silage requiring only 82 kW (110 hp) is without a doubt the less demanding of energy. De-watering and making protein concentrate and silage can only be justified on the basis of:

1) Having a harvesting system independent of the weather.
2) Saving a higher portion of the protein produced in the growing crops.
3) Providing a protein concentrate supplement for very high producing dairy cows and for monogastrics or humans incapable of utilising appreciable quantities of forage protein in its natural state.

If the total energy required by a wet fractionation system combined with final dehydration is compared with a conventional total dehydration system, the potential fuel saving due to mechanical de-watering is very obvious. Mechanical de-watering and processing the plant juice for protein concentrate may serve to delay the complete demise of the dehydration industry now operating on gas or liquid fuel.

Conclusions

The design of wet forage fractionation machines and processing equipment with sufficient capacity to synchronise operation with normal large farm harvesting systems or commercial dehydration facilities does not appear unrealistic.

The power requirements of such machines fall within the range available on large farms.

The heat requirement for preheating green juice and coagulating the protein is probably within an acceptable range. Fifty per cent or more of this heat is reclaimed from the brown juice before discarding.

The quantity of heat required for dehydrating the protein concentrate begins to border on unacceptability and points up the need for additional development work on mechanical de-watering of wet protein, drying procedures, or utilisation of wet protein without dehydrating.

Because of limitations of processing technology, the labour requirements, and the required investment in equipment, it is questionable if the final processing step, the dehydration of wet protein concentrate, should be carried out as an on-the-farm operation. It should rather be delegated to a central processing plant.

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Symposium on humidity measurement

THE enthusiastic response by participants at Sira Institute's seminar on humidity sensors and their range of application, held in November 1976, has prompted Sira to follow up that event with a symposium featuring recent developments in the application of humidity measurement. The symposium, *Applying humidity measurement in science and industry*, is to be held on 9 November 1977 at The City University, London.

The programme will consist of a review paper on humidity measurement by Dr K G Parkes of the Moisture Measurement and Control Centre at Sira, followed by case studies selected to cover a wide variety of applications ranging from the chemical industry to farming and measurements on plants. The emphasis will be on the practical use of humidity sensors. Accordingly, speakers will come from organisations having practical experience of the use rather than the manufacture of humidity instruments.

Speakers presenting case studies will include:-

B Arnold, Mars Ltd
P S H Boyce, Imperial Tobacco Ltd
C A Cove, National Institute of Agricultural Engineering
Dr J C Harrison, The Post Office
Professor P G Jarvis, University of Edinburgh

The symposium will be of interest to scientists, engineers and technical managers who are concerned with humidity measurement. It will not be necessary for those attending to have a detailed knowledge of humidity measurement techniques.

Further information about the symposium may be obtained from Mrs R G Keiller, Sira Institute Ltd, South Hill, Chislehurst, Kent BR7 5EH, England.

Waste from animals – Food?

J K Grundey NDA NDAgrE

ANIMAL excreta contains proportions of the many nutrients contained in the feed consumed. In the poorer countries of the world it has been a standard practice to feed some animals with others' excreta but in the western world this is usually regarded as repulsive.

However in the past decade the practice has begun to establish itself in some parts of the USA and in the UK. Most interest centres around poultry excreta because of its higher protein levels and better digestibility than say cow faeces.

The high cost of world protein has stimulated this development so that currently an estimated 100 000 tonnes of dried poultry manure (DPM) are utilised in UK livestock feeds. Inclusion rates at up to 20% of the compound ration have been fed successfully to cows, beef and sheep.

Drying poultry manure is an expensive business. Oil consumption alone may exceed 270 litres/tonne for drying which is accompanied by the generation of most unpleasant odours. A simple and effective treatment for such odour is the fitting of an after burner to the exhaust drying air. This may add a further 200 litres of oil per tonne to costs.

The economic viability of DPM is tied to the world price of protein, which fluctuates. The rising cost of oil and the increased environmental resistance to foul smells are rapidly rendering the drying of poultry manure less attractive. There are estimated to be considerably fewer than 100 on-farm drying plants at work now in the UK.

An alternative method involving much lower energy inputs and costs is to ensile the poultry waste anaerobically when pH can drop sufficiently to sterilise the excreta and render it fit for feeding.

About 650 000 tonnes of droppings and litter is left over from the production of some 47 million broiler chickens each year in the UK. With a crude protein of 25% this represents a considerable potential of animal feed available at low cost.

Animal nutrition is a complex science and to state a fixed financial value fcr ensiled poultry litter (EPL) as a feed can be misleading. Whilst nutrient content can be calculated, there are inter-actions between the EPL and other fractions of the feed which influence overall digestibility or utilisation by the animal. The potential value of EPL as a feed supplement is around £55–65 per tonne of dry matter with which may be compared barley straw at £41, average hay at £54, barley grain at £93 and ground nut at £177.

Work is currently going on by ADAS and others to investigate the development of this process for on-farm application. To the droppings plus straw (or shavings) litter mixture is added water to bring moisture content to 40–50%. This material may be ensiled alone or with the further addition of small amounts of organic acids eg 2–4% or higher rates, up to 20%, of molasses.

A period of 6–8 weeks ensilage can result in sufficiently low pH. Ruminant animals of all sizes and ages have been fed such material with no ensuing problem. Growth, appetite etc have been maintained compared with conventional feeding methods.

All of this of course assumes that the process effectively kills off all harmful organisms present in the original faecal material. The salmonella species are probably the most noteworthy disease risk to man and the "salmonella cycle" is well known in which such organisms may be transmitted from infected poultry to man, to rivers, to other livestock etc. This is causing concern to authorities both in the UK and especially in Europe.

Thus there is an obviously large risk when feeding excreta directly to animals of salmonella transmission to man. It is likely that society will not knowingly tolerate such a risk.

Hence although investigations are going on to examine the idea it must be realised that at present ensilage of poultry litter etc is not to be recommended for general farm use.

Turning to the agricultural engineering involvement, problems which relate include:

a) The application of sufficient water to poultry litter and mixing to achieve the target moisture content evenly.
b) The application of low to moderate amounts of other additives eg organic acids and molasses.
c) The handling into and out of the ensilage process at reasonable speed and without spillage to avoid cross infection.
d) The design of a cheap and satisfactory ensiling system: Can a surface clamp be made airtight in everyday practical farm conditions? Can a truly airtight plastic film be produced for this and the horizontal sausage ensiling machine?
e) Can tower silos provide an economic solution?

J K Grundey NDA NDAgrE, Head, Farm Waste Unit, ADAS, Reading.

Paper presented at the annual conference of the Institution of Agriculural Engineers, held on 10 May 1977, at the Bloomsbury Centre Hotel, London.

Protein production: Problems for the agricultural engineer

Fish farming - the economics and engineering problems

Dr C J Shepherd BVSc MRCVS MSc

Summary

THE paper draws attention to the place for fish farming in the world, its economic prospects and the contribution which the engineer can make to its success.

1) Introduction

FISH farming, or aquaculture as it is often known, can be defined as the rearing of aquatic organisms under controlled conditions. As such it covers the farming of fish, shellfish, or even seaweed for food production, as well as providing live fish for restocking lakes, rivers and aquaria. Although practised in China for thousands of years, fish farming has only recently become a globally established form of animal husbandry and now produces over six million tonnes/annum worldwide.

Since fish are cold-blooded, tropical climates are conducive to fast growth and in countries such as Israel, half of the fish eaten is produced by farming. By comparison, fish farming is an embryo industry in Britain and emphasis to date has been mainly on higher priced species.

2) Market aspects

The best established type of farming in Britain is that of rainbow trout, currently producing about 2500 tonnes each year. This is worth over £3 millions ex farm and retails at around £5 millions, but is insignificant in relation to the total UK market for fresh, frozen and smoked fish, which was worth nearly £300 millions at retail value in 1975.

Any consideration of likely growth in sales of farmed fish in Britain must recognise that as a whole, fish is a minor and generally declining part of the average British diet. Thus *per capita* consumption of fish in the UK for 1948 and 1973 was 16 kg and 8 kg/a respectively and home expenditure on fish is now only 1/6 of that for carcass meat. There is a continued decline in sales of fresh fish and this has not been fully compensated by the persistent growth in frozen fish sales. The reason is partly that conventional fish supplies are becoming scarcer due to problems of overfishing with consequent stock depletion and fishing limits. Therefore market values have escalated accordingly, although the rate of recent price inflation for fish has not necessarily exceeded that for other forms of meat. To put all this in perspective, it is also true that in Britain we have too long taken for granted relatively cheap supplies of fish, which are historically under-promoted. The situation is very different even in continental Europe, which produces over 60 000 tonnes of farmed trout/a and *per capita* consumption of trout in France or Italy is five times that in Britain. Of course, the underdeveloped countries provide a stark contrast to all this with average *per capita* consumption of all animal protein sometimes less than 10 kg/a. Under these circumstances, the problem is usually desperate need for adequate intake coupled with the inability to pay for any fish available, particularly in land-locked countries. It stands to reason that in such countries fish will need to be farmed for home consumption as cheaply as possible. This is again in strict contrast with the situation in Britain and other countries where the taste is often for carnivorous fish, which need a high proportion of animal protein in the diet. This means that the market price has to cover significant farming costs, particularly for fish feed.

3) Husbandry methods

Rearing systems need to offer a cost/effective means of farming the chosen species and in practice this usually means a compromise between providing a suitable environment for optimal fish growth and for husbandry operations. With certain species having a simple life cycle (eg trout), it is possible to control the entire production artificially from spawning of mature broodstock, egg incubation, and hatching of fry, through to production of marketable fish. Many fish and shell fish have a more complex life history involving several larval stages each with different food requirements. With others it may not be possible to breed them at the present time; thus eels cannot be spawned and eel farmers need to buy in wild stocks of baby elvers. The biological characteristics of the particular animal will also dictate the quantity and quality of water used at different stages of growth. Salmon spawn in cool freshwater streams and the resulting juveniles need to migrate to the sea before returning as mature adults. By contrast the giant freshwater prawn (*macrobrachium*) requires a tropical environment and undergoes the reverse migration (from a freshwater stream to a brackish creek) in order to breed. Animals which are high on the food chain and often supported entirely by direct feeding (eg trout) are usually reared by cultivating a single species within a pond. Polyculture is the simultaneous rearing of a number of different species to make more efficient use of the entire pond environment. The intensity of stocking also has an important bearing and extensive methods often rely on the natural productivity of the water, which may be enhanced by fertilisation especially under tropical conditions. By contrast high yields and good control over the stocks require scientific pond design, supplementary feeding and good husbandry. By this means, tropical fish harvests exceeding 10 tonnes/ha/a have been obtained from freshwater or brackish ponds of essentially stagnant water. If water resources permit, yields far in excess of this may be achieved using running water and entirely supplementary feeding methods in a manner somewhat analogous to battery chicken farming.

4) System design

The engineering criteria for efficient design of fish farms vary greatly depending on factors such as species farmed, site conditions, and husbandry method. The choice of appropriate husbandry method for a given species is itself influenced by various factors, including management attitudes to cost and risk. Thus for trout production there is some uniformity in hatchery systems, but on-growing of 5 g fry to a marketable weight of about 200 g may be undertaken using a choice of excavated earth ponds, linear raceways, circular tanks, floating cages, netted enclosures etc. Provided that dissolved oxygen levels are sufficient and metabolic wastes are not allowed to accumulate, the rearing unit acts simply as a vehicle in which fish are stocked at a density constrained by water flows and exchange rate. For instance, water requirements for efficient production of 1 tonne/a of trout are usually about 5 1/sec, whereas typical stocking densities for earth ponds and concrete raceways are in the region of 5 kg/m^3 and 50 kg/m^3 respectively with a tenfold difference in water exchange rate between the alternative systems. If earth ponds are lined to reduce erosion and equipped with aeration facilities, heavier stocking may be employed. Use of circular tanks with a peripheral inlet and central standpipe allows a degree of self cleaning, particularly if a venturi is fitted beneath the central drain. Pelleted diets may be delivered automatically (eg using compressed air pipelines with time switch gear) or using devices which the fish soon learn to trigger in order to feed themselves. Of particular importance is the installation of alarm systems to monitor any interruption in water flow as oxygen levels can become limiting for heavily stocked trout within minutes of this occurring. Thus it is also essential that, if pumped supplies are used, adequate back-up facilities will be automatically switched on in the event of a pump failure.

Various marine fish are now successfully reared in seawater and floating cages or pens are often used. In this case it is necessary to consider storm exposure in selecting suitable construction materials and mooring techniques. A hydrographic survey is also useful to determine temperature and salinity profiles and to ensure that

Dr C J Shepherd BVSc MRCVS MSc is Director, Fish Farm Development International Limited, Glasgow.

Paper presented at the annual conference of the Institution of Agricultural Engineers, held on 10 May 1977, at Bloomsbury Centre Hotel, London.

adequate water circulation will be achieved even at periods of slack tide.

In tropical freshwater or brackish ponds, where fish or shellfish with less critical environmental requirements are reared under stagnant conditions, water evaporation and seepage are often grave problems. The amount of seepage flow from a body of impounded water varies greatly with the permeability of pond soils at various strata and of embankment materials, size, shape and compactness of embankment, as well as the fluctuations of water table under the pond bottoms and of water level in the pond. In order to minimise the large amount of water loss through seepage, engineering design and proper construction of these types of fish pond are of paramount importance.

The engineer is increasingly called upon to provide specialist knowledge on problems such as the provision of economical water recirculation and reconditioning systems. However, his main role will continue to be in the design and construction of fish farms which are simple to operate and truly appropriate to the varied needs of the site, the fish and the farmer.

5) Economic aspects

Numerous factors influence the capital cost of fish farms, among which are:-

i) Husbandry systems used
ii) the natural characteristics of the site
iii) the cycle of operations performed
iv) the scale of production
v) the constraints on finance, labour etc of the investor.

It does not necessarily follow that a highly capital intensive farm will incur larger annual costs of production than a farm of low initial investment. The former may have a longer economic life, permit economies in certain operating costs (eg maintenance, labour) and be associated with a more favourable risk factor. Hatchery and early-rearing facilities generally account for a small proportion of total capital cost, when compared with investment in holding facilities for on-growing and the fixed overall requirements of the system, such as water supply and buildings, which show considerable cost variation.

There are also differences between the capital investments required for the various types of holding facility. Thus for trout farms, a comparison of investment per unit production capacity for different systems in order of ascending cost would generally be:-

i) Earth ponds
ii) floating systems and enclosures
iii) raceways
iv) fibreglass tanks

The largest elements of variable cost are food and labour, with food costs predominating in the production of carnivorous species. Table 1 gives an approximate breakdown of costs for a hypothetical trout farm in Britain producing 100 tonnes/a from earth ponds using gravity-fed water. Variations in factors such as food conversion ratio (FCR) have a considerable impact on overall costs and there is thus a premium on good husbandry and management (eg FCR of 2:1 would result in food costs of £48 000 in table 1). The annual production cycle may be as long as 18 months from egg to market and this is significant in terms of working capital needs.

Table 1 Estimated production costs for a rainbow trout farm producing 100 tonnes/a

	£
a) Total capital costs	
Earth ponds, hatchery, building, vehicles etc	60 000
b) Annual operating costs	
1) Food costs @ £240/tonne (FCR=1.5:1)	36 000
2) Labour (5 including manager)	22 000
3) Administration and insurance	7 000
4) Sales and transport	4 500
5) Purchase of eggs	2 000
6) Power	1 500
7) Maintenance	1 000
	74 000

Current prices for fresh trout ex farm are about £1300/tonne, which would give a gross profit margin before depreciation of £56 000 in the example. Although there is considerable price fluctuation in the ungutted fresh trout market, this margin is probably sufficient to cover fixed costs and provide a suitable discounted return, taking into account the risk element involved. On a global basis there are many factors affecting the profitability of fish farming, such as the influence of local market prices, factor costs, and management skills. In general intensive operation increases the productivity and reduces the cost of production per unit of output, and polyculture is usually more profitable than monoculture.

6) Conclusions

Fish farming is now a significant world industry and has various characteristics in common with conventional livestock production. The engineer's problem is to match the needs of the fish with those of the farmer at an acceptable cost. The appropriate solution varies greatly with fish or shellfish species, climate, site and economic factors. The key to success is likely to be in careful planning coupled with a high standard of fish husbandry.

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Edited summary of afternoon discussion

Discussion of the afternoon session was led by A Dumont BSc MSc (NIAE)

"MY particular experience in this subject is limited to leaf protein production so I will confine my remarks to this particular field.

"Professor Bruhn felt that, for dairy farms in the United States, forage protein production was possible in engineering and nutritional terms, as a method of increasing protein production on the farm.

"What he did not say, however, is what it would cost! Especially, and quite understandably, what it would cost the British farmer. I would like to put this into a British context by summarising, very briefly, some of my results of an operations research study on the economic effects of forage fractionation and leaf protein production on a British arable and livestock farm.

"In work at the National Institute of Agricultural Engineering a linear programming, mathematical model of a mixed arable/livestock farm has been developed. By comparing optimum solutions from this model, of farms that are identical except in their method of forage conservation, the saving by using forage fractionation and leaf protein production rather than conventional methods can be found. By altering variables in the model different sizes and types of enterprises were studied. The results can be summarised as follows:-

"Under a reasonably wide set of conditions, compared with haymaking or conventional silage making and before deducting the necessary equipment cost, the savings increase linearly with cow herd size up to £5000 to £6000 on the largest dairy farms. This is about £20/year/cow, and is made up of savings in bought-in feed, or increased revenue from selling the leaf protein, less the extra cost of labour and preservatives for the wet leaf protein. It does not include equipment cost.

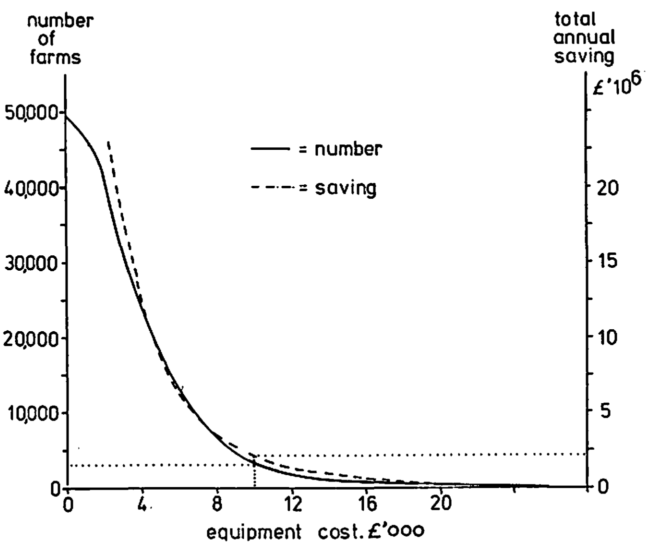
"We can relate this saving to farm size rather than herd size. There is a good linear relationship here between farm area (crops + grass) and dairy herd size. This depends on whether the farm is 'specialist dairy' or just 'mainly dairy' as defined by the proportion of total man hours spent on the dairy herd. Land commitment is also different for the two cases: "Specialist dairy" 1 ha/cow, "mainly dairy" 1.6 ha/cow.

"If we then relate the saving versus farm size to the number of

→*page 74*

such dairy farms in England and Wales, this picture emerges:-

How many dairy farms can afford to change?



"This summarises very nicely the problem for agricultural engineers: at a cost of £2000 the total saving on all 42 000 farms if they changed to forage fractionation would be over £24m/year; £11/ha on average. As the cost of equipment increases, the number that can afford to change, and hence the total saving, falls dramatically so that at an equipment cost of £10 000 (a *not* unlikely cost for the equipment) the number who can afford to change is only 3000, these being the larger farms of 100 cows or more. The total saving is reduced to less than £2½m; £6/ha on average.

"I think these figures bear out what Professor Bruhn and others have said; that for the larger dairy farms *at least* forage fractionation and leaf protein production is a practical way to increase significantly both profit on the individual farm and total protein production from forage crops in Britain, if the equipment were available.

"May I open this discussion, then, by asking Professor Bruhn: Can the necessary equipment be produced, at the required cost, for the British farmer?"

Question 6

Professor Bruhn, in reply to Mr Dumont's question, felt that an estimate of capital cost was difficult – the complete machine assembly was not yet built. The extrusion machine however weighed about 2000 lb and this class of machine could be built for less than 2 dollars/lb. The cost of the fractionation press was quite unknown since the device was still in the early design stage. Available industrial equipment however, for example screw presses, cost about 30 000 dollars or more. Professor Bruhn hoped to develop a combination of extruder and modified type of corn press to sell for a price similar to that of a self-propelled combine harvester.

K A Pollock (Newcastle University) asked Professor Bruhn for an indication of the energy requirement for the extrusion phase per kg of lucerne. He referred to his own work on the cubing of dried grass which appeared to require 144 KJ per kg to achieve satisfactory cubing. He also asked if the extruder did not also operate as a fractionator, juices being squeezed out in the extrusion process – he asked the moisture content of the material being used. Professor Bruhn acknowledged that some separation of juices and fibre did occur during the extrusion phase, however it was not the intention that any useful separation should occur during this process.

Regarding the energy requirement for extrusion, a little more than 2 kWh/ton were required. The fractionation unit currently employed was needing about 2kWh/ton but Professor Bruhn was confident that these levels could be significantly reduced. He would aim for a consumption for the fractionation stage of approximately ¼kWh/ton and estimated that overall a 3 kWh/ton target for total power consumption in both the fractionation and separation stages of a 20 ton/h plant was reasonable.

Question 7

Dr J M Thring (BOCM Silcock Limited, Goole) had spent three years developing and installing a full scale fractionation plant and referred to a problem of disposal of the resulting brown liquor. Approximately one third of the capital cost of the equipment was absorbed in the disposal system. The liquor could not be poured into the sewers because of its high BOD and equally it was not economic to recover its dry matter content for subsequent disposal. In fact 50% of the crop brought onto the sight ended up as a disposal problem. Professor Bruhn was less concerned with this difficulty, being able to return the brown liquor to the land as a low grade fertiliser via a conventional irrigation system, however he recognised Dr Thring's difficulty in situations where centralised processing plants were employed. Dehydration and the recovery of lucerne meal then appeared to be the only answer but presupposed the availability of low cost energy.

Question 8

R E P Jameson (MLC, Milton Keynes) drew the attention of the conference to the wastage of offal, blood and bone which occurred as a result of animal slaughter. In UK alone approximately 100 000 tons of blood were available per annum and a very small amount indeed ended up in food. The remainder appeared as fertiliser, a constituent of animal feed or in the sewers. Dried plasma protein could easily be prepared from blood and had many advantages and functions. Blood, hair and collagen were currently rendered into soaps etc, but could all be converted to human food. In 1975, 64 000 tons of dried plasma were imported to the UK at a cost of £2000 per ton. We needed to become much more efficient in dealing with our available resources. Dr Blaxter agreed that some slaughterhouse processes were very inefficient – also the energy costs in processing and disposing of effluent were enormous. Recent work has suggested that of the energy expended in the slaughtering and processing of meat, 50% was used on hygiene and effluent disposal. This was the price to be paid if we were to keep the salmonella incidence down to about 4000 cases per year.

Question 9

M N G Davys (Brighton), expressed interest in Professor Bruhn's machine. Could the degree of maceration be varied? It was common experience that crops vary throughout the day. If one wished to consider crop processing as an economic proposition, the quality of the compressed fibre product must be controlled and one must not extract less product than is possible from the raw material, neither must the material be "over processed".

Professor Bruhn stated that if about half of the initial moisture were extracted from the crop this would result in extraction of 25% of the initial protein. The crop could be thought of as approximately 20% protein since harvesting was programmed to occur at optimum states of maturity and was little affected by the weather. So far, the possibility of changing the degree of protein extraction had not been examined – the process involved merely squeezing out as much moisture as possible. It would be ideal to achieve 65% dry matter but usually only 70% had been achieved.

Question 10

Dr Blaxter addressing his remarks to Dr Shepherd, was anxious to identify areas of activity in fish farming where agricultural engineers could contribute.

Dr Shepherd replied that in our economy and because of taste we must rely on species which were essentially uneconomic to produce ie, carnivorous fish. These were high in the biological chain. In warm countries it was possible to achieve good production, using plankton etc, of fish further down the biological chain eg grass carp.

It would seem then that for the agricultural engineer in UK the greatest opportunity was in marine fishing – there was in any case great competition and difficulty finding adequate fresh water. This would involve considerable knowledge of marine hydrography and other related engineering expertise.

Dr Blaxter, in summing up the day's proceedings, observed that the agriculturist was usually faced with the problem of growing what people liked to eat rather than what was absolutely needed. This was an acceptable state of affairs but we should do it only within the limitations of our resources. We must endeavour to help the *wanting* nations to increase their productivity up to our level.

We are necessarily involved in using resources to produce protein for farm livestock. Animals were not wasteful – they would be able to use the by-products of forage fractionation. Farm livestock could be with us for a considerable time to come and needed feeding. Agricultural engineers could contribute in the harvesting and in the secondary processing of materials which arose from the use of land. There were many new ways to look at old problems.

Another challenge was faced in moving from laboratory bench scale to field scale in our new ideas. Cearly there was a need for collaboration at as early a stage as possible, between biologists and engineers.

Finally it was always necessary to consider economics – but not too seriously. Economics had a habit of fitting in to a situation even though the prospects for a particular enterprise may not look rosy at the outset.

R H Marsden (CoSIRA, London), in a written contribution, comments:-

IT was suggested during the discussion at the end of the Conference that there would be only very limited scope for the agricultural engineer in the sphere of fish farming, and that these opportunities would be on the civil engineering side of our discipline.

This is contrary to my experience. Some few years ago I was asked by a client firm, who run a fish farm in northern England, to gather information for them about the electrocution of fish. It proved very difficult to obtain any leads, but many interesting facets of the problem came to light. For example:

(1) Our clients were not interested in merely stunning the fish; 100% mortality was required.

(2) The fish and not the operators were to be treated.

(3) Should it be dc or ac, and if the latter what frequency? How many amps and volts?

(4) Would different varieties of fish require other levels of volts, amps and frequency?

(5) What influence would the condition of the water have, both as regards temperature and chemical condition?

These are just a few headings to illustrate the spectrum of interest, all of which is surely within the field of the agricultural engineer. Incidentally, our clients gave up the idea when they discovered that Danish fish farmers abandoned electrocution because they found it caused the blood to congeal. Whether or not any work was done to overcome this difficulty was not revealed.

Obviously, the mechanical handling of the live fish, their feed, supply and treatment of the water, disposal of effluent and the storage of the prepared fish prior to despatch, are all problems closely related to the preparation and storage of vegetables, meat or poultry – which are well within the basic training of the agricultural engineer.

AROUND THE BRANCHES

Wrekin Branch

THE Wrekin Branch awards annually the book of his choice to the top student on the agricultural engineering course at Shrewsbury Technical College. This award has been keenly competed for again this year and was won by Mervyn Smith, who is currently working for his father in a small rural agricultural engineering business. Mervyn was quick to choose the revised and much imporved *Farm Machinery*, by Claude Culpin as a valuable reference work in his future career. He is pictured receiving the book from the branch chairman, J Sarsfield (left) watched by College Principal Dr Dennis Griffiths.

W Midlands annual technical award

A NEW approach to the layout of a farm crop sprayer has been taken by Colin Shaw, an Associate of the Institution, in the design of a farm-workshop-built prototype which won the annual technical award given by the West Midlands Branch for developments in agricultural engineering.

The purpose of Mr Shaw's design was to improve on the attainable uniformity of chemical spray application in the field. Two well known important causes of uneven application were tackled: excessive vertical movement of the normal, centrally supported spray boom above and below the height at which its nozzles provide optimum distribution on the ground, and excessive reliance on driver judgment in choosing the tractor's path.

The means chosen to secure improvement in both these factors was to design a strong but light boom to support the spray supply lines and to operate with the boom extended to one side of the spray supply tank, its remote end being supported by a castoring wheel. The wheel, which is prevented from castoring to its natural extent, creates a mark which is both easily visible and ideally positioned, in that the driver has merely to follow it with one set of tractor wheels.

In Mr Shaw's design, which was built on to a trailed spray supply tank, the boom is attached to a circular yoke on the tank, and may be latched in a working position on either side of the tractor. Movement from one side to the other is achieved by releasing the latch and driving in the appropriate direction with the tank.

Part way between the two working locations for the boom is a transport position, with the boom projecting rearwards from the tank. When in this position, the boom may be folded about a central pivot, and the castoring wheel is then re-located and locked into position near the pivot point.

Over 400 acres of cereal spraying was undertaken with the 'bias boom', as Mr Shaw refers to it, during the first half of 1977. He has reported no practical difficulties, and having made patent applications, is negotiating on the subject of commercial manufacturing rights.

Cultivation trials with ox-drawn equipment in the Gambia 1973-75

M D P Matthews and D W M Pullen

Introduction

THE Gambia, West Africa, is a country of 11 300 km^2 which follows the River Gambia for 470 km between latitude 13° and 14°N. Other than 64 km of Atlantic coastline, it is totally surrounded by the Republic of Senegal. The population is approximately 520 000 of which over 85% are directly supported by agriculture. There is a very distinct agricultural season which has to coincide with the 760 – 1300 mm of annual rainfall distributed between June to October. The temperature inland can be as high as 44°C and the humidity during the wet season is correspondingly high. November to April is dry when all shallow rooting plants die-off.

The soil is generally a light sandy loam (70% sand) in the upland areas but there are heavier clays in the paddy rice areas close to the River Gambia and its tributaries. The major crop is groundnuts which forms over 90% of international trade as extracted oil or whole confectionary nuts.

N'dama cattle, selected from an estimated national total approaching 300 000 have been used since the early 1950's for draught purposes although horses and donkeys are sometimes used for light work. As a draught animal the N'dama is ideally shaped with a broad back and short legs but is very light and does not have a hump on which to carry a yoke. The normal method of harnessing is in pairs with a double head-yoke roped to prominent horns. The great advantage of the N'dama is its natural resistance to the disease *trypanosomoasis* – transmitted by the tsetse fly which is ever present in The Gambia. This resistance has been observed to break down during long periods of heavy work.

A broad training is given, at 24 'mixed farming centres', to farmers using their own oxen. This is backed up by extensive agronomic research but cultivation systems had never been evaluated. Both ridge and flat systems are practised with a wide range of equipment.

The timing, distribution and quantity of rain creates a very difficult situation in which cultivation techniques and planting dates are critical. Cultivation is impossible until the soil surface is soaked, and planting is recommended after a cumulative rainfall of approximately 25 mm. However, all upland crops must be planted by 15 July to ensure maturity at the end of the rains. In some seasons the planting period may be as short as four days but could be as long as three weeks.

In recent years the Department of Agriculture decided that a farming 'package' should be recommended including seeds, fertiliser, equipment and cultivation practices to improve agricultural production levels.

In order to provide data on which recommendations of equipment and cultivation systems could be based, an experimental programme was set up by Overseas Department, NIAE, and three seasons of field trials were carried out.

Cultivation trials

Groundnuts

Trials on the production of groundnuts were in two parts. The first part was investigating primary cultivation techniques: Ridging, ploughing, tine cultivating which were followed by hand work throughout the season. The second part was the use of machine weeding and harvesting systems. In the 1973/74 trials recordings and observations were made of the following on 0.02 ha plots.

a) Time taken in field operations
b) Date of emergence
c) Plant population
d) Plant growth
e) Intensity of weed competition
f) General field conditions, eg soil erosion or water logging
g) Net yield of field dry nuts
h) Nuts left in the soil after lifting.

Weed intensity was recorded on the day before the weeding was to be carried out and three days afterwards to provide some idea of the measure of control. A rapid assessment of weed growth was therefore required and a qualitative system was used.

In 1975 recordings were limited to the yield and the following labour inputs:

a) Planting – primary cultivaiton and sowing combined
b) Total seasons weeding
c) Harvest – lifting and windrowing combined
d) Total seasonal input

Of the three years' trials the first – 1973 – was started late and this led to severe disease attack (Rossette) and with an early end of the rains, much of the crop failed to mature. Yields were 50% lower than could have been expected and the results were not statistically analysed. However, observations made were used to plan the following seasons' trials which were very successful, when yields above 3000 kg/ha were achieved – far in excess of those usually obtained at village level.

Results showed that direct drilling was significantly the fastest method of crop establishment and successful provided the soil was not too firm. Ploughing was the slowest but the positions were reversed following the analysis of labour for weed control (fig 1).

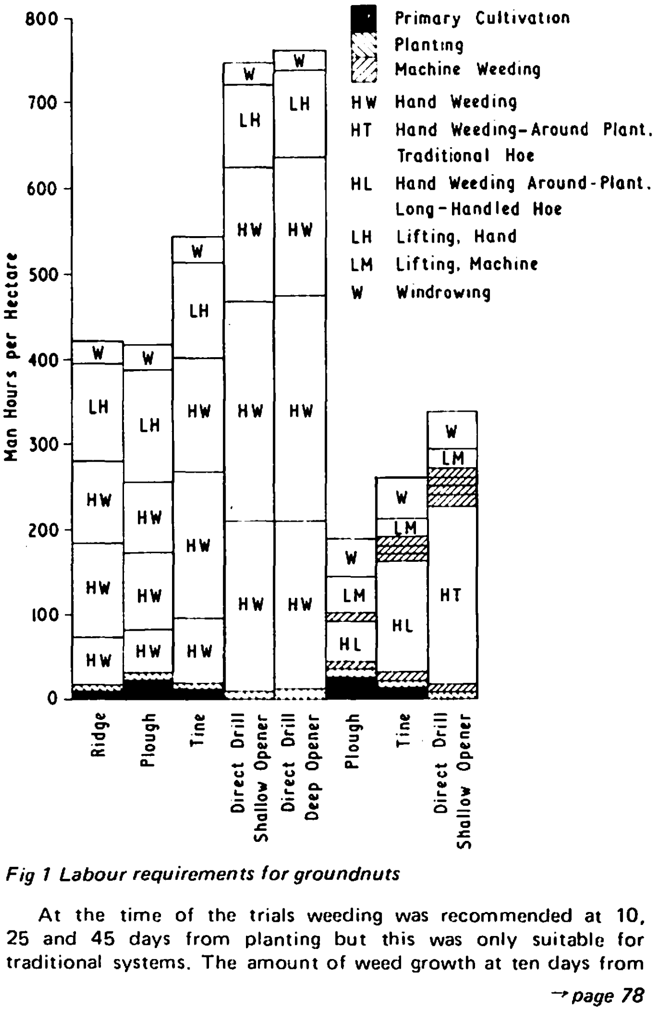


Fig 1 Labour requirements for groundnuts

At the time of the trials weeding was recommended at 10, 25 and 45 days from planting but this was only suitable for traditional systems. The amount of weed growth at ten days from

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M D P Matthews is of the Overseas Department, NIAE, and D W M Pullen of the Agriculture Department, The Gambia.

planting was found to be directly related to the primary treatment and this one factor greatly affected the amount of land one man and a pair of oxen could manage. Mechanical weeding was found to have no adverse effect on yields and could give good weed control provided weeds were not more than 50 mm high. When they were allowed to tiller and grow taller control became very difficult. Hand weeding around-the-plants was always necessary but with mechanical interrow work the system was much faster than by hand alone.

Weeds are generally a problem when showers are frequent and there is little time for wilting. Direct drilled land was particularly difficult to keep clear and traditional hand hoes had to be used in preference to long handled hoes which were being evaluated for weeding around the plants. Ridging was found to be one of the quickest ways of forming a seedbed but it was unsuitable where there was heavy weed growth. Where a ridger could be used the advantage was soon lost by having to hand plant all the crop. A successful ox-drawn, ridge seeder was not available. Mechanical weeding of the ridged plots caused the greatest problems as none of the systems were suitable. Re-ridging was unsatisfactory and tie-ridging was inappropriate because the extreme physical effort from the operator needed to use the ox-drawn blade made it unacceptable.

The Gambian rain storms can be very intense but generally soil erosion is not a major problem except where basic principles are ignored – such as farmers cultivating in directions other than across slopes. It was observed that on ridges the plant roots were sometimes left bare of soil after heavy rain. Ploughing left the surface open to serious sheet erosion especially with the weak soil structure. Weed cut, but not buried, by tine-cultivation provided some protection for the soil but a complete cover was left after direct drilling, thereby sheltering the soil surface.

Groundnut lifting could be very difficult when the soil hardened after the end of the rains. Considerable skill was required to maintain an ox-drawn lifter on the row but the main problem was in obtaining the initial penetration. The most successful type of lifter was a 350 mm sweep although it was not as controllable in ridged land as a straight blade. Dense foliage tended to impede progress with ox-drawn lifters and matted weed made it almost impossible.

Windrowing after machine lifting was more time consuming than after hand lifting and had to be completed on the same day as most of the nuts were left in contact with the soil. Hand lifting left the plants completely free of the soil and usually the nuts uppermost so that drying started immediately and windrowing was not so essential.

The advantages of cultivation at the end of the wet season were investigated. It was suggested that autumn cultivation could assist the uptake of water, allow earlier planting and establishment in the following season and improve soil structure and fertility by ploughing

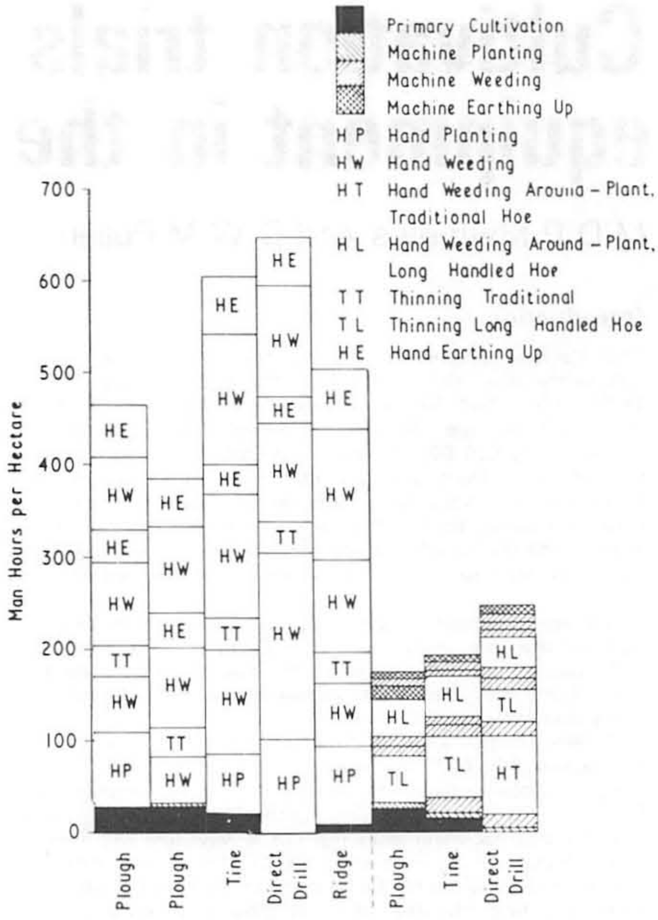

Fig 2 Labour requirement for cotton.

in green material. The results showed that there was no significant yield benefit but in certain circumstances autumn cultivation could lead to more timely operations in the spring. For instance, good spring weed control was achieved with autumn ploughing, enabling early direct drilling although weeding had to be carried out earlier

The inter-row weeding of cotton.

than after spring ploughing. Autumn made ridges were nearly flat at the beginning of the rains and tine cultivating in the autumn did not provide any spring weed control.

During the 1974 season the main trials were supplemented by direct comparisons of possible mechanization packages on quarter or half hectare plots within the five mixed farming centres. The results generally confirmed information collected on the main groundnut trials but the operators reactions to the new equipment and techniques were most useful.

Cotton

In 1975 two sites were used to evaluate primary cultivation types and to compare hand work with mechanized systems. As for groundnuts, the use of a long handled hoe was introduced for thinning and weeding around the plants. All plots were treated with fertiliser and pesticides to the Agricultural Department's recommendations.

A difference in the average yield from the two sites was believed to be caused by soil fertility and climatic conditions but on each site the individual treatments ranked in the same order. All the ploughed treatments gave higher yields than any other cultivation technique although not statistically significant in all cases. Ploughing, followed by mechanical weeding and earthing-up totalled the lowest labour input (fig 2).

Operators were inexperienced with the long-handled hoe and thinning was slower than the traditional method of hand pulling but it did incorporate around-the-plant weeding.

Sorghum and millet

Trials on the primary cultivation and seed rate for sorghum and millet were conducted on small plots – 0.001 ha. Although all the normal factors were observed and recorded only the yield was analysed. As on other experiments, the yields achieved were substantially higher than those achieved at village level. Millet averaged 1462 kg/ha and sorghum 1410 kg/ha.

Both trials investigated very early planting. The millet showed no statistical yield difference but this could be peculiar to 1975 because the rains after planting continued steadily. Long dry periods between showers are common early in the season and this could effect the survival of early germinated plants. The early planted sorghum gave significantly low yield due to poor germination with a resulting low plant population and, because it matured earlier, disproportional losses due to bird damage. The other sorghum systems seemed to compensate for minor differences in plant population. The final millet plant populations were very similar and the only significant yield difference was between the tine-cultivated and ridged plots. Poor growth on ridges was observed during the whole season and resulted in a low yield.

Paddy rice

It had been believed that cultivation for rice was too arduous for the light N'dama cattle but that if a suitable system could be developed it might be more timely and cheaper than the traditional hand work or power tiller hire scheme.

Bunded fields had various quantities of water applied. Ox ploughing and hand hoeing was carried out with secondary cultivations on some, before re-flooding prior to puddling and levelling.

The most appropriate method to produce a suitable condition for transplanting was as follows:

i The plot was flooded to a depth of 25 mm and allowed to soak. The volume of water required was difficult to assess as it depended on the moisture content of the surrounding paddies, but was in the range 1500 – 3000 m^3/ha.

ii As soon as the soil surface was dry, normally one to three days after flooding, it was cultivated with a single mould-board plough. Draught was 1.12 – 1.33 kN under optimum conditions with a 225 mm plough but as the soil dried the

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The ploughing of a rice paddy with N'dama oxen.

forces rose rapidly. Drying was often uneven causing the oxen to surge and become difficult to control. After two weeks, cultivation was impossible without the addition of more water.

iii Immediately after ploughing, it was re-flooded to a depth of 75 – 100 mm and allowed to soak for two to three weeks.

iv A 2 m levelling board was used behind a pair of oxen to mix and level the field and up to three passes were necessary to produce suitable planting conditions. Draught varied with the amount of mixing and levelling, the maximum recorded was 0.88 kN.

The trials indicated that the N'dama cattle are suitable for ploughing under the right soil moisture conditions and they soon become accustomed to working in deep mud during the puddling and levelling operations. Secondary cultivations (harrowing) were unnecessary and very time consuming. The rates of work recorded during the trials are in table 1.

Table 1 The rates of work when cultivating rice paddies.

Operation	*Oxen (ha/hr)*	*Hand (ha/hr/person)*
Ploughing	0.030 to 0.044	0.002 to 0.005
Harrowing	0.065 to 0.099	–
Levelling	0.052 to 0.100	–

Following this study it was recommended that a pilot scheme be set up to train a small number of farmers who already owned oxen and equipment, in the methods of rice cultivation, although an improved diet for the oxen would be required especially to achieve two crops per year.

Equipment performance

For use in a 'package' all the available implements were critically examined for the most needed characteristics. The toolframe had to:

i Be capable of the full range of operations (ploughing, weeding of 660 and 900 mm rows, groundnut lifting and earthing-up cotton).

ii Have adjustable handles for different heights of operator and depths of cultivation.

iii Have simple fixings and adjustments using hand or tommy bar clamps. Spanners were considered undesirable and should only be necessary for a minimum of fixings.

iv Be light but strong enough to withstand normal working loads.

v Be economically competitive.

vi Have sufficient commercial backing for guaranteed supply of whole units and spare parts.

A continuous assessment of the ease of using the equipment was made and power requirements noted using a hydraulic type tensile link between the draught chain and implement. All mechanical failures and design faults were recorded.

Table 2 shows a summary of the performance of the various implements/attachments used in the trials.

Table 2 Draught measurements

Implement/ Operation	*Working Width mm*	*Depth range mm*	*Draught kN Normal*	*Minimum*	*Maximum*
Ploughing	225	50-190	0.44-1.32	0.35	1.52
Single mouldboard	250	80-200	0.54-1.52	0.44	1.77
3 spring tines	510	100-125	0.39-1.23	0.34	1.42
3 rigid tines	530	100-125	0.49-1.67	0.39	1.86
5 spring tines	790	100-125	0.74-1.08	0.44	1.25
Ridging Emcot	660	90-110	1.18	0.88	1.42
Lightweight	660	90-110	0.98-1.37	0.74	1.64
Earthing-up					
Traditional ridger	910	40-50	1.08	0.44	1.32
Lightweight ridger	910	40-50	0.78	0.64	1.08
Tie ridging	660	30-40	0.64-0.74	0.44	0.78
Groundnut lifting					
Straight blade	350	50-75	0.69-0.88	0.44	0.88
Sweep blade	350	50-75	0.44-0.64	0.44	0.88
Sweep blade	500	50-75	0.44-0.69	0.44	1.37
Direct drilling					
Ox-drawn seeder	–	40	0.44	0.19	0.78

Oxen management

The normal situation in The Gambia is that trained oxen are only used for primary cultivations in the spring and carting of produce in the trade season. The rest of the year is spent with the herd so that a high state of training is not maintained and the oxen become difficult to manage. This has led to three-man teams becoming traditional. Single handed operation was encouraged for greater efficiency, the only exception being that the oxen could be led when using a seeder to produce parallel rows – a necessity for mechanical weeding.

By the introduction of other ox-powered operations, especially in the dry season, eg rice cultivation and domestic water lifting and carting, the oxen would be worked throughout the year and handling would improve accordingly. However, farmers would then have to pay attention to conserving more crop residues, and ideally feed their oxen a cereal/mineral supplement at peak periods.

The amount of work oxen could do in a day was not completely established but work in excess of 5 h/d could only be sustained over a few days. Without an adequate diet of forage and concentrates, daily recovery of body weight lost during hard work cannot be achieved and the animals' health suffers. Use of single oxen for light work, eg planting and weeding was found to be successful and could increase the daily work output by using one from the pair in the morning and the other in the afternoon. Oxen soon became accustomed to the single yoke, rope traces and swingletree arrangement and it was thought that the performance, when working again in pairs, was improved but this was not proven.

The normal yoke, made from a straight branch, about 100 mm diameter was probably the most suitable provided adequate padding was used with the rope ties. It was very cheap and easy to make – especially important as three sizes were required: for ploughing, and 660 mm and 900 mm row spacings. The use of collars as on draught horses would place the force onto the shoulders instead of through the neck, and head movement would not then effect the line of draught but their expense would be prohibitive. The traditional yoke with modified reins attached at the nose, improved the handling of poorly trained oxen.

Conclusions from the cultivation trials

Ploughing provided the obvious benefits of reduced weeding and improved yields of particular crops. However, it was a slow operation in a short planting season and increased the risk of soil erosion. Ridging had no significant advantage. Mechanical weeding on all crops planted on-the-flat was quick and easy and, if conducted early and regularly enough (50 mm limit) required only a small amount of around-the-plant hand weeding early in the season.

There were three options when establishing a crop of groundnuts; direct drilling, tine-cultivating and ploughing. Direct drilling had to be carried out before weed seeds germinated and although it could cause lower yields, it would increase the seasonal area particularly in a late season. Groundnuts direct drilled into a fallow which had been ploughed at the end of the previous season could achieve maximum yields. Usually, early light showers would germinate weed seeds before planting could start and primary cultivation would be required.

With weed less than 100 mm high, the land could be tine cultivated, but it had to be ploughed when the weeds were more established. Weeding was recommended as previously stated but had to cease when the plants were so well developed that they could be damaged by the tines. Harvesting with the ox-drawn lifter had to be followed immediately by windrowing to ensure rapid drying.

For cotton, direct drilling and tine cultivation both lead to stunted plants and lower yields. Ploughing was recommended and its good weed control allowed the first around-the-plant weeding to be combined with thinning. When the plants were about 300 mm tall, around-the-plant weeding could be achieved with a combination of inter-row cultivation and earthing-up.

Ploughing followed by the mechanical systems of weeding was recommended for sorghum, millet and maize.

Trials with long-handled hoes proved that they were satisfactory and had great potential. How acceptable these would be to farmers was uncertain, although in some areas a traditional form was already used for weeding.

Acknowledgements

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