Aston University

Some pages of this thesis may have been removed for copyright restrictions.

If you have discovered material in Aston Research Explorer which is unlawful e.g. breaches copyright, (either yours or that of a third party) or any other law, including but not limited to those relating to patent, trademark, confidentiality, data protection, obscenity, defamation, libel, then please read our Takedown policy and contact the service immediately (openaccess@aston.ac.uk)

THE FUTURE ROLE OF NOVEL FOOD SOURCES IN THE UNITED KINGDOM

by

RICHARD PIERS STANLEY

Submitted for the Degree of Doctor of Philosophy

At The University of Aston in Birmingham

MARCH 1980

SUMMARY

This thesis considers the current state of technology in three areas of novel protein production, namely: single cell protein, leaf protein and novel oilseed crops, with particular reference to oilseed rape. These three topics are chosen for study because of the potential contribution which they could make to UK food supply, and it is the quality and quantity of that contribution which is explored in this work. The assessment of the technologies is achieved by a broadly based and thorough literature review to enable likely future developments to be made clear.

A forecasting study is used to assess future prospects for oilseed crops such as oilseed rape, lupin, sunflower and linseed in the United Kingdom. Energy and economic analyses are used to develop a comparative picture of the three novel processes. Finally, a model predicting the protein and energy supply of UK agriculture based on a vegan system is considered and the novel technologies are applied to it. Similarly, vegetarian and conventional systems are reviewed and the contribution of oilseeds, single cell protein and leaf protein are included in those systems. Little advantage is revealed by the use of the novel proteins in a vegan system of agriculture. When animal production is included in the model a contribution from novel proteins is seen to be of some value.

However, taken in turn, single cell protein is seen to have a limited future owing to its high energy and capital requirements, and the success of leaf protein is still limited by necessary further technical and process innovation. Agriculturally produced proteins are the cheapest and most acceptable in the UK, with home-grown oilseed rape providing an increasing proportion of our requirements.

Leaf Protein
Oilseed
Single Cell Protein

Richard Piers Stanley.

Submitted for the Degree of Doctor of Philosophy, 1980.

This research was carried out with the support of the Vegetarian Society (UK) Ltd. under the auspices of the Interdisciplinary Higher Degrees Scheme and the Technology Policy Unit of Aston University.

CONTENTS

Chapter 6 cont.

LIST OF TABLES AND FIGURES

1

INTRODUCTION

During the last thirty years there has been an increased awareness of the fact that large numbers of people in the developing countries are seriously undernourished(1). More recently this has been attributed not only to a general shortage in food supply but also to an inequitable distribution of food throughout the world(2). General concern over food resources for a growing world population led to greater efforts in the form of new research programmes to develop existing methods of food production. In the Western world this push for more food was spurred on by high consumer demand as incomes rose and by the need to increase farmers' revenue by raising the efficiency of agricultural production. This led to a broad range of research programmes designed to explore and develop the capabilities of agriculture and associated industries as a food producing system.

The livestock industry has received much attention with experiments to evaluate different feed rations for ruminants and monogastrics. Breeding work has produced animals with better conversion ratios of feed into meat or milk. Intensive systems of management with carefully controlled housing and feeding were developed to produce meat more quickly or cheaply than traditional methods. New drugs have been discovered which can control diseases previously very damaging to animal health; the use of antibiotics both as a preventive measure and a growth promoter is a notable example.

On the crop production side plant breeding has produced dramatic increases in yield and disease resistance among the staple cereal and forage crops of the world[3]. Fertilisers, particularly nitrogen, have been heavily promoted as yield boosters under intensive cropping systems. The accompanying pest and disease problems in such systems have been controlled by newly discovered chemicals which have become increasingly complex and specific in their action upon the target plant or insect species.

Great advances have been made in terms of agricultural practices; tractors have become more powerful and more adaptable, as have the implements that they power, and the result has been greater speed and efficiency in all operations from seed time to harvest. Methods of hay and silage conservation have improved and great advances have been made in systems of crop and stock management. There has been a large content of this Western style approach to agricultural improvement in the so-called green revolution which produced new crops dependent on Western technology in the form of fertiliser and chemicals for the Third World to incorporate into their less sophisticated agriculture. The now recognised partial failure of the green revolution, particularly after the lack of success with crops such as the ill-fated miracle rice IR 8, has led to a more holistic approach to development[4] [8].

In parallel with these advances in conventional agriculture have been suggestions that food production could be increased by more novel techniques. The introduction of previously unexploited species of animal into agricultural systems has been suggested, from the rearing of deer on the Scottish highlands, to the introduction of aquatic mammals into the waterways of Britain to clear the build-up of weeds and to provide a new source of meat[5]. The farming of fish has been developed for trout and potential exists for similar projects using carp. The production of protein concentrates from undesirable species of fish has been suggested, as has the extension of marine culture to produce more shellfish and even to harvest krill from the open oceans.

Since 1930 there has been a growing awareness of the importance of protein in the human diet. Experiences of poor diets during the war and new work on blood transfusions led to a lot of research activity concerning protein metabolism. The recognition of the high incidence of malnutrition throughout the third world hastened the identification of protein deficiency as a specific disease in undernourished people. Concern on an international level led to the establishment of conferences and committees by the United Nations Organisation, whose sole purpose was to identify the precise role of protein in the diet and quantify man's needs for that material more precisely. Though later this emphasis on protein supply was criticised(6), this spotlight on problems brought about by its deficiency and the precise requirement for it, led to a renewed interest in research into methods of producing protein rich food products and even protein isolate type products(7). It was this impetus which gave strength to the case for developing such technologies as single cell protein and leaf protein. These essentially involved completely new routes to protein production. Single cell protein is the name given to products high in protein which are derived from the culture of micro-organisms on suitable substrates; the organisms include yeasts, bacteria and fungi, and the range of substrates include molasses, paraffins, alcohol and effluents rich in carbohydrates. Leaf protein production is a process by which the protein in green crops such as grass or lucerne can be physically extracted to yield a high protein product suitable for a monogastric digestion.

The research project presented here was initiated by the Vegetarian Society and the Technology Policy Unit of the University of Aston in order to assess the potential of some of these new technologies for food production. New crops were an obvious choice, as only those processes with a non-animal base were considered to fit in with the aims of the Vegetarian Society, and their possible contribution to a vegetarian or vegan diet were to be assessed. The brief review of recent projects on these pages shows that many have their base in animal production. Three technologies were chosen for assessment among those which are based on crop production or non agricultural processes. Single cell protein has potentially much to offer, as does leaf protein production, so their selection for this study was not a difficult choice. Finally, the recent interest in novel crops for British agriculture has led to the introduction of oilseed crops previously not commercially grown in the UK. It was felt that an examination of these crops with an assessment of their potential value in human nutrition would make a third part of this study.

2

SINGLE CELL PROTEIN

HISTORICAL INTRODUCTION

Since ancient times man has made use of micro-organisms in the production of both food and drink. Pliny was known to have enjoyed eating a mould ripened cheese in the first century A.D. Workers believe that the fungal fermentation of soya beans to produce "miso" in Japan may have been carried out for as long as one thousand years[1]. Lockwood and Smith[2] have found references to household processes for the production of soy sauce in books 1500 years old.

Other ancient civilisations developed the more well-known western fermentation processes of brewing and baking. The Egyptians were known to have produced a leavened bread from a culture of the naturally occurring yeasts present in wheat grains. The Romans produced wines, beers and mead by the fermentation of grapes cereals and honey to produce alcoholic beverages. Again the yeast organisms necessary to ferment these drinks were those naturally occurring in the fruits at the time of harvest.

The production of yoghurt has its origins in Europe and the Middle East and relies upon the culture of <u>Lactobacillus bulgaricus</u> upon the milk of cows goats or horses to form the characteristic consistency of this fermented milk. Its acidic nature renders the milk proteins more digestible to man. The Mongols of the Central Asian steppes have ancient traditions of preparing Kumiss, a fermented drink prepared from mares milk, a similar preparation from camels milk is called Kephir(3). A further development of this was to produce a wine from milk and meat. One such brew called mutton wine contains one sheep, sugar, honey, kephir and fruits; this has an alcoholic content of over 9% when correctly prepared. This type of brew was also known in England in the 18th Century when it was thought advantageous to add a cockerel to a ferment of beer.

A fermented food made entirely from soya beans called Tempeh originates from Indonesia. This preparation has the appearance of cheese as the soya beans are made soluble by the Rhizopus fungus and bound together by the filamentous hyphae(4). This renders the beans more digestible and when fried or baked Tempeh is said to be delicious. The average daily consumption of Tempeh in Indonesia is about 150 grams per person, thus several grams of fungus must be eaten each day(5).

Another traditional preparation - sauerkraut - is a pickle of cabbage brought about by a proliferation of lactic acid bacteria. Cabbages are first washed to remove contaminating bacteria on the outer leaves, then sliced and placed in salt. In such an environment the Lactobacillus brevis and L. plantarum produce lactic and acetic acids which preserve and flavour the leaves.(6)

Modern bread making relies upon the production of carbon dioxide gas by the yeast Saccharomyces cerevisiae to raise the dough, a mixture of flour, water and salt. The mechanised Chorley Wood process has reduced the proving time for a loaf from 12 - 14 hours to about 4 hours by an intense mechanical kneading of the dough(7). Yeast is still used, however, and the baking industry is fully dependent on this single celled fungus to produce a leavened loaf.

Two distinct micro-organisms are used in the production of beer and lager: S. cerevisiae for beer and S. carlsbergensis for lager. The malt extract or wort is boiled under pressure with hops, the resulting liquid is cooled and filtered, then allowed to ferment with the appropriate yeast. The principal difference lies in the fact that the lager yeast settles to the bottom of the fermentation and beer yeast floats to the top of the vat. The added nutritional value of unclarified alcoholic drinks made by primitive societies was due to the presence of protein rich yeasts. Today a filtered strong ale may contain up to 0.7% protein.

Cider production relies upon the presence of naturally occurring yeasts both inside the apples and on the damaged exterior. However, the treatment of freshly pressed juice with sulphur dioxide gas will bring the pH to about 3.5 at which acidity the predominant yeast is S. cerevisiae. Wine may be similarly controlled in its fermentation(8). There remain some wines with particular methods of preparation. Sauterne grapes are left on the vine to dry in the sun when over-ripe and become naturally infected with grey mould caused by Botrytis cinerea. This will dehydrate the grapes and produce glycerin. When subsequently allowed to ferment the wine develops a sweet, fruity flavour for which Sauterne is renowned. Similar individualities apply to the production of perry from pears and sherry and madeira, the flavour of which comes from the production of aldehydes by the yeasts concerned.

Cheese production is one of the most important methods of preserving milk nutrients at times when supply exceeds demand. The process is a dynamic one with a succession of micro-organisms involved in the development of maturity of specific cheeses.

A starter of Streptococcus lactis is added to the pasteurised milk, this will produce lactic acid in the resulting curd. The streptococci must remain predominant in the curd or competing clostridia may produce taints and faulty colours. Rennet is added to decompose the casein, the curd is broken up and salted, then packed into moulds. As the cheese slowly matures the original streptococci are inhibited and the *lactobaccilli* become predominant. In the production of Camembert the starter is *S. lactis*; then there is a predominance of *Penicillium* and *Oidium*, and finally present is *L. casei*. Coloured cheeses, for example Roquefort, owe their colour to a specific mould - *Penicillium roquefortii* - known only in that region.

The use of algae in human food is also a long established tradition. Probably the most well-documented case is that of *Spirulina*, a filamentous cyanophyte which is known to have been growing naturally in alkaline lakes such as Lake Chad in Africa and Lake Texcoco in Mexico for centuries. This alga has been harvested and utilised as a food by African tribes and by the Aztecs. The lakes in which it is found are naturally at a high PH and a yield of 12 gm. per square metre per day of algae is obtained at temperatures of about 32°C(9). The nutritional value of *Spirulina* is high as its protein content can be as much as 70% when dried; it is the principal ingredient of a traditional native food in Chad called "dihé".

Current research has extended the application of these traditional techniques into systems of protein production which bear little relation to the craft-based industries described here.

The term single cell protein was introduced at the Massachusetts Institute of Technology in 1966 to denote the cells of algae, bacteria, yeasts and fungi grown for their protein content. Bacteria - the simplest micro-organisms - have the fastest growth rate and can be cultured on a range of carbon based substrates under the right conditions. The cells can be recovered from the fermentation medium and dried to produce a buff coloured powder very high in protein.

The fungi can be classified into three broad groups: the single celled organism known as yeast; the multicelled fungi, often in filamentous form; and the higher fungi, popularly known as mushrooms. Both the yeasts and fungi can be cultured on carbon based substrates under suitable conditions and the cell mass harvested to provide a protein rich product.

Finally, the algae have a particular appeal in single cell protein production as they photosynthesise and can therefore use CO_2 from the air via the photosynthetic pathway. In addition the blue-green algae have the ability to fix atmospheric nitrogen, thus both C and N can be obtained from the atmosphere if these organisms are used. However, for optimum photosynthetic efficiency the algae rely on high light intensity. So unless artificial light is used they can only be successfully cultured in regions up to 35° North and South of the Equator. As these techniques are inappropriate for development in the U.K., the work in Mexico reported by Clement (1973)[9] and (1975)[13] will not be discussed here.

The culture of micro-organisms specifically for human consumption was first reported in Germany in 1910[11]. The process involved the culture of a yeast, Candida utilis, on a molasses substrate. Since this time the same organism has been successfully cultured on a wide range of substates including starch wastes and crude oil. Food yeast was used to supplement the diet of both soldiers and prisoners of war by the Russians and Japanese as well as in Germany, where production rose to 16,000 tons in 1917[12]. It was incroporated into dried soups and pastes and powders for military rations.

REVIEW OF CURRENT SINGLE CELL PROTEIN PRODUCTION TECHNOLOGY

The wide range of processes available for SCP (single cell protein) production involves several combinations of organism and substrate yielding a variety of microbial products each with different applications in the food or feed trade. For the purpose of this review I have divided the processes according to their substrate. First I have considered those systems based on by-products and wastes - principally carbohydrates; and the other main division is those systems based on primary raw materials, principally hydrocarbons and alcohols derived from the oil industry.

FERMENTATION OF CARBOHYDRATES

PAPER PROCESSING WASTE

To produce paper, wood is steam treated to divide insoluble cellulose from soluble polysacharrides. A tree will produce nearly 50% insolubles which are subsequently used to make the paper and 50% solubles which are thrown away, causing a high biological oxygen demand (BOD) in rivers leading to death of fish and plant life.

It is these soluble fractions which have been the subject of SCP production research. An international company called Cellulose Attiholz has developed a process to cultivate yeast on the sulphite liquor to provide a protein concentrate for animal feeding. A development of this process utilises the liquor first to produce alcohol, then a further fermentation to give a yeast protein product.

A Finnish research consortium has developed the Pekilo Process to obtain protein from paper waste. This process utilises the liquor from the sulphite pulping operation, about 30% of which consists of monosacharrides, polysacharrides, carbohydrate derivatives and acetic acid. First the liquor is steam treated to drive off sulphur dioxide and the resulting product is sterile and ready to be fed into the fermentor.

The fermentation is a continuous process and retention time is about 5 hours, pH is constantly monitored and regulated by addition of ammonia. When the fermentation is running with a mycelial concentration of 17 gms per litre, the mycelium is de-watered and filtered off. Next the biomass itself is dried in such a way as to preserve its nutritional value.

This product Pekilo Protein is cream coloured and odourless and contains about 60% protein at 87% digestibility. It has been sanctioned by the Finnish Authorities for use in animal feed. The yield of biomass from this substrate is very low, however: 0.008 kg per kg of substrate. The current production unit in Finland has a capacity of 10,000 tonnes per year output of product and has been in commercial operation since 1975. Continuous operation is limited by the availability of raw materials but runs of 2000 hours have been made.[10]

The St. Regis Paper Company in the USA has been producing a human food grade yeast from spruce pulp sulphite liquor using Candida utilis since 1952. The plant output of 10,000 tons per annum is directed entirely at the health food trade and the product contains about 50% protein.[17]

TATE AND LYLE

Development work on SCP production from sugar and its by-products was pioneered by Tate and Lyle. Work carried out in Cyprus involved the fermentation of carob pods which are high in sucrose and glucose. The micro-organism was Aspergillus niger and the original process was a batch fermentation. A. niger was found to grow well on the carob extract and it is thought that it may contain growth promoting substances. The compatibility of the substrate and fungus is such that no competitive organisms were found in the culture, which is not completely sterile nor operated under aseptic conditions.

Optimum yields of 45% initial total sugars have been obtained at temperatures between 30-36°C. The fungal mycelium is separated from the fermentation broth by a rotary vacuum filter; this is a simple process using existing equipment. The dried biomass contains about 35% protein(14). Doubling time for the organism is between 4-7 hours, depending on conditions within the fermentor.

Other work has been done by this company on the utilisation of citrus waste and a pilot plant of 100 tons per annum capacity has been set up in Belize. Here a substrate of pulped citrus is fermented with two organisms Aspergillus niger and Fusarium moniliforms desiginated M1 and M4(15). This will convert one ton of dry peel containing 70% carbohydrate into 0.65 tons of dried material at 27% crude protein - this is not a pure SCP product but a mixture of biomass and pulp. It is hoped that this product can be used to contribute to the animal feed market in Belize.

Neither of the pilot projects in Belize or Cyprus have been taken to a commercial scale operation, however.

Current research effort by Tate and Lyle is to develop a system of Biological Oxygen Demand (BOD) reduction in effluents from food processing and confectionery plant(16). This involves the fermentation of effluents using A. niger to produce a saleable protein product contributing to a reduction in running costs of such an effluent treatment system. Their interest is to produce a commercially viable process of effluent reduction even on a small scale village level — technology. Great potential exists in developing countries for the recovery of protein from carbohydrate wastes and this could be valuable in regions where the nutritional status of the people is low.

RANK HOVIS MACDOUGALL

The Lord Rank Research Centre at High Wycombe has been engaged since 1967 in developing a fermentation based upon starch derived sugar substrates, using a Fusarium species fungi to produce material suitable for human use[20]. The research effort was also backed by the American chemical company Dupont in 1973[18]. But this association lasted only 3 years when Dupont withdrew from SCP research in 1976.

Suitable substrates high in glucose polymers could come from the food processing industry or could be directly produced by cultivating such crops as cassava or potato. Alternatively sucrose type carbohydrates are suitable such as those obtained from cane sugar or molasses. Lactose based substrates such as milk whey were also screened, but the organisms under consideration by the centre have uneconomic growth rates on lactose[19]. Published information is not available except through patent applications and the future plans for the project are unknown. It is believed that pilot scale studies with the starch substrates and filamentous fungi were satisfactorily concluded but commercialisation of the process has been shelved.[25]

STRAW AS A SUBSTRATE FOR SCP PRODUCTION

Cereal straw is the world's largest source of agricultural carbohydrate, producing one kg of straw for each kg of grain. Total annual production of straw in the UK is around 10 million tons; at present about half of this is either fed to animals or used as bedding on the farm. 4 million tons are burnt and about 0.2 million tons ploughed into the soil[21].

Apart from these traditional uses of straw there has been growing interest in utilising this resource in animal feeding or possibly human food via a fermentation to SCP. Straw contains about 45% cellulose, 30% hemicellulose and 15% lignin, and it is the lignin which renders the straw difficult to digest and of low nutritional value[22].

Early work by ICI involved treating the straw with alkali to break down lignin and make available the cellulose for feeding to ruminants. This gives the product twice its feed value if incorporated into rations for ruminants. Work on this process has been done by BOCM Silcocks and they have established three processing plants already and plan to invest £3½ million in five more plants, ultimately having the capacity to process 200,000 tons of straw annually. Additionally, BP Nutrition (UK) announced in 1977 that they are taking over a straw processing concern in Oxfordshire. They too have plans to develop this industry to provide cubed and treated straw for sale to the animal feed trade[23].

Monogastrics, however, cannot utilise cellulose, so to produce a useful food it must be hydrolysed with acid or with enzymes to produce fermentable sugars. This essentially carbohydrate substrate could then be used to produce SCP using existing knowledge of fermentation. Economic size for such a plant would need to be in the region of 100,000 tons annual production of yeast, requiring an input of 500,000 tons of straw equal to two-thirds of all the straw produced in the eastern region of England.

At present no commercial plant produces SCP from cellulosic wastes such as straw, but acid hydrolyses of wood and straw is carried out in Russia producing alcohols and phenols by fermentation.

FERMENTATION OF FOOD PROCESSING WASTES

Food processing wastes are another object of fermentation technology particularly as their seasonal nature often poses particular problems for disposal. Church[26] discusses a large corn canning plant in Minnesota, USA, which discharges 15 times as much effluent into the sewers as the population of the local town during busy periods. Also the variable nature of these wastes may pose particular problems to municipal sewage treatment plants.

Pilot plants have been set up in Minnesota and at a similar factory in Iowa to reduce effluent levels by culturing fungi on the process waste. Both fermentations were continuous and were carried out in large open lagoons of 10,000 gallons capacity. The organisms cultured were Trichoderma viride and at the second plant Gliocladium deliquescens. Additional nutrients were supplied to ensure success of fungal growth. Some imbalance in nitrogen or phosphorus may have been responsible for shifts in dominance of fungal species to a Geotrichum spp and at one point a Fusarium spp.

BOD levels of the effluents were around 2000 mg per litre and these were effectively reduced to below 80 mg per litre. Protein levels in the biomass were in the region of 55%. Sufficient mixing of the fermentation was attained by mechanical agitation and aeration.

Work at present being carried out at Aston University is concerned with BOD_5 reduction in food process waste effluent, for example palm oil process and milk waste, which are typically produced in large quantities and are very dilute. The research is directed towards developing a fermentation which occupies a minimum of land area, effectively reduces BOD under non-aseptic conditions, and can handle large quantities of waste water. The organism used is a strain of Aspergillus niger and the fermentation is carried out on a continuous basis in a tubular reactor. The design was chosen as this permits maximum flow rates of effluent with minimum risk of wash-out of biomass.

Air is introduced into the base of the fermentor to provide agitation and maintain the organism in suspension. It is found that the milk fats present in the effluent help to prevent foaming, which could otherwise become a problem in such fermentations. The biomass obtained contains about 40% protein[27].

Other work at Aston involves finding a range of micro-organisms for fermentation of wastes discharged from palm oil mills in Malaysia. These mills produce effluent of two types: a condensate with BOD of 4000 mg per litre, and a sludge with BOD of 34,000 mg per litre. Current practice is to pump these effluents into local waterways. Successful results of this research could eradicate what is becoming a serious pollution hazard and one which will be legally controlled by 1984, and contribute to protein supply in a part of the world in need of food. A pilot plant of 20,000 litres has been set up in Malaysia[28].

At Birmingham University, Herrington[29] has looked at the suitability of culturing various micro-organisms on brewery effluent to reduce its BOD. He points out that each barrel of beer brewed produces 13 litres of waste liquor with a BOD in the region of 25,000 mg per litre. This effluent is high in sugars but low in nitrogen and phosphorus.

Using A. niger he attained an 83% reduction in BOD on a laboratory scale. An economic appraisal of such a process showed that SCP yield was so low that such treatment was uneconomic at 1976 costings.

A Swedish development named the "Symba" process is based on the production of yeast protein from starch wastes, particularly those from potato processing. This fermentation incorporates two yeast species, one of which breaks down starch to glucose which is utilised as a substrate by the second. The Symba process is reported to be in commercial scale operation in Sweden.[24]

FERMENTATION OF ANIMAL WASTES

At the University of Sydney in Australia, work is being done on biological treatment of pig effluent to produce a single cell product for stock feeding.

Initially the slurry is screened to remove large particles, then it is digested anaerobically to produce methane gas. A second stage of fermentation involves containing the slurry in an illuminated vessel to encourage the growth of photosynthetic bacteria - *Rhodopseudomonas capsulatus*. After removal of this bacterial growth by sedimentation the liquor is illuminated and aerated to develop growth of *Euglena gracilis*. These algal cells are recovered by sedimentation and the final liquor is pumped into fish ponds.

This three stage treatment produces methane gas, about 2.5 g of SCP product per litre of effluent, and provides a basal diet for fish farms. In addition, the problem of smell from pig slurry is effectively controlled.

This type of integrated fermentation technology is particularly apt for pigs where large numbers of animals are kept on a comparatively small land area. An intensive pig unit may house 5000 pigs on an area between 5 and 10 acres. Each pig will produce one gallon of slurry per day and to safely dispose of 5000 gallons of effluent daily, an area of up to 300 acres is necessary. Transport costs would prohibit the carting of slurry more than a few miles, so an effective method of effluent treatment with saleable by-products is a definite bonus for such intensive units. BOD_5 reduction is quite adequate - initial levels in the slurry can be 4000 mg per litre and the four day process will reduce pollution to 50 mg per litre[30].

This type of process will be discussed further in Chapter 6.

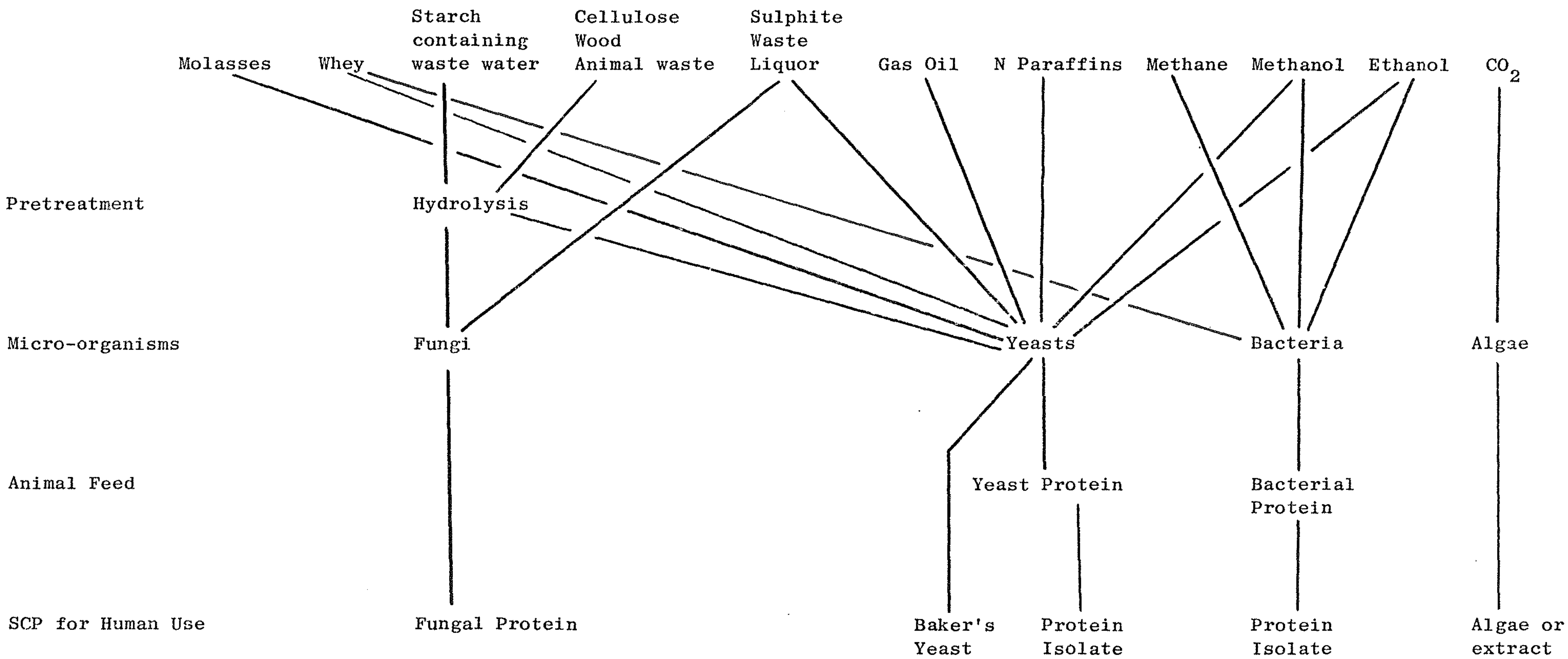


Fig I Principal routes for SCP production

FERMENTATION OF HYDROCARBONS

BRITISH PETROLEUM

The development of protein synthesis from hydrocarbons by BP was begun in 1959 by a French worker named Alfred Champagnat. He was, in fact, investigating the potential of various micro-organisms to de-wax crude oil but recognised that in doing so an appreciable yield of protein rich biomass was obtained.

Two similar processes were devised and pilot plants built, one in the south of France at Lavera, the other in Scotland at Grangemouth. Small scale production began at the former in 1963 and at the latter in 1965. Semi-commercial production of SCP began in 1971 and 1972 respectively. The Grangemouth plant has a capacity of 4,000 tons per annum and at Lavera 20,000 tons per annum was the optimum production level.

The French process uses gas oil, more commonly known as diesel fuel, upon which is cultivated a yeast called Candida tropicalis. The gas oil contains about 15% normal alkanes which are metabolised by the yeast; the residual hydrocarbon is said to be de-waxed by the fermentation and is subsequently of higher market value. However, the resulting biomass after centrifugation contains hydrocarbon residues which must be extracted using solvents. Due to the cost of separation of the biomass from the unused feedstock and the subsequent solvent extraction of residual lipids, the gas oil process was dropped in favour of the Grangemouth plant design. After several years of operation the Lavera plant was shut down in 1976.[31]

The Grangemouth plant uses purified normal alkanes as a feedstock; this involves a pre-treatment of the crude fraction using a molecular seive. In this way the feedstock is concentrated and of 99% purity, n-paraffins being of carbon number range C_{10} to C_{23}.

Aromatic fractions are reduced to 50 ppm. Other impurities consist of iso-paraffins and napthenes but purity of the product is sufficient to pass the FDA test 121.1146 which controls the level of polycyclic hydrocarbons in foods and feeds. The resulting biomass is easily separated using a centrifuge and no solvent extraction is necessary. It is this plant design which was adapted by BP for their ill-fated commercial scale unit built at Sarroch in Sardinia and completed in 1976 at a cost of 80 million dollars[32].

The entire process is aseptic and operates as a continuous fermentation running for up to 3,500 hours. In addition to the purified normal alkanes, the basic feedstock is supplemented with inorganic nutrients required for optimum growth of the yeast organism. The nutrients and the feedstock are sterilised by heat and the large quantity of air needed is also sterilised using a microbiological filter.

Total nutrient requirements for a 100,000 ton per annum plant are as follows:

	Tons per annum
Hydrocarbon	100,000
NH_3	14,000
PO_4^{-3}	5,200
SO_4^{-2}	2,000
K^+	1,800
Mg^{+2}	200
Mn^{+2}	50
Zn^{+2}	40
Fe^{+2}	20

The oxygen requirement for such a process would be 2.1 kg of oxygen per kg of biomass produced. The heat of metabolism is 28 megajoules per kilogramme of biomass[33].

The fermentors themselves, of which there are three at Sarroch, are mechanically agitated and operated at above atmospheric pressure. This is necessary because the paraffin and water are immiscible and must be agitated to form a micro-emulsion to permit an efficient fermentation. Temperature control is achieved by passing the fermentation liquor through external cooling loops. Constant monitoring of the temperature and pH is vital to the successful progress of the fermentation. Consistent product quality can only be maintained if the temperature is between 31-33°C. Particularly large capacity pumps were installed at Sarroch in order to cope with pumping aerated broth which presents peculiar mechanical difficulties.

Centrifugation of the biomass is not a technically complex task but, nevertheless, each ton of biomass must have removed from it about 20 tons of water. Attempts to separate the yeasts by gravity filtration were abandoned as the settling rate is only a few centimetres per hour. The centrifuges installed are of a continuous discharge conical disc type already in use in the bakers yeast industry. They are capable of operating at high speed and generate forces up to 9000 G. The Sarroch plant uses the largest available models installed in parallel to permit servicing of plant whilst in continuous operation. A single centrifuge will reduce the yeast to a cream of 15% weight but two passes of the centrifuge will raise the concentration to 25%. The next operation is to spray dry the resulting cream.

Technical difficulties encountered in handling the cream involve: fouling of surfaces, hygiene risks, and problems of pumping such a viscous yeast preparation.

Flash drying will produce large particle size; spinning disc atomisers are also used depending upon the final form of product required.

It was BP's policy to minimise pollution hazards from this plant and all aqueous phases are recycled to the fermentors, including washings and rinsings from plant cleaning operations. Yeast dust produced by spray drying operations cause another potential pollution hazard and it is undesirable both economically and environmentally that any of the final product be released into the atmosphere. As a result, bag filtration and wet scrubbing is carried out on the off gas from dryer cyclones.

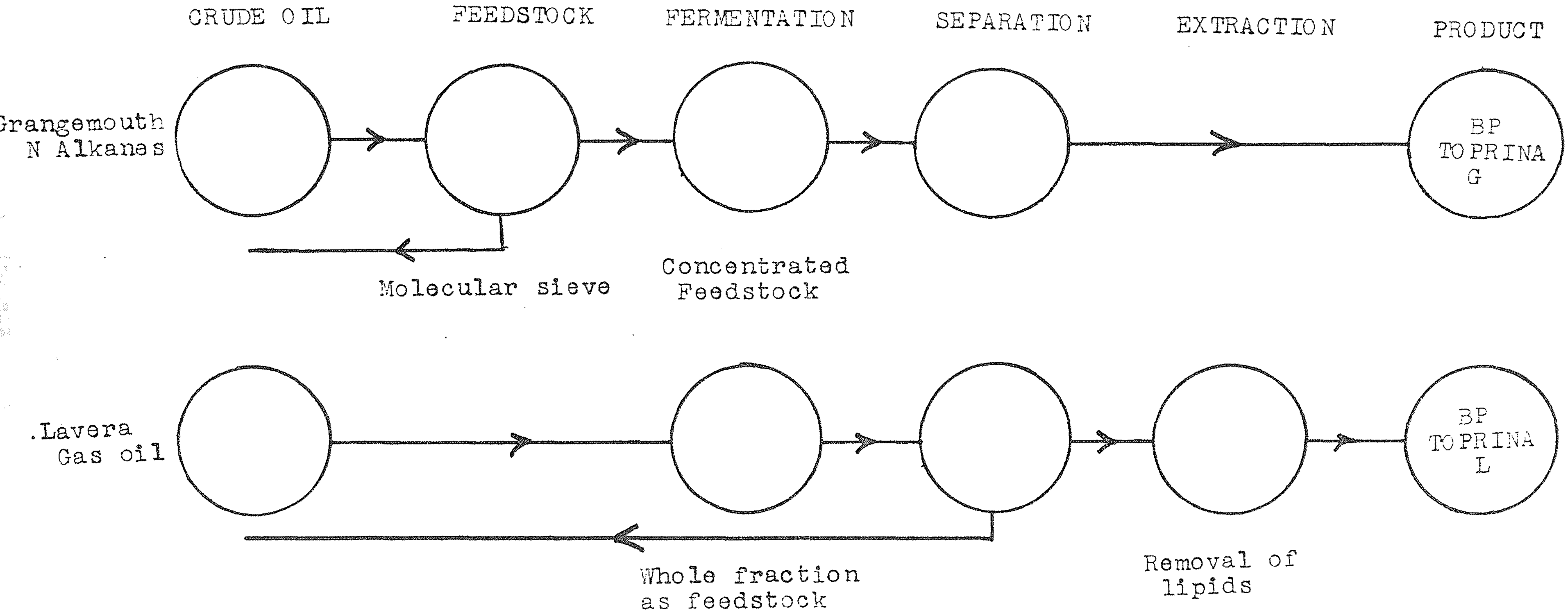
The technical skill required of fermentation scientists is largely one of scaling up a successfully designed laboratory fermentor to an industrial size unit. The problems of ensuring total mixing of all phases in a vessel larger than 1000 cubic metres whilst maintaining control over temperature and pH are not simple. Other aspects of scale up problems are found in designing the pipework for circulating the liquor, such that no quiet areas or eddy currents cause impeded flow and possibly local areas of reduced or increased temperature, which could easily disturb the equilibrium of the entire operation. Accurate control of pressure within the vessels and problems related to vibration from pumps and agitation paddles are further aspects of the precision required in commercial SCP production.

It was the successful design of such a commercial unit using computer aided analysis of the physical and chemical restraints which led to the presentation of the Kirkpatrick Chemical Engineering award to BP Proteins Ltd. in 1973[34].

Unfortunately the BP story does not remain on such an optimistic note as the Sarroch plant, built with the co-operation of ENI (Italproteine), an Italian owned company, has never been operated commercially. The Italian government revoked an EEC ruling to permit the operation of the plant, saying that it was a pollution hazard and that the product is not sufficiently proven to be commercially produced. The Italians allowed the plant to run to produce 1000 tonnes of product trade-named "Toprina" for further testing in 1976 but since then it has remained inactive, and in April 1978 BP decided to close down the plant completely following repeated refusal by the Italian authorities to sanction the product on health grounds. This was followed in July 1978 by a decision to close down the pilot plant in Grangemouth. The current situation is that BP has no production facility for SCP despite holding the licence for all the necessary technology. Attempts to sell the process to Venezuela and Russia have not so far met with any success[50].

Similar events had occurred in Japan some years previously, as plans to construct large SCP plants in Japan by the Kanagafuchi Chemical Industry Company were suspended in 1973 because of public protests over the product's safety. The carcinogen 3-4 Benzopyrene was identified in the product and nutritional evaluation is still going on[51]. It was this setback which led Kanegafuchi to sell their process to the Italian company Liquichimica Biosintesi, who constructed a 100,000 tons per annum SCP plant in Calabria, Southern Italy. The product registered as "Liquipron" would have been in direct competition with BP's venture but it, too, suffered the same fate. Liquichimica underwent financial collapse from which it is only now emerging[52].

Whilst these ambitious plans to produce protein from hydrocarbons in Western Europe and Japan have come to nought, there is still active development in Eastern Europe. Recent reports[53] claim that there are seven plants operating in Russia and a joint venture, involving all the European Comecon countries, plans to build a massive 300,000 tonnes per year SCP plant in the near future.



BP process

figure 2 Flow diagram for production of yeasts from hydrocarbons

IMPERIAL CHEMICAL INDUSTRIES

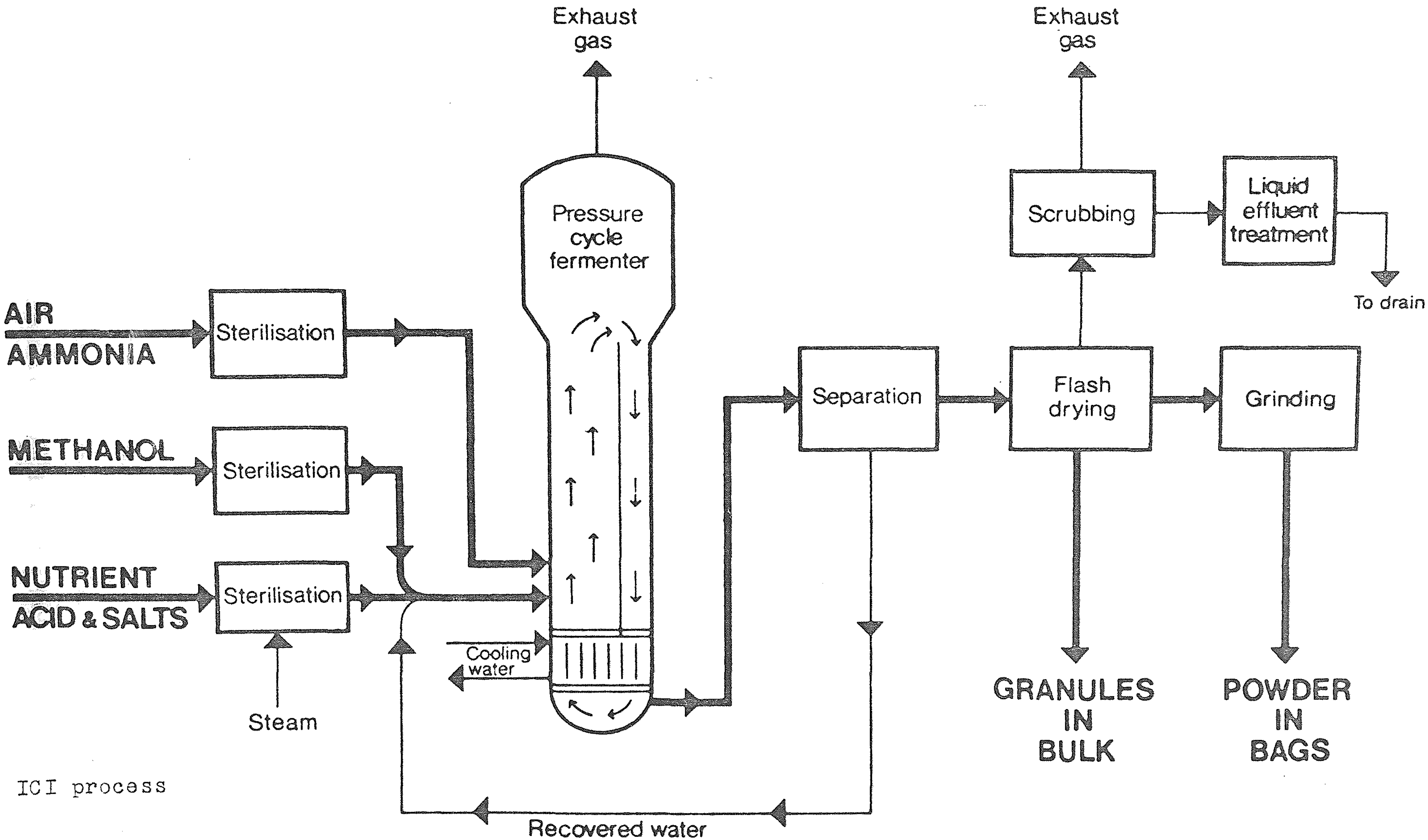
The agricultural division of ICI turned their attention to the production of a protein supplement for animal feeds in the 1960's. Their choice of methanol as a feedstock for SCP production was based upon its ready availability at Billingham, particularly as it may be produced by catalytic oxidation of North Sea gas, which is almost pure methane. It is also soluble in water and presents a low explosion hazard; it is reasonably pure and thus unlikely to contribute to toxicity problems.

A bacterium a strain of methylophilus methylotrophus, was chosen as the most suitable organism, as it has a high growth rate and a high protein content. Extensive tests have established the stability of the organism and it offers apparently no pathogenicity. Experiments were carried out to innoculate the bacteria with sewage sludge but no bacteriophage infection was observed. ICI are satisfied that the organism chosen is sufficiently safe and, with suitable monitoring, presents no risk of toxicity[49].

Another aspect of the bacterium is that in their dried condition the product is quite bland and presents less of a problem with palatability than other micro-organisms. However, the size of the bacteria is in the order of one micron and its density is similar to that of water, so the problem of harvesting the successfully fermented organism is not a simple one. ICI have succeeded in perfecting a technique of de-watering and drying which can remove 99% of biomass from the medium by the development of a secret process which is an improvement on existing centrifuge technology[35].

The fermentor design for this project is the result of a great deal of thought and would appear to be a concept well suited to the type of fermentation used. Stirred tank fermentors were thought too problematic for scaling up to the size of plant envisaged for

ICI PROTEIN PROCESS



ICI process

figure 3

Flow diagram for production of bacterial SCP from methanol commercial production, so a tower type fermentor was designed (see page 26) to permit a continuous operation of the process. The diagram shows the layout of the pressure cycle fermentor with a wide riser, narrow down-tube and heat exchanger. There are no moving parts as circulation is obtained by passage of air bubbles in the riser. The overall height of the installation is 200 feet, making it the world's largest fermentor.

The design allows an optimum time for oxygen in the air to be taken up by the bacterial ferment; this is aided by careful monitoring of the bubble size. Doubling time for bacteria under good growth condition may be as short as 30 minutes. Crude protein levels for the bacterial product trade-named "Pruteen" are in the order of 83%. Non-protein nitrogen levels in bacteria can be high, however, and ICI Pruteen contains about 16% nucleic acids. This presents no problem for animal feed but if incorporated into human food could be dangerous unless removed.

Maximum theoretical yield for methanol-based fermentations is 0.5 kg dried biomass per kg of substrate. However, a normal yield is found to be around 0.4 kg[36].

A pilot plant producing 3 tons per day is already in operation at Billingham but the full scale production plant is under construction and should be on stream in 1979. This represents an investment of £50 million and will have a production capacity of between 50 and 70,000 tons per year depending upon the grade of product required.

SHELL RESEARCH LTD.

The idea of using methane gas as a substrate for SCP production was a logical one in that it arises naturally at high purity and is often flared off from oil wells which are too remote from suitable markets. The Shell research team at Sittingbourne in Kent has worked on the direct use of methane as an input to SCP production. Previous work on gaseous substrates involved the use of propane/butane and carbon dioxide/hydrogen mixtures[37].

The fermentation proceeds by bubbling methane gas through the aqueous fermentation broth either in an agitated tank or a tower. To find methylotrophic organisms has proved to be difficult and work has been done using mixed cultures of bacteria. These have been found to be inhibited in their growth rate due to oxygen deprivation, so some workers have bubbled oxygen and methane through the fermentation medium. The idea of operating the process at above atmospheric pressure to improve oxygen transfer was abandoned due to the risk of explosion.

Mixed cultures of bacteria have proved valuable as some species of methane utilising bacteria (of the Hyphomicrobium spp) can also metabolise methanol, which is an inhibitory by-product of the more productive bacteria in the fermentation.

Pure cultures of Methylococcus capsulatus produce metabolites which depress growth rates. This is thought to be a characteristic of methylotrophic organisms and the efficient utilisation of methane as a feedstock may rely upon the success of mixed cultures, or upon an effective method of removal of these self-inhibiting products.

The only other route to SCP production from methane is to oxidise it to methanol and use that as a substrate. As ICI had already licensed the technology for this process and Shell were unable to perfect the direct methane route, the company have now withdrawn from SCP research[50].

AMOCO FOODS COMPANY

The Amoco Foods Company is a subsidiary of the Amoco Chemicals Corporation and has become involved in the production and marketing of a food grade yeast called "Torutein". This entails the culture of torula yeast (Candida utilis) on food grade ethyl alcolol produced by hydration of ethylene. The process uses a continuous aseptic fermentation which is rigidly controlled and monitored to produce a consistently high quality produce suitable for incorporation into human food preparations.

At present there is only one plant in Hutchinson, Minnesota, U.S.A., which produces about 7,000 tons per year. It began operating in May 1975[38].

Although the organism used is similar to that used by BP and the traditional food grade yeast processes developed during the war years in Europe, the substrate is a highly refined hydrocarbon produced at considerable expense and is chemically similar to popularly consumed alcohols. It looks and tastes like vodka. In this way the Amoco process and product has been sanctioned for human use by the Food and Drugs Administration. This sanction makes Torutein unique among commercially produced SCP products.

Pure ethylene obtained from crude oil is first hydrated to ethyl alcohol or ethanol, which is used after sterilisation as the principal nutrient in the culture of Candida utilis. The fermentation vessels are 30 foot high 20,000 gallon tanks mechanically agitated and fed with filtered air. The whole process is monitored by computer. The final centrifugation and flash drying is accompanied by pasteurisation to maintain the high hygienic quality of the product.

This is a food grade yeast aimed at a specific role as a functional ingredient of processed foods. Consequently, it is a low volume, high quality, high value product.

EXXON CORPORATION - NESTLÉ

Some years after the development of hydrocarbon fermentation technology by BP, a joint research effort was initiated by Exxon and Nestlé with the aim of producing a food grade single cell protein from a similar substrate.

Early work was with purified mormal alkanes and several different micro-organisms, of which a bacteria Micrococcus cerificans was selected. Due to the undesirably high fat content in the product, it was decided to change to an ethanol substrate. The very high cost of ethanol then forced a change to methanol. This entailed searching for a new organism. The one chosen was a Pseudomonas species and the project is now in the process of re-adapting to this new strain of bacteria.

The combination of ethanol and bacteria resulted in an acceptable product, its only drawback being a high level of nucleic acids.

The nucleic acid content of micro-organisms will be discussed later but essentially it is a function of growth velocity. To render the product more suitable for human nutrition, the dried cells were further processed to reduce nucleic acid levels from 16% to 3%[41].

Exxon-Nestlé claim that the processed product is superior in nutritional value to yeast and has already been extensively tested on animals and humans. Due to the very high cost of production of this bacterial protein, progress beyond this pilot study has ceased[59]. It is felt that the practical use of this product to solve world food problems is not an economic proposition at present. This work seems to have been confounded by economic pressures causing constant need to modify their line of research.

Bacterial culture has been used for some years by Union Carbide in Puerto Rico to clean oil from tanks and to decompose waste oil. The bacteria are cultured on molasses then added to the waste oil along with necessary mineral salts and the resulting fermentation degrades the waste oil, such that it can be safely discharged into the sea. The Union Carbide plant is capable of treating 4 million gallons per day[(42)].

Hoechst, the West German chemical company, began SCP research in 1971. In a government backed research programme to look at methanol as a fermentation substrate, they have recently opened a 1,000 tonnes per year demonstration unit. They claim not to be interested in commercial development at this stage and are concentrating on applying fermentation technology to the manufacture of other products, such as amino acids and antibiotics[(50)].

COST AND ENERGY ANALYSIS

Having reviewed the technology available for SCP production, it is now proposed to examine its cost both in energy and economic terms.

Work done by Slesser[60], Leach[61], and Lewis[54] on energy analysis of SCP products is valuable here. These workers are able to attribute an energy value to the quantity of raw material, electricity or manpower necessary in a process and draw up a list of energy requirements, which when added give a Gross Energy Requirement (GER) per unit weight of product. Due to the different protein contents of SCP products from various sources, these GER's are often quoted in terms of unit weight of protein produced by a system. In this way the relative efficiency in the use of energy by several protein producing systems can be compared. Whilst these estimates may not be accurate to the Mega Joule, as they are based on predictions of fermentation performance which may not always be attained and limited by the amount of information made available to the researcher, they do provide a guide to the relative quantities of energy which are needed to produce these different types of protein.

The production of SCP from methanol by bacterial fermentation has been analysed by Lewis[54]. He considered a plant producing 50,000 tonnes per year and the figures showed:

Physical Inputs	GER MJ/kg product
Methanol	84.4
Ammonia	7.08
Ammonium Salts	5.26
Other Salts	0.48
Water	0.02
Electricity	18.62

Capital Inputs	
Stainless Steel	0.26
Steel	0.30
Cement	0.08
amortised over 40 years	
Total:	117 MJ/kg product

The Shell Company who provided these figures also claimed that there were potential improvements in the technology which would reduce the GER to 111 MJ/kg.

At 80% protein the actual total = 146 MJ/kg protein

potential total = 139 MJ/kg protein

Figures provided by ICI[55] show a GER of 133 MJ/kg and Leach[61] has 136 MJ/kg for the same process.

At 80% protein these become: ICI 165 MJ/kg protein

Leach 170 MJ/kg protein

Lewis's work also shows an analysis of the bacterial/methane SCP route which requires 130 MJ per kg of product, which is equivalent to 163 MJ/kg protein.

The analysis of SCP production from Normal Paraffins by yeast is also made by Lewis and although the components of the analysis are different, he comes up with the same figure as the methanol/bacteria process:

Physical Inputs	GER MJ/kg product
N. Paraffins	45.27
Ammonia	6.33
Ammonium Salts	6.04
Other Salts	1.47
Water	0.13
Kerosene (fuel)	25.15

Electricity	31.5
Product recovery	4.62
Drying	2.38
Pumping	2.52
Capital Inputs	
Stainless Steel	0.33
Steel	0.35
Cement	0.10
amortised over 40 years	
Total:	117 MJ/kg product

However, the lower protein content of yeast at 63% means that the value of GER per kg of protein rises to 186 MJ.

Looking at the SCP processes based on carbohydrates, Tate and Lyle provided figures for their small scale plant in Belize. Lewis analysed these to give a figure of 44 MJ/kg product, which at 55% protein is 80 MJ/kg protein. Figures provided by the Distillers Company Ltd. for their batch process yeast production from molasses showed a need for 48 MJ/kg product at 63% protein: thus 76 MJ/kg protein.

Lewis in a detailed but theoretical study of the conversion of cellulosic wastes like straw, newspaper and sawdust to SCP via hydrolysis to a sugar substrate, analyses the energy requirements for the entire process. Due to the high energy requirement to convert the cellulose to fermentable sugars, the SCP end product has a GER of 239 MJ/kg which at 63% protein is 379 MJ/kg protein. The theoretical size of this plant was 160,000 tonnes/year input of newsprint/straw, giving an output of around 70,000 tonnes SCP product per year. This type of project will be discussed in greater detail in Chapter 6.

Table 1 shows a summary of the gross energy requirements for various systems.

Table 1

Process route	GER MJ/kg protein
Bacteria - Methanol	
Lewis actual	146
potential	139
ICI	165
Leach	170
Bacteria - Methane	
Lewis	163
Yeast - N Paraffin	
Lewis	186
Leach	195
Yeast - Molasses	
Lewis	76
Tate & Lyle Belize	80

COST ANALYSIS

Assessment of the cost of production of SCP products is confounded by the wide variety of inputs and systems by which these materials are produced. Costs also vary according to the scale of the operation and the siting of the process. For example: oil prices have risen dramatically since 1972, making methanol and paraffins less attractive as fermentation substrates than they were in the 60's when many SCP projects were launched. Nevertheless, siting an SCP plant close to a source of oil supply or tailoring refining capacity to the requirements of a plant can affect considerably the cost of raw materials.

An analysis of the costs of production for a paraffin/yeast process at an output level of 100,000 tonnes per year is made in the Wolfson Report[56]:

	£/tonne product
Materials cost	66
Operating cost	68
Capital cost	22
	156

This is an updated analysis to show the cost at 1973 prices. The yeast has a 60% protein content, so the price per tonne of protein is £260.

Worgan[57] presents an analysis of yeast protein production from paraffins based on 1976 prices:

	£/tonne protein
Feedstock	160
Operating	30
Capital	100
	290

Sources of information on production costs are not always consistent with each other. Worgan quotes some American figures for the relative cost of SCP products showing methane derived SCP to be the most costly and molasses derived yeast to be relatively cheap:

	Product cost US $/lb 1972
Glucose/yeast	4.7
Paraffin/yeast	6.4
Methane/Bacteria	8.6
Methanol/Bacteria	8.1

However, Lewis(54) presents a similar type of relative cost table from UK figures showing the glucose/yeast route to be the most expensive and the methane/bacteria product to be the cheapest:

	Product cost £/tonne 1974
Molasses/yeast	233
Paraffin/yeast	176
Methane/bacteria	118
Methanol/bacteria	150

Of course these figures could be explained by changes in technology and temporary fluctuations in raw material costs. The question of the methane/bacteria process is now largely academic, as the system was never perfected.

Litchfield(51) also discusses relative costs in his work, and based on 1976 prices he expected a food grade yeast product grown on molasses to be marketed at about $1 US per kg, whilst BP's feed grade Toprina was expected to be sold at about $0.45 per kg. At this time soya bean meal was selling in the USA at $0.2 per kg.

	US $ per kg	1976
	Product	Crude Protein
Food grade yeast	1	1.9
Feed grade yeast - Toprina	0.45	0.75
Soya bean meal	0.2	0.42

Cost estimates for the ICI process have not been published but it is evident that the ready availability of methanol at Billingham means that the substrate costs will be below the market price and will be provided from resources within the company.

Current predictions of the market price of the Pruteen product[58] are that it will be linked to the price of soya. It may cost about twice as much as soya when it comes onto the market, presumably because ICI expect it to replace soya in that proportion; which means a selling price around £260 tonne of product.

The fact that SCP is an expensive source of protein has been a feature of the process since the oil crisis. When the price was calculated to be £150 - £200 tonne in the early '70's, soya meal was about £80 tonne and now that ICI are about to market Pruteen, its price is still twice that of soya at £260 tonne. It is possible that even this price does not reflect the true cost of development and testing of the product.

Development and testing are an even bigger feature of the food grade products like Torutein, which has a low volume sale as an ingredient of processed foods - it is marketed at around £600 tonne in the UK.

In Lewis's report[54] appendix 4, he briefly shows that the only cheap SCP process are those where the substrate is an effluent or waste with either no cost or simply the costs incurred in transport to the production site.

NUTRITIONAL VALUE

Single cell protein products are characteristically high in protein content and rich in vitamins, particularly those of the B group. Their amino acid profile is good, being high in lysine which is deficient in cereals and legumes (see appendix). It is logical, therefore, that an ideal application of these products is to use them to supplement cereals to improve their protein quality in diets for monogastric animals, which include pigs, poultry and man.

As these are totally new sources of food, there arose a need for thorough evaluation of SCP products to establish their safety as animal feed components and, indeed, the safety of the meat produced for human consumption. For this purpose regulations were drawn up covering both animal and human consumption of SCP products.

Probably the most widely read guidelines regarding novel protein sources are the statements issued by the United Nations Protein Advisory Group (PAG). This group is an interdisciplinary body from which the UN itself seeks expert judgements on global protein supply. In their statement No. 4 on Single Cell Protein (June 1970) they state:

> "There is adequate evidence to indicate that some species of yeasts, algae and bacteria can be safe and useful sources of proteins, vitamins and minerals, for animal and human feeding. However the safety of such materials will depend upon the organisms selected, the quality of the substrates utilised and the conditions of growth."

The statement goes on to refer to further guidelines issued by the PAG on pre-clinical testing procedures and human testing of supplementary food mixtures(47).

It is made clear that all rapidly growing cells have a high nucleic acid content, and that these must be excreted by humans as uric acid. A high intake of nuclec acids can predispose some people to gout, a condition characterised by deposit of uric acid crystals in joints and in the urinary tract. For this reason it recommends a limit of 2 grams of nucleic acid as a miximum daily intake - this is equivalent to about 25 g. of unprocessed cells (statement No. 4, para. 5).

The statement calls for greater clarity and precision in defining substrates for SCP production, and that there should be no significant amounts of potentially carcinogenic polycyclic aromatic hydrocarbons present in petroleum based fermentations. It is stressed that materials used for animal feeding should not render the resulting milk, eggs or meat unsafe for human food.

Finally, the statement calls for more research in areas of SCP technology, such as improvement of biological control of fermentations; effects of nucleic acids; methods of reducing nucleic acid levels in SCP's; selection and testing of new strains of micro-organisms and purification and production of protein isolates.

Much work has been done at various times on human feeding trials of SCP and some authors report feeding up to 100g/day to human subjects with no adverse effects. However, in 1947 in Puerto Rico, Torula yeast grown on molasses was fed at 15g/day and produced unacceptable gastro-intestinal effects. It was later thought to have been caused by an anti-foaming agent added to the molasses. US army trials during World War II showed no disorders for 30 days, then some digestive intolerance developed amongst some subjects.

At MIT* Torula yeast grown on sulphite liquor was fed to 72 subjects with no adverse effects. Dosage ranged from 45g to 135g/day for 60 days. Only 12 subjects on the high intake developed self-

* Massachusetts Institute of Technology.

limiting desquamation of the skin on the palms and feet, which disappeared when the trial ended. Also at the high intake level two subjects developed a transient skin rash which lasted only 48 hours.

At the University of California, Calloway[48] fed a variety of SCP products to animals with no adverse effects, but when fed to male human volunteers, they produced nausea and vomiting and some subjects even developed vertigo and asthenia.

Other work at MIT showed a syndrome of sensitivity found in some humans but not in others. During a 6 month trial 80% of subjects showed no adverse effects but 20% developed a condition of nausea, vomiting, diarrhoea and even prostration. This was possibly related to substrate contamination but illustrated that human response to this contaminant was not predictable.

Human feeding trials in Russia are reported to have produced oedema of face and hands, peeling of skin, with itching and pain in the toes when subjects were fed SCP products.

It is reassuring to see that the major companies involved on SCP production are carrying out long term multi-generation toxicity tests on their products. BP began their testing in 1963 in collaboration with CIVO (Central Institute for Nutrition and Food Research) at Zeist in Holland, and their test procedure is identical to that recommended in the PAG guidelines. More nutritional evaluation of Toprina has since been carried out by ILOB (Institute for Agricultural Research on Biochemical Products) at Wageningen also in Holland. This latter organisation being one of the most respected and thorough institutes for feed evaluation in the world. All results of this work are published and freely available - they show Toprina to be a useful protein component in the diet of a wide range of animals and fish. Similarly, ICI have carried out extensive tests on Pruteen at several centres in Germany, France and England during the past five years, using 200,000 animals including poultry, pigs, calves, lamb, mink and fish, feeding a total of 500 tonnes of Pruteen.

NUCLEIC ACID HAZARD

One of the problems associated with feeding high levels of single cell protein to monogastric animals, including humans, is the level of nucleic acids (NA) ingested. Humans and the higher apes lack the enzyme uricase which catalyses the oxidation of uric acid to allantoin, which is soluble and can be easily eliminated via the kidneys.

In the past, yeast extracts have been used at low levels as a vitamin supplement to human diet and no urinary uric acid increase was observed. However, proposals to incorporate yeasts and other micro-organisms into the human diet at higher levels than a simple vitamin supplement could lead to a problem of nucleic acid metabolite imbalance.

Unusually high levels of NA in foodstuffs are not restricted to micro-organisms; it is observed in any rapidly multiplying cell system. Sardines contain up to 2.2g of nucleic acids per 100g of protein, liver may have up to 4g and fish roe may contain 5.7g. Young seedlings such as bean sprouts, as consumed in the East, are also known to contain elevated levels of nucleic acids(43).

The guanine and adenine are metabolised to uric acid, and individuals with a genetic tendency for over-production of this metabolite may develop precipitation of crystals in the joints - a condition known as gout - or the formation of stones in the urinary tract.

The most rapidly multiplying micro-organism is the bacteria and Bacterial/SCP may contain up to 25g NA per 100g protein (dependent upon species and growth conditions), whilst yeasts and the slower growing fungi with lengthy doubling times have nucleic acid contents between 7g and 12g/100g

Several experiments have been performed to investigate the relationship between nucleic acid intake and resulting blood plasma and urinary levels of uric acid.

Endozien (1970) fed a basal diet containing 100g of purine-free protein to human subjects and observed a blood serum level of uric acid of 4.5 mg/100 mls.(44)

When feeding 45g of yeast containing 2.9g of nucleic acid, serum levels rose to 7 mg/100 mls. When feeding 90g of yeast containing 5.8g of nucleic acid, serum levels rose to 9 mg/100 mls. The basal diet gave 600 mg per day of urinary uric acid, whilst 45g of yeast per day raised urinary uric acid to 1,000 mg per day.

Waslien et al. (1968) found that a basal diet gave 5.5g uric acid per 100 mls of blood plasma, while 1g of NA per day gave 6.5g of uric acid/100 mls plasma and 4g of NA per day gave 8.4g uric acid/100 mls plasma.

From this work it has been concluded that the upper limit for uric acid concentrations in the blood should be 7g/100 mls serum and that the urinary levels were difficult to fix as they are dependent upon fluid intake and sweat loss. However, the recommendation for nucleic acid consumption is that it should not exceed 2g daily.

<u>TECHNIQUES FOR REDUCING NUCLEIC ACID LEVELS IN SCP</u>

The reason for high nucleic acid levels in the cells in the first place is their very high rate of multiplication, so one of the most obvious means of reducing NA is to slow down growth rates. This can be done either by constant dilution of the growth medium - which is, of course, counter-productive - or by culturing an organism such as Fusarium spp, which is inherently slow growing.

There are also chemical processes involving base hydrolysers to precipitate proteins. This results in the production of a protein concentrate relatively free of nucleic acids, which could lend itself to further processing into foodstuffs[45].

Treatment with hot sodium chloride will deplete nucleic acid levels, and subsequent solvent treatment with phenols is effective but may also remove amino acids and vitamins.

Both physical and chemical cell disruption have been successfully tried. Initial disruption or homogenisation of the cells using high pressure homogenisers or using hot sodium dodecyl sulphate leaves the cell contents open to enzymatic hydrolysis of nucleic acids. Hydrolysis may occur slowly by the action of endogenous enzymes, or by addition of bovine pancreatic enzymes the process is speeded up, but this enzyme is expensive to use in this context. Enzymatic treatment can result in a high weight loss in the final yield of treated cells.

Work done by Maul (1970 involves initial heat shock to the medium - a few seconds at $54^{\circ} \rightarrow 70^{\circ}C$ followed by incubation for a period between $45^{\circ} \rightarrow 50^{\circ}C$, then a period between $55^{\circ} \rightarrow 60^{\circ}C$. Maul believes that the initial heat shock causes disturbance of the ribosomes and the ensuing incubation allows complex enzymatic hydrolysis reactions, resulting in the leakage of the products into the medium. Using this technique a sample of Candida utilis with a NA content of 7% was reduced to 1.5%[46].

Tannenbaum is looking at the possibility of mutant SCP's which will stop nucleic acid synthesis at critical temperatures.

APPLICATIONS

Having established that the nutritional value of SCP products is adequate provided all conditions regarding quality of substrate and organism are adhered to, their range of possible applications in animal and human diets has been found to be very wide.

ICI's Pruteen which will be coming on to the market in late 1979 is destined for incorporation into animal feed and as a component of artificial milk feeds for veal calves. Pruteen has also been found to be useful in fish diets which require particularly high levels of protein. It is not the intention of ICI to market Pruteen as a human food ingredient. Evidently this would not be possible without further processing to remove nucleic acids and further nutritional evaluation.

Amoco are interested in promoting Torutein as a food additive with properties additional to the nutritional advantage of a protein concentrate. For example, it is seen as a valuable new product in food processing, as it can bind fat and water, provide emulsification, and stabilise emulsions. Also it enhances the flavour of meat, cheese, spices and seasonings in foods and acts as a thickener in sauces, gravies and salad dressings. In fact, the first product to use Torutein was Milani brand low calorie Thousand Island Dressing, which was launched in 1975. Studies have also been made on its ability to boost perceived flavour level in chocolate[39]. Other positive aspects of this product stressed by Amoco are its long shelf life, its lack of after-taste, and its ability to enhance colour, texture and flavour.

From a nutritional point of view, yeasts are low in methionine but high in lysine, which suggests that a yeast and a cereal would complement each other well to provide a food of high nutritional status in protein. It is found that a 5% addition of Torutein to a wheat pasta will give a 35% rise in PER (Protein Efficiency Ratio). Similarly, a 9% addition will almost double PER[40].

However, the production of food grade yeast to a high hygienic standard using a high cost substrate is expensive, and in 1977 Torutein was selling in the UK for about £600/tonne, which at 52% protein is very expensive. Soya beans at 40% protein sell at under £200 a ton, which goes some way to explain why Torutein is promoted as a multi-dimensional ingredient for the food processing industry and not simply as a protein concentrate. In fact, reviewing the product literature, it is projected as a new product of multiple benefit - the food processor's panacea, which as an added bonus also contains 52% protein.

The other growth area for SCP products which Torutein is expected to move into is the pet food industry. A modified form of the yeast called PT 9 is marketed specifically for this market. The literature suggests incorporation in meat or cereal preparations at 2 - 3% to improve flavour and boost lysine levels.

It is interesting to see examples of the product's publicity literature (Fig.s V and VI) which projects Torutein as a straight alternative to conventional agricultural products like meat. It is claimed to be half as energy intensive as beef, independent of weather, requiring no land, using no pesticides and containing no residues.

It was the intention of Rank Hovis McDougall to produce a fungal SCP product specifically destined for human use. Its slower growth rate meant low nucleic acid levels and the fungal mycelium gives structural properties which would lend itself to the formation of textured meat-like products. In this way, a useful food grade product could be made without the expensive processing needed by yeast and bacteria based products.

3

LEAF PROTEIN

INTRODUCTION

It is widely accepted that the seeds of plants may be used to produce foods or feeds of high nutritive value, but the use of green leaves in this context is not a familiar one.

Traditionally, the green photosynthetic leaves of plants are utilised by ruminant animals in the upgrading of these feedstuffs into meat or milk. Whilst this practice is universal, it is recognised that it is inherently low in its efficiency to convert forage protein, unavailable to man, into a more accessible food like meat.

The most efficient conversion of this type is the production of milk, where 600 kg of vegetable protein will yield 240 kg of milk protein, an efficiency of 38%[1]. Wilson, who made this estimate, admits that this could only be achieved by a high yielding animal, of which only a small proportion are found in the UK national herd. A more typical figure for milk production may be around 27%. Wilson goes on to show that the efficiency of protein conversion is 15% for pigs and 6% for beef animals. An overall level of conversion efficiency of forage protein to animal protein for an agricultural system must lie between 10 - 20%.

The yield of crude protein in green forage is far higher than most people realise, though it is poorly utilised by non-ruminants because it is bound by cellulosic material. Using ruminants to graze upland pasture, about 100 kg per hectare of protein can be recovered annually in the form of meat[3]. A more productive pasture for a dairy herd will yield 250-300 kg of crude protein per hectare. In an arable system the grain of a wheat crop yields 550 kg of crude protein per hectare, and field beans 840 kg CP/ha. But the yield of protein actually produced by one hectare of grassland is around 1,800 kg which, as has been pointed out, is inefficiently converted to meat or milk by ruminants.

It is also known that the concentration of protein in green crops is much higher than that needed by a ruminant. For example, a beef animal requires a diet containing about 15% crude protein and dairy cows about 13%, but the concentration of crude protein in grasses and legumes is between 18 - 25%[3].

It is evident, therefore, that the high level of protein in forage crops is inappropriate to the feeding of ruminants. This led workers to suppose that greater efficiency could be generated if the protein could be freed from the cellulosic material by which it is bound and a portion of it fed to monogastric animals. The mechanical fractionation of forage enables this greater efficiency to be realised. Pirie[2], the pioneer of this work in the UK, has done much to take this theory into the realms of practical research and development.

Pirie suggests that by fractionation of a green crop, 40% of the protein can be recovered for use in monogastic diets including man's, 5% can be recovered by feeding to ruminants, and 7% recovered by using the residual products as a substrate for SCP production. This concept of a 52% utilisation of forage protein in a modified agricultural system is very different to Wilson's 10 - 20% efficiency in our traditional methods. It is the purpose of this chapter to evaluate the feasibility of this fractionation process and see to what extent these theoretical improvements in protein utilisation can be attained in practice.

DEVELOPMENT OF TECHNIQUES FOR FORAGE FRACTIONATION

In 1773 a man named Henri Martin Rouelle first recognised the proteins in the leaves of plants as a distinct component of a leaf. This discovery remained of only academic interest until the early part of this century, when researchers proposed that the protein fraction of a leaf may be freed from the cellulose which surrounds it and rendered suitable for feeding monogastric animals.

Early equipment for the separation of the forage into different fractions utilised a screw press similar in action to the domestic meat mincer. A unit of this type(4) was brought into commercial production as a result of early work by Pirie, then director of Rothampstead Experimental Station. During the 50s and early 60s, several techniques were evaluated for the pulping and pressing of grass and other crops. The roller presses used to crush sugar can were tried with some success but were found to have an excessive power requirement.

The machine developed by Pirie for the International Biological Programme funded project to evaluate leaf protein in 1966 was a hammer mill type pulper running at 3,500 rpm and designed for production of samples for analysis. It was not suited for commercial production but has been used in the assessment of different crops throughout the world.

A larger unit capable of processing 1 - 2 tons per hour of forage was also developed by Pirie, incorporating a separate pulper and press. The pulper consists of a cylinder with a co-axial shaft on which are mounted beaters which rotate at 800 - 1,700 rpm. This will produce a pulped mass from which the juice is expressed by a press arrangement consisting of a conveyor belt passing round a perforated pulley into which the juice is forced(6).

By the early 1970s, research activity in this field had broadened into three main topics: 1) evaluation of the suitability of different crops, both temperate and tropical; 2) the growth stage at which highest protein yields were obtained; and 3) a more precise definition of the physical requirements for optimum performance of fractionation equipment[5].

An American worker named Koegel developed an extruder which pulped the forage by forcing it through an array of holes drilled in a steel plate[7]. Another technique developed was that of macerating the forage between two discs counter rotating at relatively high speed. As various design features become clear, current research attempts to optimise the performance of the pulper and press as separate units.

It is now known that the pressing of the pulped forage to separate the juice should maintain a pressure on the pulp for at least one minute and that the thickness of the pad of material being pressed should not exceed 10 cms. The maximum pressures needed are known and are not as high as originally thought necessary. The favoured press designs at present are those using the external surface of one cylinder rolling on the internal surface of a larger cylinder, known as a "horn angle" press. Another effective design is a device consisting of two concentric cones known as a "Vee press".

The range of pulpers developed is also wide, the hammer mill type and screw press using excessive amounts of energy are not now popular. Both Pirie's model using rotary beaters and Koegel's extruder are capable of design improvements, but are most likely to be applied in commercial development. It is the opinion of Thring[8] that the greatest area for improvement lies in the press for "juice extraction".

After pulping and pressing the forage, it is effectively divided into two fractions - juice and fibre. The fibre fraction may be dried for storage, fed directly to animals or made into silage. The juice fraction containing 35% of crop protein can be further treated by steam or acid to coagulate that protein; this is then extracted and dried to produce leaf protein concentrate. This concentrate contains only 9% of crop dry matter but 26% of crop protein, and it is from this product that human food preparations can be made (see figures 1 and 2). The remaining brown juice left after protein coagulation is known as the de-proteinised juice and this is often put back on the land, using irrigation equipment.

As is shown by figures 1 and 2, the process does "fractionate" the protein: 65% remains in the forage, 9% remains in the de-proteinised juice and 26% is recovered in the form of a concentrate. The eventual adoption of this process at a commercial level may depend upon the economic use to which each of these fractions can be put, as it is now clear that the costs of fractionation cannot be borne by the returns made from leaf protein concentrate production alone.

OPTIMUM CROP MANAGEMENT FOR FORAGE FRACTIONATION

The yield of protein from grassland is limited not only by the efficiency of the fractionation machinery but also by the species of crop harvested and its growth conditions.

Most crops reach an optimum age at which protein yield is highest. Beyond this time the protein content falls off quite rapidly and significant yield loss is observed if harvest is delayed. Protein yield is affected by climate and the level of nitrogen fertilisation, as well as the frequency of harvest and the speed of regrowth.

Lucerne and clover regrow well after harvest and can be cut three or four times in a UK season, giving yields of 1,000 kg/ha of protein. Wheat, barley and rye will yield 300-500 kg/ha, depending on growth conditions. Yields as high as 2,000 kg/ha have been achieved using wheat at a high level of nitrogen fertilisation[9] in the UK.

FIG. 1

PROCESS ROUTE FOR FRACTIONATION OF A FORAGE CROP

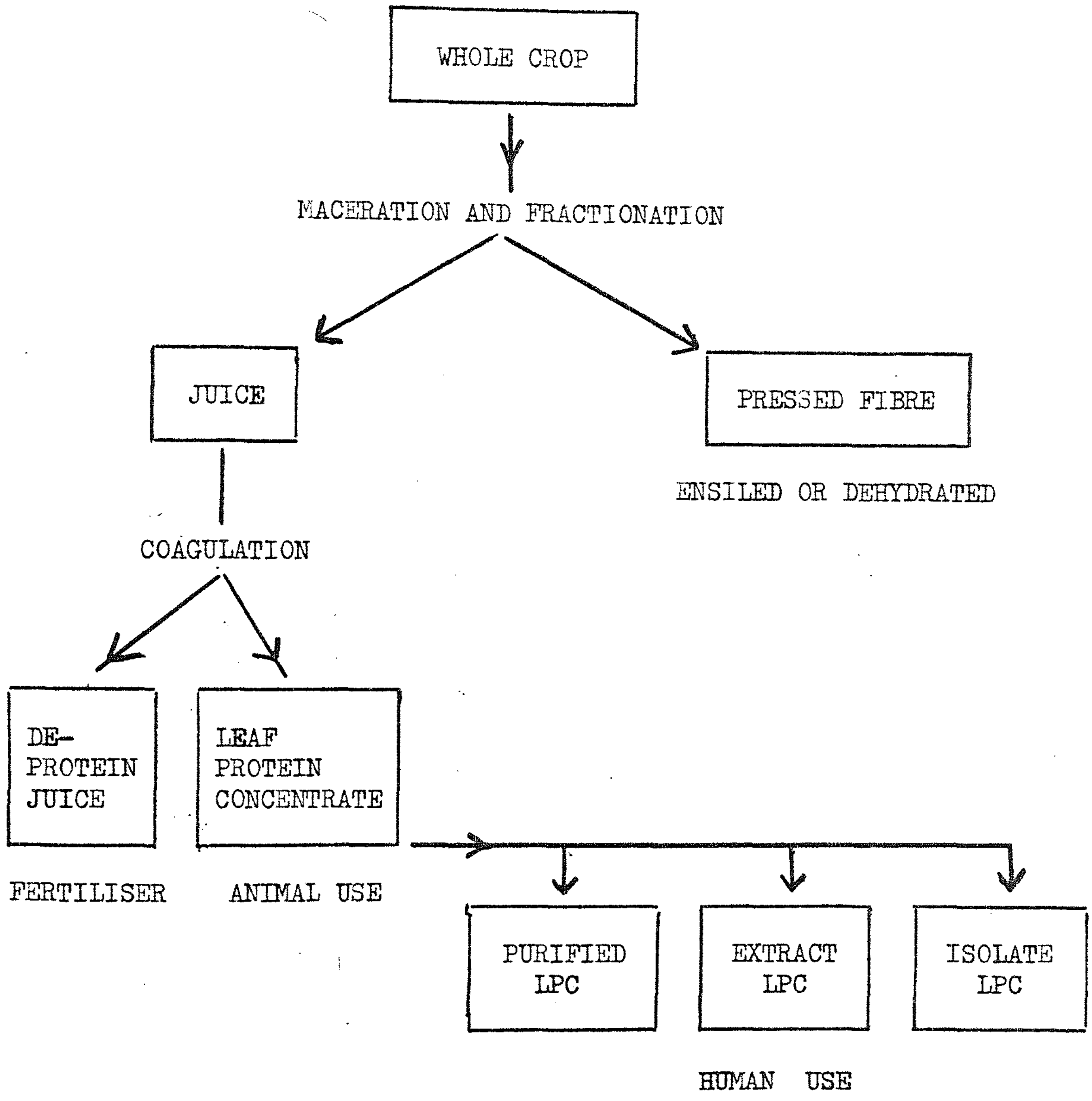
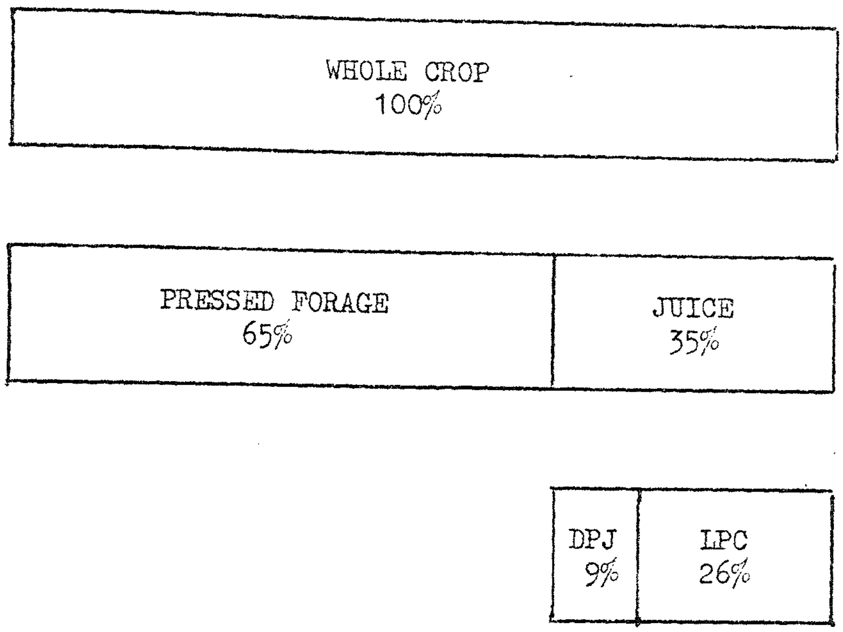
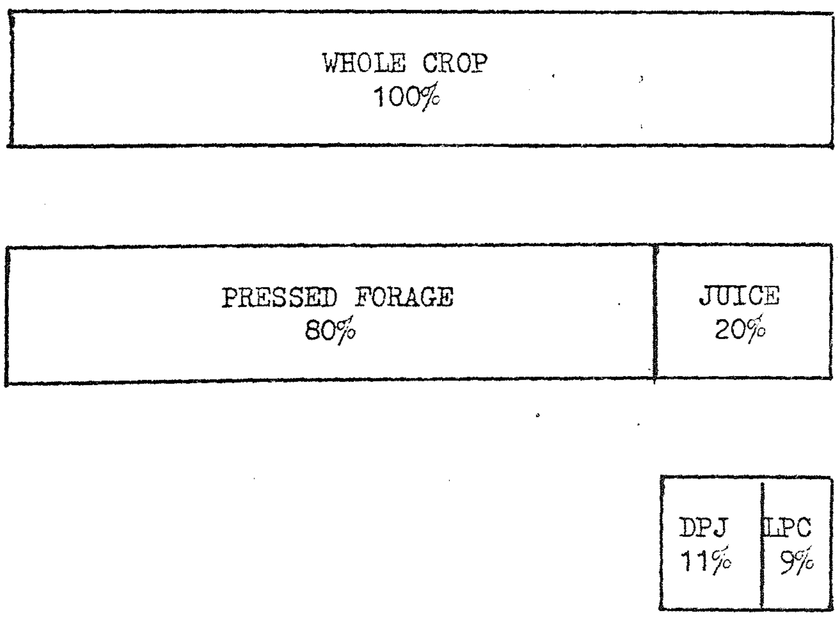


FIG. 2

RELATIVE YIELD OF CRUDE PROTEIN



RELATIVE YIELD OF DRY MATTER,



From S.B. Heath, 1978.

Much higher yields are possible in the tropics, with up to 5,000 kg/ha of protein from fertilised wheat crops and 3,000 kg/ha from legumes. Several workers including Pirie believe that it is in the tropics that the true benefits of leaf protein extraction techniques can be realised.

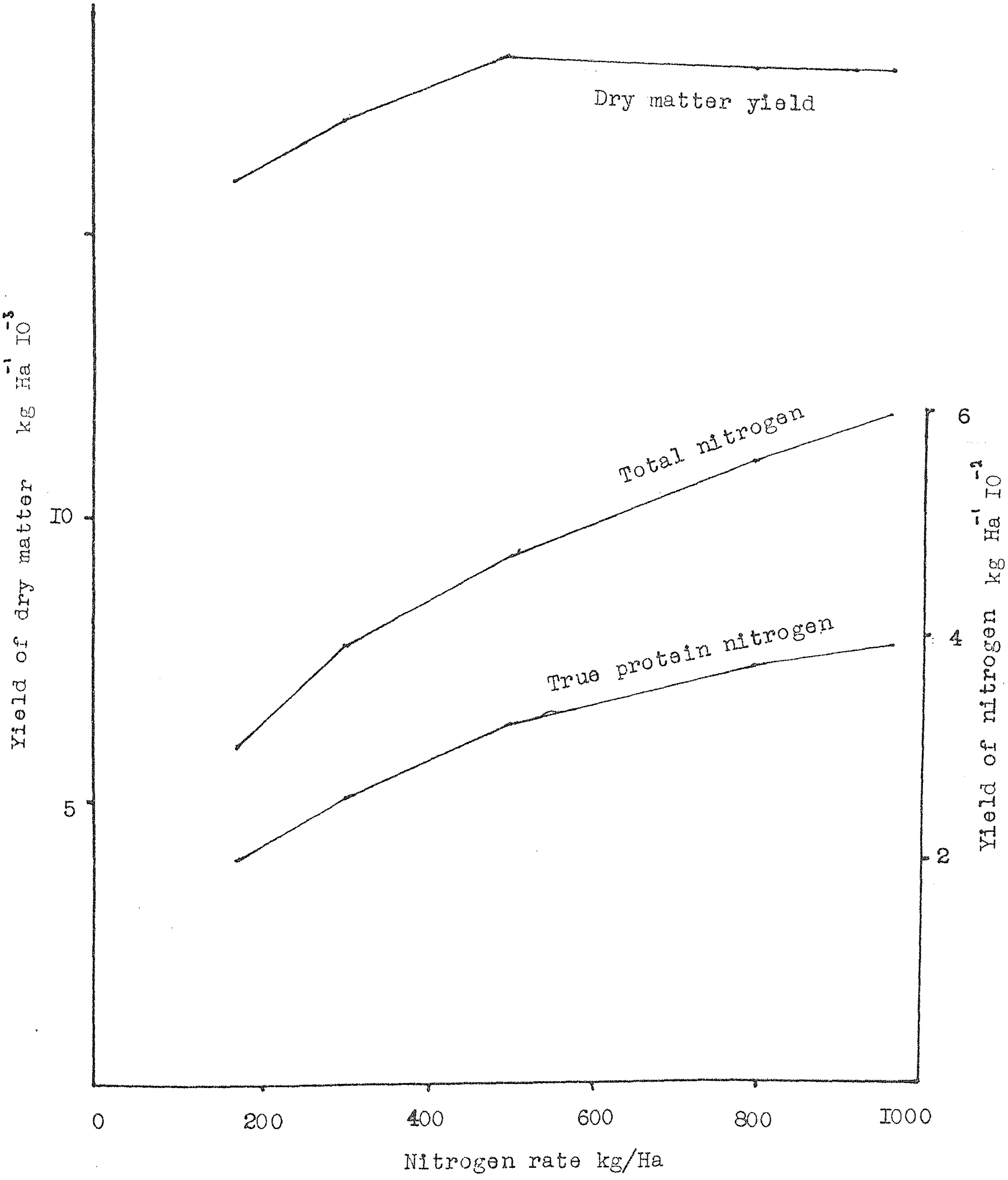
Work reported by Heath[10] shows that the response of dry matter production to nitrogen fertiliser levels off before the response of total nitrogen production (protein) which goes on rising with added nitrogen fertiliser (see Fig. 3). This graph would indicate that, whilst current levels of nitrogen fertiliser application optimise dry matter yield at around 4-500 kg/ha of nitrogen applied, an application rate of twice this figure could improve protein yield by 30%, whilst dry matter yield remains relatively unaffected by this increased input.

This highlights the fact that no forage crops have been bred to optimise protein yield, and that were such a project to be embarked upon, it is possible that a species of forage plant could be selected to produce very high protein yields with more moderate fertiliser use.

Work done by Heath and King at Reading show that highest yields of protein are obtained if the crop is harvested as the rate of accumulation of protein is slowing; this enables the regrowing forage to embark upon a new phase of rapid protein accumulation. Using this technique, six, monthly cuts were made in one season, resulting in a diminished dry matter yield compared to a more conventional three harvests per season, but a 20% increase in protein yield.

The relationship between dry matter yield and protein extraction has been investigated by King[24] at Reading University. He finds that, whilst crops vary in their protein yield, as dry matter yield rises there is an overall negative correllation, as shown in Fig. 4. This clearly shows that the higher the dry matter content of a variety of forage crops, the lower is their true protein extraction ratio.

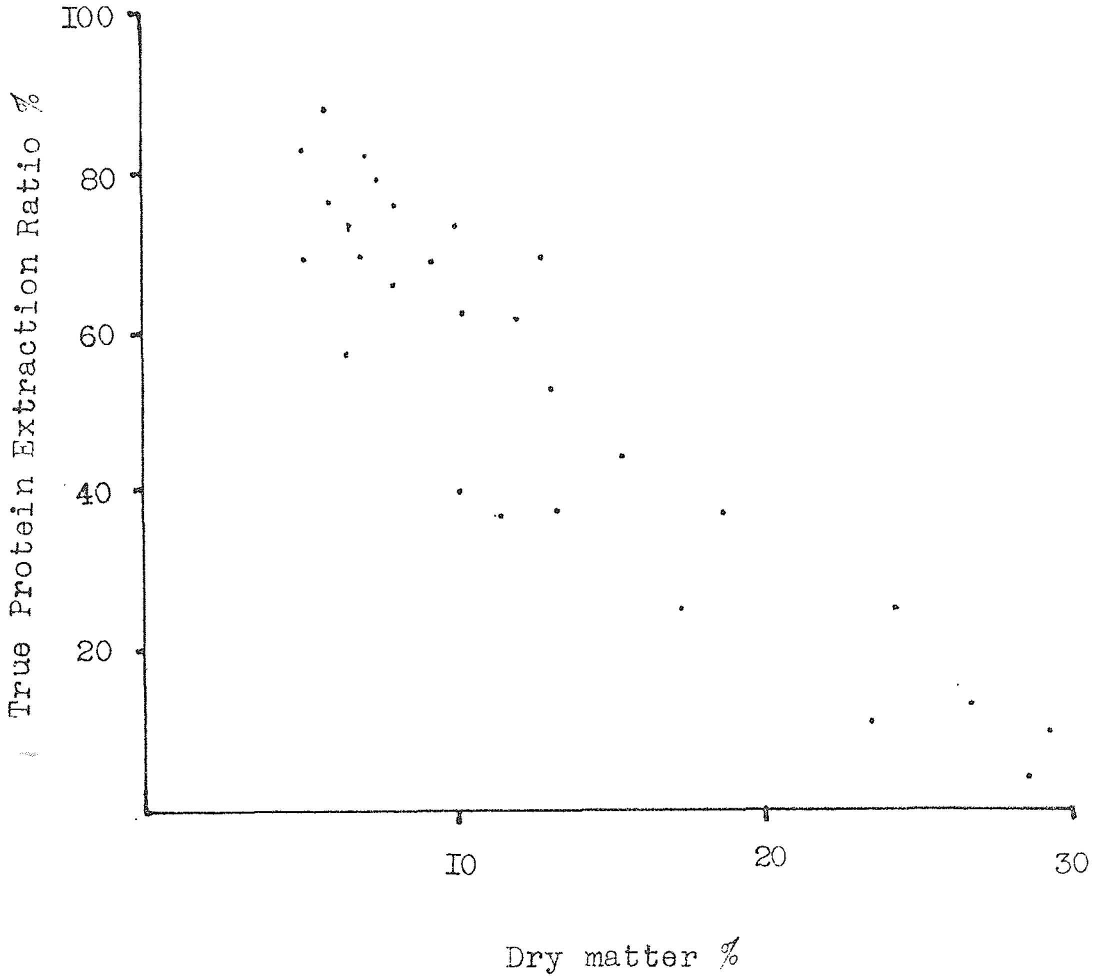
Fig 3 Response to nitrogen fertiliser of dry matter yield, total nitrogen and true protein nitrogen of Italian Ryegrass



Ref Onwubuya, I.I. PhD Thesis 1976 University of Reading

Fig 4

Scatter diagram showing relationship between true protein extraction ratio and dry matter content of kale, mustard fat hen and fodder radish (ref IO)



Of course, this kind of correlation is probably affected by other factors, and these are currently under investigation at Reading.

One other critical factor revealed by this research is the rate of decline in extractability of the protein with age of the forage. Some species under investigation will only give their optimum protein yields if harvested during a short critical period. Beyond this, the lignification of the plant prevents an adequate extraction of protein if the harvest is delayed. On the other hand, a crop which lignifies slowly may be quite usefully harvested over an extended period if, for example, the weather delays cutting operations. For the successful development of leaf protein extraction it will be important to select crops which show a slow rate of decline in extraction ratio, making harvest dates less critical.

Having looked at the rate of accumulation of protein in perennial grass crops and suggested harvest techniques for optimum yield, it has also been proposed that a sequence of annual crops could be grown and each one harvested only once. Arkoll[11] claims that this method would be likely to produce higher yields if, for example, a winter rye crop were followed by a sequence of plantings of fodder radish. Critics have pointed out that to establish several separate crops would require a higher standard of management, compared to a single crop of grass harvested and fertilised several times.

Pea vines, potato haulm and sugar beet tops could also be used to fill in gaps in supply according to the region in which the fractionation plant is situated. American research has now turned to an evaluation of water weeds as material for fractionation, and species of Eichhornia have yielded 600 kg/ha of extracted protein[25]. This is of greater significance in India, Africa and the USA, where this plant is a weed of navigable waterways, than it is in the UK.

NUTRITIONAL ASPECTS OF LEAF PROTEIN

Having reviewed the many variables revealed by research in both the agronomic and industrial aspects of leaf protein production, some space should be allotted to the discussion of the nutritional value of the product.

Bray[12] points out that of the several protein products obtainable from leaves, three are important in human nutrition. These are:-

1. Purified Leaf Protein Concentrate.
2. Extracted Leaf Protein Concentrate.
3. Leaf Protein Isolate.

The purified LPC is a refined form of the whole dried LPC used in animal feed trials, and is the only type of LP product so far used in human feeding trials. The recently completed trial at Coimbatore in India shows that after two years' experimental work with 250 children eating leaf protein every day, no ill effects were seen. The children grew at an acceptable rate and their standard of health improved[13]. The product used was made from lucerne and contained 50-60% protein, rich in lysine but deficient in methionine and cystine (see appendix). Additionally, leaf protein has been tested in many human diets by Pirie and used in a number of famine relief programmes.

Whilst the nutritional value of leaf protein concentrate is not questioned, its acceptability definitely is. The purification process renders the product dark green or black and gives it a strong flavour. Additionally, shelf life is limited, as the product can develop rancidity if not stored at low temperatures in the dark. Consequently, the likelihood of this product finding widespread acceptance is slim, despite the fact that it is relatively inexpensive to produce.

Extracted LPC is produced by removal of the colour and flavour, using solvents. This will also improve the keeping quality of the concentrate which has the appearance of a bland off-white powder. Unfortunately, the nutritional quality is not improved by this process, though digestibility increases by about 10%. The overall effect of solvent extraction of the purified LPC to produce extracted LPC is to raise its cost considerably and render it colourless and flavourless.

The final product to be considered, LP Isolate, is bland in taste, white in colour, and has a high nutritional value. This is obtained by separating the two types of protein in the juice. Essentially, the juice proteins are either contained in the chloroplasts or dissolved in the cytoplasm, the former being mainly responsible for the strong colour and flavour. By separating and purifying the proteins, an isolate is obtained from the cytoplasmic fraction. Not only is this isolate free from the strong colour and flavour but it is also free from the material of low digestibility. The dramatic improvement in nutritional quality is seen in the figures for Protein Efficiency Ratio produced by Clifford(26) in the USA. These show the white LP Isolate, which contains 90% protein, to have a PER of 2.68, whilst the purified LPC has a PER of 1.84. Work by Betschart(15) shows that by amino acid supplementation the PER of LPC can be raised to 2.83. Casein, the accepted reference protein, has a PER of 2.5.

Although the general amino acid profile of LP products from many different crops is consistent (see appendix), its appearance and nutritional quality are widely varied depending upon the method of preparation and refinement of the final product. The degree of processing and the techniques used can greatly change the application to which this food product is put.

COMMERCIAL PRODUCTION

Only a few organisations have carried development of forage fractionation to a commercially viable scale. In the UK, Dengie Crop

Driers and BOCM-Silcock have developed the process beyond a small pilot plant.

The Essex based Dengie Crop Driers Ltd. is already actively engaged in producing dried grass and lucerne as a feed for ruminants. Their interest in fractionation originated in a desire to reduce fuel costs by removal of crop moisture using a screw press. Subsequent development of the process in 1973 led to the installation of equipment to dry the coagulated juice proteins to produce an LPC product of 50% protein content. This is a whole LPC containing the xanthophyll pigment, and it could only be sold in France where this type of pigmented product is valued in poultry rations. The presence of xanthophyll in poultry diets gives the flesh a yellow colour. This "golden flesh" is favoured on the continent, but in the UK we prefer a white meat, so the LPC ration is not in demand by British poultrymen.

However, the fractionation plant which was set up in co-operation with Simon Engineering, using equipment taken from the food industry, never gave entirely satisfactory performance. By 1977 the LPC project was shut down and the plant dismantled, although the crop drying operation carried on as before.[29]

Since 1975, BOCM-Silcock, the animal feed division of Unilever, have established a forage fractionation plant in Yorkshire based on lucerne. This prototype full-scale study allowed for any eventuality by construction alongside the fractionation equipment a crop drier of sufficient capacity to handle all the pressed forage from the extraction equipment. The projected output of this plant is 470 tonnes of LPC and 5,000 tonnes of dried grass cubes. To provide the necessary raw material, 1,100 acres of lucerne are being grown on contract by local farmers.[23]

Interestingly, this plant is also being used to produce "nutritionally improved straw" during the winter months. This is evidently an attempt to spread the overheads of manning a large unit throughout the year by developing a straw treatment industry alongside the fractionation plant.

In 1978, the plant's first full season, the results were disappointing. The low market price for dried lucerne - around £50 per tonne imported from the USA - meant that the dried forage side of the enterprise operated at a loss. Also technical difficulties with the fractionation plant meant that the process was out of action for much of the season.[30]

It is currently the intention of BOCM-Silcock to optimise production of LPC and dried lucerne whilst developing the necessary commercial scale equipment. Thring[17], who is head of research and development for BOCM-Silcock, made some pertinent comments at a conference in 1976:

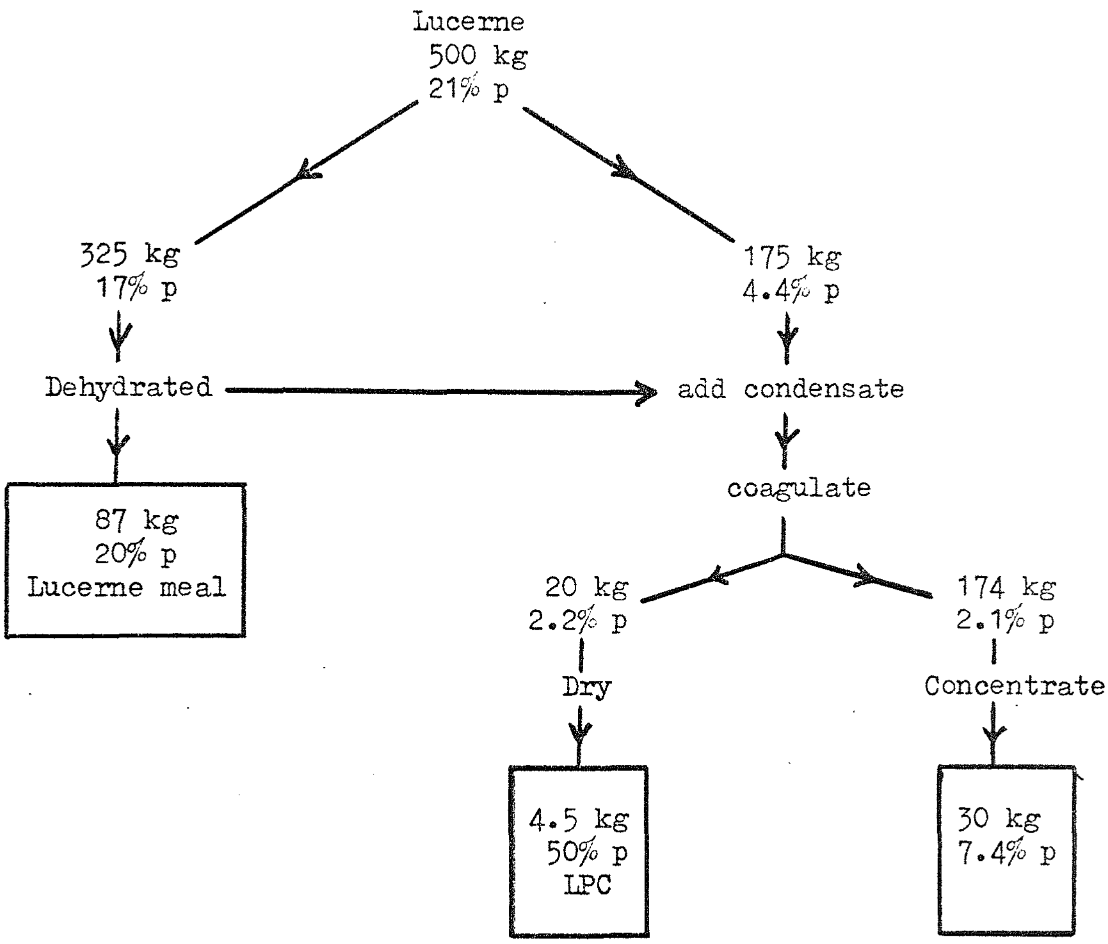
> "Even in its simplest form a green crop fractionation system involves several process steps. As the system becomes more sophisticated, the number of process options at each step, as well as the number of possible steps, increases dramatically."

In the USA, lucerne is again the chosen crop for commercial extraction of protein. The process known as PRO-XAN[22] produces three fractions: the dried pressed lucerne cake; dried LPC; and concentrated solubles from the de-proteinised juice. (See Fig. 5)

It is interesting to note that maximum protein yield has been forsaken in this process to optimise large throughput and consistent quality. As a result, sugar cane rollers are used to crush the forage, although their effectiveness in rupturing and pressing the plant cells is not as great as more sophisticated machinery; but it does ensure high output and trouble-free operation. The full-scale plant, which is in California, has a capacity to process 50-70 tons of lucerne per hour.

FIG. 5

PRO-XAN PROCESS - PHASE I



More recently, this American work has concentrated on the production of a white LPC product from the soluble protein fraction of the lucerne juice. This is found to have a higher lysine and methionine/cystine level than whole LPC, and is thought to be suitable for addition to low protein foods for human consumption. The process for production of this protein isolate is a development of PRO-XAN and is designated Phase II.

There is a significant commercial leaf protein industry in Hungary[27]. One unit there has an output of 40-60 tonnes per day of product and forms part of a concerted attempt to provide a protein concentrate for animal feed to reduce soya bean and fish meal imports. In this process developed by a Hungarian company called Vespex, the forage used comes from a series of crops including rape, lucerne and kale. The leafy material is macerated and extracted in several stages and the fibrous residue is dried. The juice is heated to precipitate the protein and the de-proteinised juice is concentrated in a vacuum evaporator. Then the condensed DPJ and the precipitated protein are mixed together to form a sludge which is spray dried and pelleted.

One other commercial operation is found in France where a company called France Luzerne have a plant for producing LPC from lucerne. As with Dengie Crop Driers, the product is sold as an ingredient of broiler rations. In 1976 its output was 500 tonnes per year of LPC[28].

ECONOMIC AND ENERGETIC CONSIDERATIONS

An examination of the economic or energy efficiency of leaf protein production is dependent upon the choices made of the scale and the technology of the process. Most analysis already carried out is based on small-scale operations, but some work has been done on theoretical plants producing large quantities of LPC.

Heath's[18] work on this topic shows return on capital invested to vary according to the product range available from the process. For instance, if the whole juice is simply coagulated and fed to pigs and the pressed forage dried, a return of 27% is seen; but by further processing the juice to dried LPC, the estimated return on capital is only 7%. The extra capital needed to produce the refined produce is not reflected in its price. Heath also calculates a 27% return for the drying of the fresh crop without fractionation, so there is clearly no incentive to develop this process on purely financial grounds. An analysis of the return on capital invested for LPC production when added to an existing green crop drier shows an 11% return on extra capital, compared to 20% return on existing capital. The only case where returns improved were with the production of coagulated whole juice added to an existing green crop drier. Here the existing capital return is 20% and the return on extra capital invested is 35%.

A study by RHM[19] in 1975 to cost the construction of an LPC plant showed an investment of £2½ million and running costs of £1½ million, from which the return was estimated to be 19%. RHM decided against construction of the plant.

The return on capital for fractionation systems would increase if the cost of the purchased crop were lower and the length of the season were extended. Heath also adds that relatively small changes in the cost of the pulper and press would make production of the coagulated whole juice and dried pressed forage more profitable than conventional dehydration.

Lewis[20] has analysed the energy requirements for LP production, taking into account the growing of the crop, steel and machinery, fuel and electricity. He calculates a gross energy requirement of 61 MJ per kg of protein. It should be pointed out that only about 30% of this protein would be suitable for human use and not without further processing.

Another salient point is that the GER for lucerne production is only 1.9 MJ/kg, so almost 97% of the energy needed to produce LPC is expended in the transportation and processing of the forage and only 3% in the production of the raw material.

Calculations based on Bruhn's[21] work in the USA show a GER of 65.6 MJ/kg of product. This is for the production of dried LPC from lucerne, containing about 50% protein for animal feed.

Some conclusions drawn by Spedding at the British Grassland Society Conference in Harrogate in 1976 are pertinent here. He shows that the only energetically efficient use of a fractionation system is to produce LPC for human use. (See Fig. 6)

The energy input to different systems of producing protein using forage and animals, with the output measured in terms of protein for human use, can be seen in this table. The most energy efficient conversion to protein for human use is the production of LPC integrated with a beef enterprise, Case (3). Whilst this has a high energy input of 164 x 10^3 MJ/ha, the output is also high - 582 kg/ha of protein. Conversely, the traditional grass/silage beef system, Case (1), has low inputs and outputs. Case (2) with beef from a dried forage system shows the high level of energy input necessary to produce dried forage which is then wastefully fed entirely to ruminants, giving a low level of efficiency.

FIG. 6

SUPPORT ENERGY USE IN PROTEIN PRODUCTION

	(1) Grass/Silage → Beef	(2) Dried Grass → Beef	(3) Fractionation → Beef + LPC for man	(4) Fractionation → Beef + LPC for poultry
(A) Support Energy MJ x 10^3/ha	32	184	164	174
(B) Output of Protein as human food kg/ha	78	87	Beef 83 LPC 499	Beef 83 Poultry 50
Efficiency $\frac{B}{A}$	2.2	0.47	3.5	0.76

From Spedding: British Grassland Society Symposium No. 9, 1976. p. 179.

4

OILSEEDS

INTRODUCTION

Oilseeds are of value to man principally for the lipids they contain, which can be used according to their properties in the preparation of salad and cooking oil; margarine; paints; varnishes and soaps. The most important of these oil rich seeds are soyabeans, cottonseed, sunflower, groundnut and oilseed rape. The demand for these products, particularly in the Western world where frying and baking of food is widespread, has caused the development of a strong world market for oilseeds.

Historically, these commodities were of tropical origin, Africa and India being major producers. The increased demand in recent years has been met by a dramatic expansion of temperate oilseed production by Western nations. The last fifteen years have seen a 50% increase in world production of the five leading oilseeds. Yet over the same period, African groudnut production has remained constant, Indian cottonseed production has risen only 15% and her output of groundnut has risen only 10%. In Europe, sunflower seed output has almost doubled, EEC production of rapeseed has almost trebled as has that of Canada, whilst US production of soyabeans has risen 70% over the same period. The world oilseed market is now dominated by the production of soyabeans, of which 55% are grown in the USA[(1)].

ASTON UNIVERSITY LIBRARY

Fig. 1

CONSUMPTION PATTERNS OF VEGETABLE OILSEEDS, OIL AND CAKE IN THE EEC 9, 1955 & 1975

(excluding olive oil)

OILSEED	1955			1975		
	Seed	Oil	Cake	Seed	Oil	Cake
Total (1,000 tonnes)	4,169	2,718	4,273	11,195	3,575	14,522
Percentage of total						
Soyabeans	23	6	-	73	31	66
Rapeseed	5	2	-	9	5	4
Sunflower seed	1	1	-	3	8	3
Linseed	10	13	-	2	2	3
Groundnut	18	20	-	4	10	5
Copra	15	16	-	6	13	6
Palm Kernel	18	12	-	-	6	3
Cotton Seed	6	5	-	1	1	5
Palm	-	16	-	-	18	-

From Parris and Ritson - EEC Oilseed Products Sector and the CAP, Wye College, 1977. (1)

Changes in the EEC consumption of oilseeds and of sources of supply are shown in Fig. 1. Here an overall pattern can be seen: a rise from 11,160,000 tonnes of all oilseed products in 1955 to a consumption of 29,292,000 tonnes in 1975. Not only has EEC consumption trebled in those twenty years, but the sources of supply have changed. In 1955, our seed was provided by soya at 23% of total requirements, with groundnut and palm kernel supplying 18% each; groundnut also provided 20% of our oil needs. By 1975 the situation had changed dramatically: 73% of European Seed imports and 66% of the European oilcake requirement were provided by soyabean, while the importance of groundnut and palm kernel had dropped to 4% and 1% for seed supply, and 10% and 6% for oil supply.

The soyabean has attained this remarkable success partly because it is valuable as an oil crop, but also as a source of protein. After removal of the oil, of which the crop contains about 20%, the crushers are left with a protein rich meal which has found widespread application in the preparation of animal feed compounds. This soyabean meal is found to be a highly acceptable protein source for animal feeds and contains fewer anti-nutritional factors, which are often a feature of vegetable protein sources. The speed and success with which the US has been able to develop this crop has created the present situation in which EEC countries are dependent upon US soyabean imports to support their large livestock populations. Indeed, France presently imports 80% of its requirements of livestock feed, mainly soyabean meal but also rapeseed, linseed, peas and beans. In the UK we spent £54 million on soyabean imports in 1977 and £56 million on fishmeal. The total cost of importing protein feeds to the UK in 1976 was over £200 million[2].

It is this overall deficit of protein for animal feeding which has led Europe to reconsider its major dependence on US soyabean production and take a serious look at alternative solutions to the problem.

In the agricultural EDC report "Agriculture in the 1980s", it is shown that the use of concentrated feeding stuffs in UK agriculture rose by 12.7% between 1964 and 1974, and that it is predicted to rise 18.6% between 1974 and 1984[3]. This report goes on to stress the various ways in which UK farmers can improve efficiency. Points discussed include the need for a high degree of management expertise applied to the feeding of livestock, and attention paid to the nutritional value of different feed components. The efficient utilisation of grassland is stressed and the need for conservation of good quality forage as hay or silage. It points out that an improvement in the health of farm livestock will lead to an improvement of feed conversion efficiency. In discussing raw materials, it mentions the benefits of upgrading waste materials such as straw, and the benefit from replacing maize with feed wheat due to its higher nutritional value, and the need for an increase in the use of home-grown oilseed rape as a protein input to replace soya.

As the soyabean will not grow successfully in the UK, and has found only limited acceptance amongst farmers of south-western France where the climate is more suitable, the report suggests that UK farmers should be encouraged to grow those oilseed crops which could be nutritionally acceptable as substitutes to soyabeans. Reference is also made to the value of novel protein sources such as dried poultry manure, single cell proteins, and leaf proteins, but adds that these will be available in too limited quantities to have much commercial impact in the next few years. The Government white paper "Food from our own Resources"[4], presented to Parliament in April 1975, discussed possible future targets for agriculture production. It pointed out that our current level of self-sufficiency for oilseed rape was 37%, and projected a UK target of 200,000 tons output by 1980.

It is with this background of economic events that there is interest in the UK to establish an oilseed crop. Oilseed rape is without doubt the strongest contender as the major oilseed for UK agriculture, and it is my intention here to review the many factors governing its success and look at other plant species which may become important in a future agricultural system.

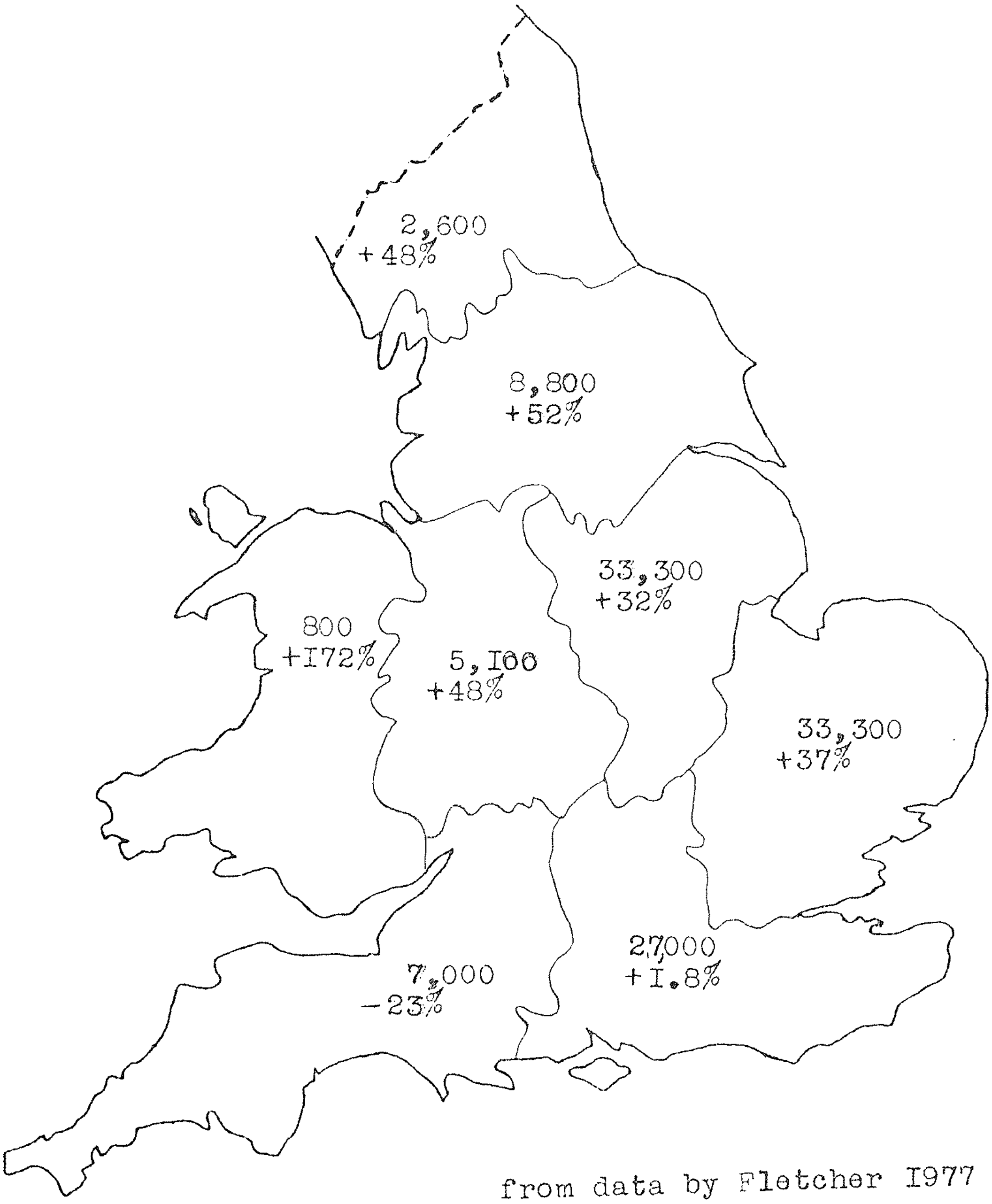
OILSEED RAPE

1. Background to its present status.

Oilseed rape is the fastest expanding crop in UK agriculture. It has risen from an output of about 3,000 tons in 1961 to over 100,000 tons in 1976. (See Fig. 2.) Originally, much of the crop of Canadian origin was grown for the erucic acid content of its oil, which has several industrial applications, including lubrication of continuous castings in the steel industry and as a jet engine lubricant. It is also a component of plastics and plasticisers and has derivatives used in cosmetics and nylon manufacture[(6)]. High erucic acid varieties were also used in food applications in the 1950s and 60s, but nutritional investigations in Canada showed that oils high in erucic acid (in some varieties up to 50% of fatty acids are erucic 22:1), if fed at high levels, could lead to poor animal performance. This discovery had the effect of stimulating a research programme in the 1960s to produce a strain of rape which had a lower level of erucic 22:1 in its fatty acid profile. This programme was successful and resulted in a variety of rape called Oro containing an oil high in oleic acid 18:1, making its analysis similar to that of peanut oil. Due to its lower yield, the new variety was not quickly adopted by farmers nor demanded by processors, despite the added bonus of the oil being less prone to auto-oxidation than soyabean oil.

However, at the International Rapeseed Conference in Quebec in 1970, nutritional studies from Europe and Canada were presented. These showed that when young test animals were fed high levels of high erucic rapeseed oil, undesirable physiological changes occurred in the heart muscle. No evidence has been put forward to show that this effect has been observed in humans and even today there are workers who doubt that erucic acid is truly a danger to human health. However, Fig 2 Acreage of Oilseed Rape by region I976

showing % change over I975



from data by Fletcher I977 (22)

I976 total II8,086 acres
Increase over I975 22.6%

as a result of these findings, it was decided to limit the level of erucic acid in human food to 5% of the fatty acid content by issuing recommendations to the food industry. This obviously had an immediate effect on the demand for low erucic varieties, and once the necessary seed stocks had been built up the changeover in Canada was very rapid, such that by 1975 the erucic level in the entire Canadian crop was below 4%[5].

One reason for the comparatively rapid rate of change from one variety to another is a particularly interesting aspect of plant breeding. It has been found by a worker called Downey[7] that the fatty acid composition of rapeseed oil is determined by the genotypic character of the embryo and not the plant from which it came. This mechanism of inheritance is of great value to the plant breeder, as half a seed can be tested to ascertain its fatty acid composition and, if suitable, the other half can be grown. In this way, the breeding programme for oil quality can be brought to a conclusion more quickly.

Downey says that if the pathways by which each component of the seed oil is synthesised can be elucidated, then plant breeders could develop a crop to produce the precise mix of fatty acids which is required by the market. This has already been demonstrated by the reduction of erucic acid and elevation of oleic acid in rapeseed oil. If the linolenic component could be raised to improve the nutritional properties of the oil and linolenic component reduced to improve stability and thus shelf life of the refined product, then the oil may become even more valuable to the food industry.

Whilst Canada was quick to convert to a low erucic acid rape variety, this was not the case in Europe. Sweden, Germany and France have accepted the need for the improved varieties, but have found that the Canadian strains are not suited to European climates and have had to breed their own new varieties. There have been problems with unimproved type seed lying dormant in the fields and verges causing contamination in the new crops.

The other aspect of oilseed production which has come to the fore in recent years, is the value of the seed meal, after oil extraction, for feeding to animals. Livestock numbers in the EEC are so great that their demand for protein feed far exceeds available home production. The necessary imports to support this sizeable herd amounts to about 25 million tons of soya products, of which 15 million tons are meal, each year. This makes Europe the largest market for soya outside the USA.

Feeding trials with oilseed rape meal have shown that in its unimproved state, it does not substitute directly for soya meal. The rapeseed contains glucosinolates, which break down by enzyme action to form isothiocyanates and nitriles. These glucosinolate breakdown products are the pungent factors found in the seeds of other brassicas such as mustard and, of course, give that desirable flavour which we seek when applying mustard to our food. However, these pungent chemicals in the rapeseed meal are not beneficial if the meal forms a significant proportion of the whole diet. Particularly when fed to pigs and poultry, the rapeseed meal has been seen to cause enlargement of the thyroid and reduction in feed intake. For this reason, the unimproved seed meals produced in this country can only be added to dairy cow rations at a rate of about 8%. If the level of glucosinolate in the meal were low or zero, this inclusion rate could be raised, but more significantly the seed meal could then also be used in pig and poultry rations[8].

There are two ways in which these anti-nutritional factors can be eliminated: one, by heat-treating the seed during processing and oil extraction to destroy the myrosinase enzyme; and secondly, by removing the glucosinolates from the seed by plant breeding. The first method, though effective, can fail due to variations in the processed sample, and there is a risk of re-introduction of the enzyme to the meal after processing. In the long term, therefore, the second method is favoured, as this will ensure the production of a constant supply of low glucosinolate material with no risks, once the appropriate varieties have been introduced.

Plant breeders have now perfected a number of low erucic varieties, which have also a low level of glucosinolate. These are designated double low or double zero. Only one company is planning to market a double zero winter variety for sowing in 1979. Called Glumander, it is likely to be more expensive to buy and will possibly yield as much as 30% below single zero varieties. Unless there is a strong preferential demand for the new rape by the processors, it will not command a premium, so rival seed companies will watch its progress, or lack of it, with some interest[9].

The variety Primor is now the most popular single zero variety grown in Britain. It was developed at Rennes in France and was bred from a Canadian variety, Canbra, using a technique called cytoplasmic male sterility. This method is also being used to improve the Polish spring variety, Bronowski, which is very low in glucosinolate. Preliminary testing of some rape varieties by the National Institute of Agricultural Botany (NIAB) show Primor to have a yield index of 109, the newly introduced Quinta 110, and the original French Lesira 93. The only commercial double zero variety tested, a spring type called Erglu, scores 92. By contrast, the unimproved variety, Rapol, which is not low in erucic nor glucosinolate, scores 114[10]. It is apparent from these indices that attempts to improve the quality of the crop initially, at least, show a negative correlation with yield. (See fig. 3.)

Direct introduction of the Canadian double zero varieties is no solution to this dilema, as they are all spring varieties suited to

Fig. 3

NIAB Yield Index Figures for Oilseed Rape, 1978 (from ref. 10.)

WINTER VARIETIES		
	Yield 100 = 2.61 t/ha.	Oil Content %
Low Erucic Acid High Glucosinolate		
LESIRA	93	43.6
PRIMOR	109	44.6
QUINTA	110	44.1
High Erucic Acid High Glucosinolate		
RAPOL	114	45.3
SPRING VARIETIES		
	100 = 1.55 t/ha.	
Low Erucic Acid Low Glucosinolate "Double zero"		
ERGLU	92	42.3
DUPLO	96	42.9
Low Erucic Acid High Glucosinolate		
CRESOR	108	40.4
MARIS HAPLONA	101	41.0

the extensive, low input agriculture of the Canadian prairies, yielding only about 12 cwt/acre[8]. This is equivalent to an NIAB relative yield index of about 80.

The quality of rape oil in France is something of a major health issue, and there has been strong consumer opposition to the product, which often appears in the shops as an unblended oil for salads. This concern dates from the use of unimproved varieties with high erucic acid levels, but now French authorities would like to see the product renamed to establish a clear difference between the original rape oil and the improved low erucic product now on sale. The consumption of rape oil in France fell from 100,000 tonnes in 1973 to 40,000 tonnes in 1977, such was the strength of feeling among consumers that the oil was not safe. Italy, too experienced a similar drop in consumption, which fell from 200,000 tonnes in 1971 to 21,000 tonnes in 1975[1]. An inter-professional organisation for the oilseed industry in France, ONIDOL, is working on restoring the image of rapeseed oil as a wholesome product.

At a seminar in Brussels organised by the EEC commission in April 1978[9], research results from Europe and Canada were discussed. These established that the low erucic rape oil was indistinguishable from groundnut, sunflower or soya oils in its effect on human health. While there might be something to be said against too much fat in the diet by consuming groundnut, sunflower or rape oil, it was concluded that there are no grounds for allegations of a specific health risk for rapeseed oil now that low erucic acid varieties are so widely used.

The seminar concluded that: "The research which has been carried out shows that rape oil used in normal doses has no effects which differ significantly from those of other oils."

2. Agricultural Aspects.

From the farmers' point of view, rape has many points in its favour, not least of which is that it is a valuable cash earning crop, able to produce a good margin of profit if properly handled. It appeals to the cereal grower as a break crop, providing an interruption of the disease build up which is seen in intensive cereal cultivation. The prostrate growth habit of the crop provides natural smothering of the broad-leaved weeds, and gives an opportunity to control grass weeds such as wild oats and black grass.

It is becoming increasingly apparent to farmers that the rape plant has a deep tap root which develops soil structure and aids drainage, leaving the land in good condition for a following crop. The early harvest date of rape, usually July or early August, leaves good time for seed-bed preparation for winter cereals, and takes the pressure off the post harvest work-load associated with cereal cultivation. Having said this, the winter crop must be drilled in the last week of August or first two weeks in September, which means, ideally, that it should follow a winter barley in a cereal rotation[11]. Drilling the crop after the end of September will result in poor establishment and insufficient growth for over-wintering. Many farmers are using a direct drilling technique with zero or minimal cultivations, but conventional stubble cultivations followed by a coulter drill are also quite adequate[25]. Rape will not do well in soils of pH below 6, nor in soils which tend to dry out or are badly drained. A final plant population of 100 plants per square metre is desirable, which means 6 plants per 30 cms in 18 cm rows. To achieve this, a seed rate of between 8-10 kg per hectare is needed, depending on seed-bed conditions and seeding technique used.

It is particularly important to use new, breeders' seed every year, as the oil quality of seed saved from a commercial crop will deteriorate even in one generation. Saved seed may produce a crop with a high erucic oil content, even if the parent crop was a low erucic variety. This is caused by cross pollination with wild progenitors of the brassica family, ie. charlock, or with degenerate rape plants in hedgerows from previous crops.

Nitrogen is a key nutrient for the crop. 40-60 kg/H (30-50 units/a) is a good seed-bed application for the winter crop, with a similar dressing of P+K at the same time. According to the quality of the soil, 125-225 kg/H of N (100-180u/a) can be applied in the spring as early as February or March. A split dressing is possible on lighter soils where the N may be rapidly leached if single high dose applications are made. But the advantage is lost if excessive wheel damage occurs. It is important to ensure even application of these heavy nitrogen doses, as any striping of the crop will result in uneven ripening and subsequent harvest difficulties. There are a number of chemicals available for weed control in winter rape, details of which are shown in various trade publications and the ADAS (Agricultural Development and Advisory Service) leaflet on rape, No. 76[12]. Recommendations vary according to soil type and weed species which predominate. A high incidence of runch charlock or mustard can cause problems in the crop, as the seeds of these wild members of the brassica family to which rape belongs contain very high levels of erucic acid which can contaminate the harvested seed. Unfortunately, weed killers are not sufficiently selective to eliminate these weeds from an oilseed rape crop.

On the question of pests and diseases of the plant, there are several, notably: flea beetle, pollen or blossom beetle, and the seed weevil. The damage done to the flower of the plant by the pollen beetle is now thought to be of little significance,[13] as trials at Rothampstead experimental station in Hertfordshire have shown that only with 50% destruction of buds was there a significant yield drop. This character of the crop to make compensatory growth after insect damage is of great value to its success as an agricultural crop. Seed weevil can also be tolerated to some extent, as it has been observed that if 25% of the pods are affected, yield loss is only 5%, as each weevil eats only one seed, of which there are many in each pod.

The most potentially damaging pest is the pod midge, the larvae of which usually develop late in the season, by which time the crop cannot make compensatory growth. This pest played a large part in the reduction in profitability of oilseed rape in France. After a rapid expansion in rape growing in the early 1970s, there was an equally rapid build up of pests, particularly pod midge and seed weevil. Yields in France dropped from 3 tonnes to 2 tonnes per hectare and many farmers switched to sunflower cultivation to provide a break from these insect pests.

Trials are in hand to deter these pests by trapping the adult, using synthetic mimic smells to lure them away from the growing crop, a technique known as trap-cropping. Suitable chemicals are available to control these pests, but many are dangerous to bees which are vital to the pollination of the flowers, so care must be used when applying these sprays.

Some diseases of rape can be borne by other crops, such as club root in brassicas, canker and sclerotinia. These can become a problem if the crop is grown for several years in the same field. Risks of many of these diseases can be reduced by ensuring a three-year gap between brassica crops and effective destruction of crop residues to prevent over-wintering of the disease organism.

Harvest of the winter sown crop can start in late July; direct combining is possible but swathing or windrowing the crop is preferred. A windrower will cut the crop just before maturity to allow final ripening to occur in the swath. A tall stubble should be left to allow air to circulate around the swath, which can be combined within 7-10 days. Windrowing can be carried out when the seeds from the middle of the plant are brown, but direct combining must be done only when the seeds are black. If the crop is left too long and becomes over-ripe, there may be excessive seed loss due to pod shattering. A conventional modern combine can successfully harvest rape if the appropriate adjustments are made to the sieves and threshing drum speeds.

The seed if damp at harvest will deteriorate in store, so drying of the crop is essential. Damaged seeds will cause rapid rancidity and mould to develop, so the harvested sample must be cleaned and dried down to 8% moisture before storage.

The production of oilseeds is encouraged in the EEC by the Common Agricultural Policy. Each year a target price is set and deficiencies between this and the market price are made up to the grower using European Community funds. Owing to this price support, rape is a profitable crop to the UK farmer. A gross margin analysis for oilseed rape production in 1977 (see Fig. 4) shows an output per acre of about £160 and total variable costs at £45, giving a gross margin of £115 per acre. This is comparable with the margin from winter wheat.

The 1978 intervention price for rape was £188/tonne, but even with increased costs of production, the gross margin remains favourable at £127 per acre.

Current discussions amongst farmers and seedsmen are considering setting up a national development organisation for oilseeds. This could form a structure for national breeding and marketing programmes. Also, such a body could monitor contracts between farmers and processors and offer expertise at all levels of the trade.

Having shown that oilseed rape has established itself as a viable crop for UK agriculture, and, indeed, there are signs that it will continue to expand for some years yet, we may now go on to discuss the future of the crop once it has left the farm and enters the food/feed processing industry.

Fig. 4

GROSS MARGIN ANALYSIS FOR WINTER OILSEED RAPE, 1976/77

Price of crop	£160 tonne	
Yield	1 tonne per acre	
Output	£160 per acre	
Variable costs	£	
Seed	4.50	
Fertilizer	25.00	
Spray	10.00	
Contract windrow	5.00	
TOTAL:	44.50	Gross Margin: £115.50

ANALYSIS FOR 1978/79

Target price	£188 per tonne	
Yield	1 tonne per acre	
Output	£188 per acre	
Variable costs	£	
Seed	6.00	
Fertilizer	32.00	
Spray	15.00	
Contract windrow	8.00	
TOTAL:	61.00	Gross Margin: £127.00

(From: Bearman M., Farmers' Weekly, 10.3.78)

3. <u>Processing the crop.</u>

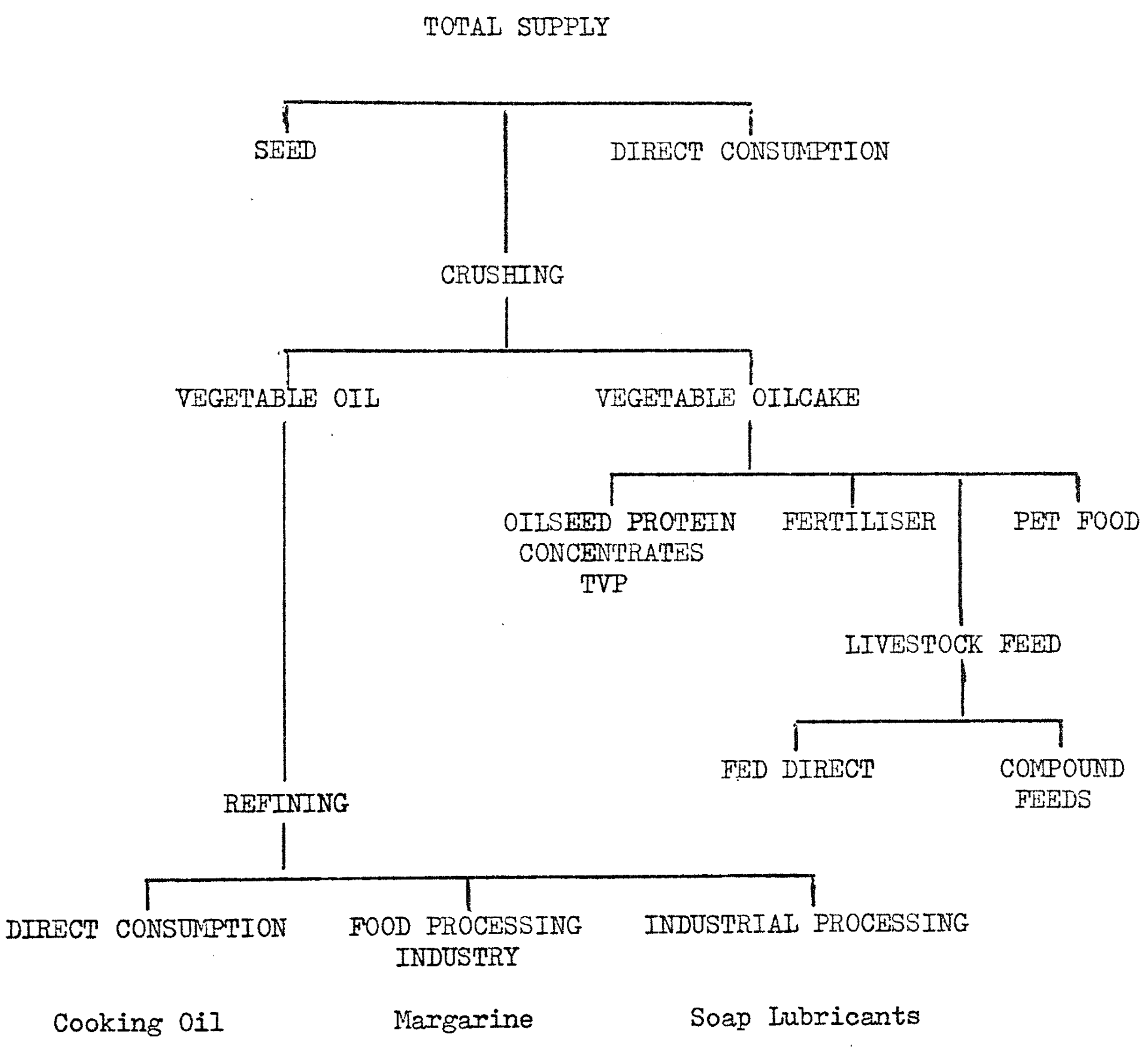
After harvest the rapeseed is sold through agricultural merchants to brokers, who arrange to store and supply the seed to the processors who are able to extract the oil for various food uses. Rapeseed contains about 40% oil, most of which can be removed by modern techniques. First the seed is crushed between rollers, then it is heated by steam, before being subjected to high pressure in a type of screw press called an expeller. This removes about half the oil and the remainder is removed by leaching with solvents. The solvent extracted oil is then mixed with the expelled oil and the product is refined to remove impurities and free fatty acids. After neutralisation the oil is bleached and deodorised, using steam to remove volatile fractions. The seed meal is desolventised and stored to be sold to the animal feed trade.

This process, described briefly, is applicable to any oilseed, and is carried out at several of our major ports by the larger oil refining and crushing companies, notably Bibby in Liverpool, Unilever at Erith near London, and Croda Premier at Hull. The products derived from this processing are refined rape oil, which can be used for frying, baking and salad oil, or be made into margarine by hydrogenation. (See Fig. 5.) The high quality of the oil and its suitability for various products, gives it a high value - up to £300 per tonne. However, the rapeseed meal, despite containing 40% protein with its residual glucosinolates, is worth only about £100 per tonne in the trade, owing to its limited application in animal feed. The introduction of true double zero varieties and their acceptance by the feed trade, would make rapeseed meal a direct competitor with soya meal, and would increase its demand in the market and profitability to the processor.

Having used as my terms of reference up until now the value of rapeseed meal to the animal feed trade, I will now try to discuss some

Fig. 5

UTILISATION OF VEGETABLE OILSEED PRODUCTS



From Parris and Ritson[1].

aspects of rapeseed meal in the context of human nutrition.

Techniques for converting soyabeans into textured protein products and flours for inclusion in baked goods have been perfected for several years now. To some extent, the limited popularity of these products is related to the almost universal predilection for meat and a suspicion of meat substitutes, which has only recently shown signs of abating[27]. Price must also be part of that choice for the consumer, as most TVP products based on soya are not significantly cheaper than meat products, except perhaps at the bulk buying and catering level of sales. Whilst some observers see these products as having "potentially limitless vistas", others feel that this type of sales potential is far from being realised and may even no longer exist[26].

Work has been done to examine the suitability of rapeseed meal as a base for textured meat analogues, to see to what extent it can play the same role as soya in this new human food market.

Jones and his colleagues, working in Ottawa, perfected a method of preparing a protein rich flour from rapeseed, low in fibre and glucosinolates. This process has been designated FR-71[14]. The product contains between 60-70% protein, with an essential amino acid profile adequate in lysine but deficient in methionine and phenlyalanine compared to FAO reference protein. (See appendix.)

Using this product, they showed that feeding rapeseed flour to rats produced characteristic goitrogenic effects of enlarged thyroid with high glucosinolate flours. But using low glucosinolate varieties, there was no obvious toxicity and a minimal effect of thyroid enlargement. Similar trials by Swedish workers using rape flour showed toxic symptoms of loss of appetite, wasting and apathy, but these were attributed to a zinc deficiency in the diet caused by high levels of phytic acid, a component of cereals and oilseeds. However, it was found that supplementation of the diet with zinc eliminated these problems[16].

A French process to purify and extract rapeseed proteins has been developed by Staron(17). It is an interesting process in that the seeds are subjected to a fermentation using a yeast micro-organism called Geotrichum candidum. Essentially, the rapeseed is fermented for forty hours at 37°C, which enables the yeast to metabolise the toxic factors present in the seeds and render the proteins soluble, making them easily recoverable by centrifugation and untrafiltration.

For the success of this process, the seed sample must be very clean and dried to 7-8% moisture. The oil is removed by solvent extraction, leaving no more than 2% of the oil in the residue. It is this residue which is fermented, adding 0.6 litres of culture to each kg. of seed meal. The fermentation is stirred by paddles and compressed air is passed through it to maintain a homogeneous mixture.

The resulting product consists of soluble and insoluble fractions, which can be treated to produce different end products. The process lends itself to the production of an isolate of high purity and digestibility, containing 90% protein. Staron shows that the protein produced in this way is of high biological value and is well suited to the human digestive system.

At this very early stage Staron says nothing of the cost of this process, but sees it as a valuable new input into the food supply system which, when thoroughly tested, may play an important role in providing plant based foods for man.

In Alberta, Canada, a plant to process rapeseed commercially was completed in 1977; original plans to incorporate into this plant a unit to produce rapeseed protein concentrate by the FR-71 process were abandoned, and at present there is no intention to develop this facility commercially in Alberta(18). Any rapeseed protein concentrate available is produced in pilot plants, either in Canada or Sweden.

LUPIN

Compared with oilseed rape, no other oil crop has shown significant promise in the UK. In recent years researchers have examined sunflowers, lupins, linseed and soyabean, but none of these are being grown commercially in this country, with the exception of linseed, which is still valuable for its drying oil used in paints.

The lupin is of interest as it has a high protein content - up to 40% - and, being a legume, will contribute to the nitrogen status of the soil due to the action of the associated nodule bacteria[19]. Its oil content is, however, only about 12%, though its composition is similar to soya oil. Of the four principal types of lupin, pearl - high in alkaloids, blue from Australia, yellow from the Mediterranean, and white, only the white variety seems likely to succeed in this country. Other types require too long periods of maturity or are susceptible to disease. A major problem has been the alkaloids found in the seed, but these are now being eliminated by breeding.

Even with the most favoured variety, Kievski Mutant, of Russian origin, there are problems with delayed and uneven ripening and some lack of disease resistance. Yields have attained five tonnes per hectare in Russia but only half this figure has been achieved in this country. The Kievski Mutant is a spring sown type, low in alkaloids, with little frost resistance; but the blue lupin can be autumn sown allowing earlier harvest, though current trials show it to produce a lower yield than Kievski.

The innoculation of the crop with rhizobium bacteria is thought to be of some value in promoting healthy nodulation and root growth. Dessication of the mature crop is of some value in producing even ripening of the pods. Combining of the crop can be carried out using a suitably adjusted conventional machine, but care must be taken to set the reel correctly, as the pods are very susceptible to shattering when ripe.

The seed company, Hursts, in conjunction with Reading University and the Wolfson Foundation, have been running country-wide trials on new lupin types. Crossing of productive lines in this breeding programme seems to have resulted in an increase of pods formed on the branches of the plant, but a greater uneveness of ripening of these pods.

So far, it would seem that the problems of maturation and yield must first be overcome before commercial introduction is possible. Even then, the seed contains little oil at 12% and this is not competitive from the processors' point of view. The outlook on this aspect seems poor, as low oil content appears to be positively correlated with early maturity[20]. Of course, lupins can be grown on poorer, lighter soils, and require less nitrogen fertilizer due to their leguminous character, but at present the crop remains in the hands of the plant breeders and on trial plots in the fields of sympathetic farmers.

LINSEED

Linseed is the only oilseed crop traditionally grown in Britain. It has been cultivated for its fibrous stem as well as its valuable seed oils used in the manufacture of paint, inks and putty. The seed meal residue was always favoured by stockmen, who found it had a beneficial effect on the health of animals. However, since the mid 1950s, the crop has become uneconomic due to poor yields and the UK relies upon imported linseed.

In 1975 an EEC subsidy was introduced to support the price of this crop, making it an attractive proposition to the UK farmer. In 1976 about 6,000 acres were grown, showing a gross margin of between £60-£80 per acre, based on yields of 0.75 tonnes/acre and prices, with subsidy, of around £150/tonnes[23]. Problems of the crop are high seed costs, up to £30/acre, and late ripening - some fields were not combined until December, when the fibrous stem makes harvest difficult. The price, it seems, is very changeable, as is the yield, and the subsidy payment is not calculated until after harvest, so this makes the prospect for farmers a little uncertain. The 1977 harvest price was about £100/tonne and the acreage subsidy announced only recently was £24/acre, and as many farmers achieved a yield of only 0.5 tonnes/acre last year, they will not profit from the crop[(22)]. In 1978 the subsidy was about £60. Some observers think that a subsidy of £100 is needed to attract farmers to the crop in future years.

The most popular variety grown is Antares, marketed by Twyfords Seeds Ltd. This cultivar was bred in France, where the largest acreage of linseed is grown in the EEC: about 60,000 acres last year. The crop does serve as an effective disease-break in a cereal system and is relatively easy to grow.

Harvest and storage pose some problems, as the seed is very small and light and runs very easily. This can lead to losses in the field and in transit. Safety experts have also pointed out that a storage bin full of linseed, unlike wheat, will not support the weight of a man, and there is a real danger of sinking into the stored seed and suffocating.

There is uncertainty about the future of this crop in the UK, as its profitability is entirely controlled by a rather unpredictable subsidy, and consistently high yielding varieties are not available at present. Most of the crop is grown under contract with the company who supplies the seed.

SUNFLOWER

The sunflower, a plant known to many only for its large yellow blooms, became economically more significant about forty years ago when

Russian plant breeders began a programme of research to improve the crop. The original seed contained only about 25% oil and had a thick hull which made up 40% of the weight. Modern varieties contain up to 40% oil and thinner hulls contribute only 25% to seed weight.

The USSR currently produces half the total world output of ten million tonnes of sunflower seed, and in 1964 was producing 70% of a world output of 7.3 million tonnes. The growth of the crop outside Russia is attributed partly to that valuable breeding work done in the early years, but is also due to the increasing awareness of nutritionists of the high quality food value of sunflower oil, and this is reflected in an increasing demand for this product in the Western world.

The problems of adapting this crop to UK conditions are similar or greater than those discussed for other oilseeds. The growing period for most varieties is 18-20 weeks, and there are really only 16 weeks in a British growing season. Plant breeding work in France has produced some productive varieties for that part of Europe, but they do not grow very well in England.

Our more humid climate increases the risks of rotting diseases like botrytis, and resistance to such fungi must be incorporated into UK bred plants. The lateness of ripening of the flower head means harvest must be delayed until September, which in this country is usually a period of deteriorating weather. Workers at Twyfords have noted that the damp seeds and head can be harvested, but often there are large amounts of damp spongy material from the seed head which must be removed before the seed is dried. These post-harvest operations add greatly to the costs of production.

About seventy acres of sunflowers were grown in 1977, thirty-five acres in Suffolk and thirty-five acres in Sussex. Yields were poor, and only the help of a £1,500 development grant prevented farmers from losing money on this venture[24]. Most of the acreage in Sussex was grown by farmers who a few years ago were involved in the effort to develop grain maize as a UK crop. The crops were drilled in April in 45 cm rows and were not seriously checked by frost. The most popular variety was a French hybrid called Fransol. Birds caused some problems in small fields and botrytis was controlled using chemicals. Harvest was brought forward a little by applying a dessicant to the crop using a chemical used for potato haulm destruction. However, the moisture content of the harvested sample was about 30% - much too high for safe storage; so considerable costs were incurred in cleaning and drying the crop. Harvest itself can be carried out using a conventional combine, but some modification of the reel and cutter bar is essential to prevent excessive seed or head loss from over-ripe plants. The planned three year trial in Suffolk has now been abandoned after only two years, the participating farmers feeling that it is not economic to continue to grow sunflowers with the varieties at present available.

Trials carried out by Leeds University in 1977 and 1978 assessed the effect of growth retardant chemicals on sunflowers. Plant height was reduced, which could facilitate easier spraying of the crop with pest and weed control chemicals. Also high density plots sprayed with growth retardant matured two weeks earlier than plots at normal plant spacings. These results must be viewed with caution, as they were obtained on small, hand-tended plots and may not be repeated in a commercial operation[33].

The seed is worth about £200/tonne and a yield of 1 tonne/acre of seed containing 40% oil could bring a return of £200/acre. The type of crop which may finally succeed in the UK will need to be shorter to avoid lodging, about 100 cm in height; it must have a good oil yield, around 45%, and must mature within about 115 days of sowing. A hybrid with these characteristics, provided it had the necessary disease resistance, could be very profitable to the UK farmer.

Some trials have also been carried out in the north of England and Scotland on the value of sunflowers as a forage crop for silage making. This obviously involves cutting the whole crop before flowering and conserving the immature plant as winter fodder for animals[31]. Results showed the crop to be useful for dry matter production in regions where the potential for seed production is zero.

The sunflower seeds, once harvested and dried, are bought by brokers for distribution to the oilseed crushers. Modern equipment now installed in UK oil mills will successfully remove the fibrous hull from the seed. This hull has considerable calorific value when burnt, and in Russia these husks provide fuel to raise steam for the crushing process. In Canada the husks are compressed into briquettes and sold as solid fuel[29].

Once the seed is released from the hull, it is processed in a similar way to other oilseeds, and the crude oil is often dewaxed by a refrigeration technique. The seed meal contains about 40% protein and could be used in the manufacture of TVP type products. The oil itself is highly valued as it is high in poly-unsaturated fatty acids (PUFAs). The poly-unsaturated fats are thought to reduce cholesterol levels in the blood and in this way combat degenerative heart disease. The high level of 18:2* linoleic acid, 68%, is exceeded only in safflower seed oil, which contains 77%, while soya bean oil has 56% linoleic. 18:3 linolenic acid is very low in sunflower oil, which gives it good stability and long shelf life. A high 18:3 linolenic component makes an oil more prone to auto-oxidation and development of rancidity.

Interest in the high 18:2 oils associated with the idea that they combat heart disease, is shown by the introduction in 1978 of the new margarine, Gold Crop, which claims a 60% PUFA content due to the use of safflower oil[28]. This is even higher than the sunflower oil based

* 18 indicates number of C atoms. :2 indicates number of double bonds.

margarines like Flora.

With the Western world becoming increasingly concerned with the quality of the fat in its diet, the share of the market taken by the high PUFA oils like sunflower is likely to become even larger in the future. Our present requirements for sunflower oil are provided by importing the crude product from the Eastern Bloc countries and refining it in Britain.

SOYABEAN

The soyabean is the major oilseed in world production, accounting for over 50% of total output. Its cultivation is at present principally in USA, China and Brazil. Attempts to breed varieties suitable for northern Europe have so far not met with success.

Varieties of soyabean which have been grown in Europe have produced very low yields, about half the 1 tonne/acre which would make the crop economic. The only commercial cultivation of soyabeans in Europe is in south west France, where about 10,000 acres are grown. The lower yields are basically associated with the significantly lower summer temperatures in Europe. Soya will not grow successfully unless the spring temperature is above 13°C, and summer temperatures above 19°C. The problem of yield and summer temperature is well illustrated by the example of a 12 acre plot of soya grown in Essex in 1977. Using A Canadian variety, Altona, drilling the crop in May to avoid frosts and using an innoculation of N fixing bacteria, the crop was not ripe enough to harvest until 28 September and the yield was disappointing[21]. The low growth habit of the plant can make harvesting difficult and the lowest pods may not be collected by the combine[30].

Breeding work in France at the INRA station at Montpelier is continuing, but as yet no great improvements have been made over North American varieties like Amsoy. Hungarian seed seems to be a little higher yielding and earlier maturing. The lifelong work by Dr. Holmberg in Sweden has resulted in the best-known variety in the UK, Fiskeby V. Introduced in 1969, it has a notoriously variable yield and is not easy to harvest, though it does mature earlier than the French bred cultivars. The earliness of maturity in Northern Europe is connected with day length insensitivity. American varieties are sensitive to short days and when grown in Europe tend to flower very late; an important part of the work by Holmberg was to breed out this day length sensitivity to permit earlier flowering.

A German variety called Caloria is said to have overcome the problem of low pods, as the minimum pod height is 12 cms from the ground. The Russians, too, are growing soya in Sakhalin, an island in the Bering Straits at a similar latitude to Northern Europe. When Holmberg began his work forty years ago, he obtained cold tolerant varieties of soya from this region to begin his plant breeding work in Sweden. The station at Fiskeby near Norrköping in southern Sweden is now owned by Weibulls, a plant breeding company who have a joint breeding programme for cereal development with Hursts in Essex.

At the moment, it is fair to say that there is no commercially viable variety of soyabean suitable for UK agriculture. Even if a new variety were to be developed, it seems likely that it would be grown only in the southern warmer regions of the UK, and that significant introduction of this crop is distant and will be seen in Southern Europe before it appears in this country.

CONCLUSION

It is established that the UK is a net importer of oilseeds, seed oils and seed meals, also that governments of EEC countries are concerned at what they see as an over-dependence on soyabeans from the United States as a source of feed for a large livestock population.

Economic backing, in particular from EEC funds, has initiated a renewal of interest in UK grown oilseeds. Developments of this type at governmental level have contributed to a situation of forward looking research in plant breeding, bringing some of these measures into agricultural practice. Oilseed rape has now become not only a valuable break crop but is a valuable cash crop too, and could even become more profitable than cereals.

Whilst oilseed rape is seen as a successful crop with a fast expanding acreage which may well reach half a million acres by the mid 1980s, other oilseeds are far from the point of commercial success in the UK. Lupins, even with their reduced alkaloid levels and nitrogen fixing capacity, do not yield reliably, nor do they contain enough oil for economic commercial extraction. Sunflowers, though producing a high quality oil and seed meal, will not ripen well in English summers, and soya seems ill-suited to our climate, despite sustained breeding work to adapt it to North European conditions. Success has been seen in France in the cultivation of sunflowers and soya, and there is interest in the lupin in Holland. But as yet none of these crops has done well in Britain. Current opinion puts the prospect for the introduction of sunflower, lupin and soya some years into the future, by which time improved varieties may bear economic yields under UK conditions. Until that time, these crops will remain on the fringes of agriculture, in the hands of farmers who like to experiment with new types of crop. Success, too, is only likely to come with good conditions and a high level of management, as this is the only guarantee of economic yields.

5

COMPARISON OF NOVEL FOOD PRODUCTION SYSTEMS

In this chapter it is intended to compare the three chosen food production technologies by a systematic evaluation of each process. Where direct comparison is possible, as with energy and cost analysis or nutritional value, this will be done, but there are areas significant to each technology which may not have an equivalent in the others, and mention will be made of such aspects so that an overall comparative picture may be seen. The discussion will be based on five main topics common to each production system:

1. Technical feasibility.
2. Energy efficiency.
3. Economic efficiency.
4. Nutritional value.
5. Political aspects.

1. Technical Feasibility

The technology of the production of single cell protein is both sophisticated and advanced. Indeed, the imminent start up of ICI's Pruteen venture at Billingham and BP's extensive development of an SCP production system prove that at the very least there exists a high level of technical feasibility.

BP's research programme goes back 20 years, and ICI similarly have evolved their SCP technology over a long period of careful and exhaustive laboratory and pilot-scale tests. The result of such long term involvement in a project has meant that several different formulae of success have been examined and only those with a good chance of performing to a high standard have been retained for further development.

Some evidence of this is seen in the efforts of other companies examining different routes for SCP production. Shell in particular were unable to perfect the methane route, and as it was too late to join the race with ICI and BP, they dropped this project.

Programmes to develop human food products have also run into difficulties, though this may be caused by the high cost of establishing the safety of such a novel product which may have only a limited market penetration. Rank, Hovis, MacDougall set out to produce a human food grade fungal SCP product. It was based on a slow growing fungus and a starch substrate, which would have been expensive to produce and license for what may have been a comparatively small money making venture for the company. It is reasonable to assume, however, that the technology was developed to a pilot scale and the process patented before development work was suspended.

Similarly, the Exxon-Nestlé project in Switzerland was shelved due to the high cost of development of a product for which there is no great demand at present. But here too it was the cost and inappropriateness of the product and not the shortcomings of the technology which halted the work. The only commercial success in this field has been the Amoco "Torutein" project; here the high cost of production has been recouped by directing the product into specialised applications where it can command a high price.

One area in which fermentation technology has not yet been perfected is in the recovery of protein from organic effluents. Research on this topic has been carried out on many different wastes, both industrial and agricultural, and only now are pilot applications becoming common. Tate and Lyle are active in this area and seek to provide an effluent upgrading service which will recover SCP from any factory waste waters. Perfecting this type of technology is more difficult, as the wastes are not always consistent and small changes in pH or carbohydrate level could destroy the nutrient balance of the fermentation with unpredictable results.

Leaf protein production is not a fully developed technology at this stage. Whilst individual pioneers have established the possibilities of this process using essentially back yard technology, only a few attempts have been made to construct commercial scale plants for forage fractionation. Most of these plants have been based on adapted existing machinery or scaled-up equipment for laboratory sampling, and neither have produced satisfactory results. Despite the support of the United Nations International Biological Programme which terminated in 1974 and the recent interest shown by Unilever, leaf protein production has yet to be given the necessary boost which could put it onto the market. Opinions differ as to the best application of the process. Charitable organisations like Meals for Millions are trying to establish a village scale industry for leaf protein in India[1], whilst multinationals like Unilever seek to develop a high technology/ high output system as an adjunct to developed agricultural practices.

Government-backed research is going on at several centres in the UK and much information is becoming available regarding optimum requirements for the success of a forage fractionation industry. The Rowett Research Institute in Aberdeen is looking at on-farm systems; the Grassland Research Institute and Reading University are evaluating suitable crops and their management. The National Institute of Agricultural Engineering and Rothampstead have looked at small scale processes for the developing countries.

In a report published by the Grassland Research Institute[2] regarding forage fractionation, part of the conclusion states:

> "The equipment used for pulping, pressing, separating and dewatering is at present poorly developed for use with green crops. It seems that research at a fairly basic level, leading to equipment with new working principles, rather than to the adaption of existing machinery, would be the most appropriate."

Here perhaps lies the crux of the matter, that some kind of rethinking of the equipment is necessary before further progress can be made.

Agriculturally, oilseed rape is a new and popular crop, grown on an increasing acreage every year. The demands of the food and feed industries have modified the quality of that increase by insisting on the use of improved varieties which are low in anti-nutritional factors though not necessarily high in yield. The change to the improved types is slow, and plant breeders are working to incorporate good yield with quality and disease resistance. The problem may not be one of whether success can be attained but whether it can be attained fast enough. It is currently felt that commercial varieties of true double zero winter rape may not be available before 1985[3], yet Canada has already developed such varieties and are beginning to export them to the UK. So on a purely technical level there are no problems, indeed Downey[4] believes the rape plant to be very adaptable to the needs of the plant breeder, but the necessary European varieties will not be on the market in advance of the Canadian exports.

The oilseed processing industry is already a developed one, albeit based mainly on the soya bean. A modern oilseed crushing plant can be adjusted to deal with most types of crop, so the increased acreage of oilseed rape, or indeed the complete dominance of the crop in the UK oilseed industry, would not pose serious drawbacks to the processers.

A note of caution is sounded by Weigand[11] who points out that whilst double zero varieties of rape are an important step to solving the problems of toxicity and palatability, residual glucosinolates and their degradation products can still impair full flexibility of the use of rapeseed meal. Chemical and physical techniques of detoxification will therefore still have a role to play. The improved varieties of rape, low in glucosinolate and erucic acid, provide rapeseed meal which could readily be absorbed into the animal feed industry, replacing soya; and rape oil which can be used in all culinary applications. In the production of textured foods rape meal is not so adaptable, though there are techniques for producing flours and isolates of value to the food industry. The technology also exists to produce textured products from rapeseed, but it is expensive and could only be practical if advances were made in the earlier extraction processes to improve the quality of the protein.[5]

The technical aspects of cultivation of other oilseeds in the UK are limited by the climate. A combination of plant breeding and chemical treatments have not yet succeeded in producing varieties which will grow to maturity in Britain except in regions with the most favourable climate.

2. Energy Efficiency

The efficiency of a food producing system can be estimated by measuring the amount of energy needed to produce a unit of product or protein. The value of such a technique is discussed by Slesser (1973)[6]. He shows the energy subsidy needed for different food products and argues that the greater the subsidy, the less appropriate the production system to a less developed country. Updating this to the post-1973 era of diminishing energy resources, this argument could equally be restated as a case against the adoption of energy intensive food production systems in any country whether more or less developed.

It is important, therefore, to examine our novel food production systems to see to what extent they are more or less energy intensive than existing systems. It is not easy to do this, as different workers in different countries have examined different novel systems using different units. An attempt has been made to collate the published material to establish some idea of relative energy need for different novel food products. These are shown in Table I.

Here it can be clearly seen that of the systems reviewed, the production of SCP from paraffins is the most energy intensive process at 195 MJ/kg protein; similarly intensive are the other hydrocarbon based SCP products. Most of the estimates for this type of process have values in the range of 150-200 MJ/kg protein produced.

SCP products based on carbohydrate substrates have a lower energy requirement, the more moderate values of between 70-80 MJ/kg protein for existing systems reflect the lower energy value of the substrate.

Leaf protein production systems have been shown to have gross energy requirements of around 60-65 MJ/kg protein for production of similar grade products to SCP.

All these values are for producing animal feed grade outputs.

TABLE I Gross Energy Requirement for a range of protein products

PRODUCT	GER MJ/kg protein
Yeast - N. Paraffin	
(B) Leach	195
(D) Lewis	186
Bacteria - Methanol	
(F) ICI	175
(B) Leach	170
(D) Lewis - actual	146
potential	139
Bacteria - Methane	
(D) Lewis	163
Yeast - Molasses	
(D) Tate and Lyle Citrus waste	80
(D) Lewis - actual	76
potential	62
Leaf Protein	
(F) Bruhn USA	65
(G) Lewis UK	61
Soya Protein Concentrate (F)	43
	MJ/kg product
(C) US Soya Meat Analog	22
(C) US Beef production	88
(B) UK Broiler, Leach	60
(A) US Can of Corn	20.2
(F) US Soya Beans	10
(B) UK Field Beans	4.5

(A) Brown, S.J., and Batty, J.C. Energy Allocation in the food system, a microscale view.
Transactions of the American Society of Agric. Eng. 1976, p.758.

(B) Leach, G. Energy & Food Production, II ED, 1975.

(C) Henig, Y.S., and Schoen, H.M. Food Engineering International, Sept. 1976, p. 48.

(D) Lewis, C.W. Report No. 2 to SARV, 1975.

(E) Bruhn, H.D. On Farm forage protein. Proceedings of Institute of Agricultural Engineers conference, May 1977.

(F) ICI. Personal communication. A.E. Rout. Jan. 77.

(G) Lewis, C.W. Report No. 10 to SARV, 1976.

The necessary processing for nucleic acid removal or purification for human use could add up to 50 MJ/kg to the energy requirement for methanol or paraffin based products[7]. There would also be an added energy requirement to leaf protein if it were to be processed into a form suitable for human use. Lewis points out that only about 30% of leaf protein would be acceptable for food use.

The figures for the production of soya meat-extender product are based on American work and would seem to show a big advantage in energy use compared to SCP and LP. However, the values are per kg of product and not of protein. Assuming a 20% protein content, a GER of 110 MJ/kg protein is evident, which would still place it below SCP. It should be said, however, that such a comparison between unlike products is somewhat problematic.

It is interesting that the same American workers established that beef production is four times more energy intensive than textured soya protein production. In fact, the energy requirement of soya meat-extender would seem to be no greater than a can of sweet corn when calculated on a weight for weight of product basis.

3. Economic Efficiency

The efficiency of a food producing system may also be estimated by measuring the economic value of the end products. This type of information is not easy to obtain, as by their very nature novel systems of food production are not yet a part of the market structure. However, several predictions have been made of the likely prices of SCP, LP and oilseed products.

A recent review by Litchfield[8] showed the market price for a range of protein products in 1976. It shows in table II that the highest prices are commanded by food grade SCP products, notably Amoco's Torutein. The next most expensive items are the food grade soya isolates and

TABLE II

Selling Prices of a range of Protein Products

	Protein Content %	Price US $/kg	
		Product	Protein
FOOD GRADE			
SCP PRODUCTS			
Torutein (Amoco)	52	1.1	2.1
Sulfite Liquor	52	1.0	1.8
Brewers Yeast	52	1.0	1.9
SOYA PRODUCTS			
Soya Concentrate	70	0.75	1.1
Soya Isolate	90	1.6	1.7
FEED GRADE			
SCP PRODUCTS			
Toprina (BP)	60	0.45	0.75
OTHERS			
Fish Meal	60	0.42	0.7
Soya Bean Meal	44	0.2	0.42

From LITCHFIELD (1977)

concentrates. Feed grade SCP like BP's Toprina and fish meal are next, with the cheapest protein source being soya bean meal.

The very high production costs of food grade SCP products are incurred because of the need for high standards of hygiene and product surveillance - the process and product must be constantly monitored and extensively tested before being accepted for food use.

The market price which these protein products can command is a function of their production costs, protein quality, the specificity of their role and the likely market share which they could gain, either by displacement of existing ingredients or creation of new products.

The theoretical economic analysis carried out at the Grassland Research Institute mentioned in Chapter 3 (ref. 18) looked at different systems of forage fractionation. The sale of the products, leaf protein and forage was based on their value as sources of feed energy or protein, which does not give a favourable return on capital. This may explain why in France and in America the economics are more attractive, as the leaf protein concentrate commands a premium price, due to the pigments in the product which produce a desirable yellow or golden fleshed bird when fed to broiler chickens. The British preference for white fleshed birds means that no such premium is offered for LPC in this country. It is apparent that the economic aspects of leaf protein production are not favourable to its adoption in the UK at present due to the high investment costs necessary for such limited returns.

4. Nutritional Value

The main objective of this enquiry is to assess the potential for producing food grade products; so whilst there is considerable potential for producing animal feed by novel methods, the main discussion here will revolve around products destined for direct human use.

This dichotomy is clearly seen in SCP production systems, where most projects are clearly and objectively aimed at the animal feed trade. ICI's original intentions were to market Pruteen as a component of milk substitute for veal production, but the vagaries of the veal market may alter this. There seems no doubt in the mind of this company at least that there is little to be gained from adapting Pruteen to the requirements of the food trade. The only company to seriously embark on a food grade SCP project was RHM who originally co-operated with Du Pont on this venture. Spicer, the then director of RHM research, was strongly in favour of the idea for several reasons. The process was based on a filamentous fungus of the fusarium species grown on a starch substrate; this type of biomass has a slow growth rate, which means a low level of nucleic acids on the end product. This eliminates any need for further processing as would be necessary with Pruteen or Toprina. The filamentous nature of the organism enables the biomass to be comparatively simply removed from the fermentation liquor using conventional centrifuge equipment[9]. In contrast, the tiny bacterial cells in the ICI fermentation, less than 5 μm in diameter, require advanced techniques of filtration and high speed centrifuge. The nature of the filamentous product also lends itself to the production of extruded and spun meat analogues. Yeast based SCP's have deficiencies in the sulphur amino acids, while fungal SCP's have a more balanced amino acid profile (see appendix). Spicer points out that supplementation of deficient products with synthetic animo acids is not always successful, as the supplemented ingredients may be more easily lost in cooking and less readily absorbed in the gut that a product with a naturally adequate protein profile. Spicer claims the RHM product to be the first vegetable protein to be produced which has the biological value of animal protein. This combination of filamentous structure, low nucleic acid level and good amino acid profile indicates that this type of product is the most suited of the SCP's to man's nutritional requirements.

The only other human food grade SCP is Amoco's Torutein, which is currently in commercial production unlike the RHM project. Torutein is sanctioned for human use by the United States Food and Drugs Administration (USFDA), as it is obtained from a chemically pure substrate, ethanol, and an accepted food grade micro-organism, Candida utilis. (This is sometimes known as Torula Yeast, from which the commercial name is derived.) However, it is important to realise that Torutein is marketed as a "multi-dimensional food ingredient", not as a protein ingredient as such. It is expensive and specialised in its application and is not the "fungal food for the starving millions" which was envisaged by some at the outset of SCP development.

Food grade products made from oilseeds are fairly widely used now in the form of textured vegetable protein meat-extenders derived from soya beans. There are currently no commercially produced textured products derived from oilseed rape or any other oilseed. The complete dominance of US grown soya over this type of product is attributable to the efforts of American researchers, who have developed the crop and its products to a high level of technical perfection. Not that soya meal is an irreproachable commodity, for its amino acid profile is deficient in methionine and cystine, so that textured products have to be fortified. Indeed, manufacturers recognise the quality of unfortified soya protein to be inferior to that of meat[10].

Comparative analysis of Beef, Cheese and "Unico" Textured Vegetable Protein Product

	Beef	Cheese	Unico (Hydrated)
Protein %	20	25	20
Water %	67	41	70
Carbohydrate %	-	1	8
Fat	13	29	2
Energy Content K cals	197	360	130
*Protein Efficiency Ratio	3.2	2.5	2.2

$$*PER = \frac{\text{Weight Gain}}{\text{Protein Ingested}}$$

Unilever, the manufacturer of this product, claims that there is no need for fortification as the product would be eaten with other foods which would compensate for its methione deficiency and that the supply of protein in a Western diet is more than adequate anyway. This type of product is, of course, promoted for its functional properties in processed foods and the fact that it stores without deterioration. The lower fat and calorific value makes TVP a nutritionally desirable commodity to the food processor.

Efforts in Canada and France to produce rapeseed derived food products have not met with much success. The protein derived from the Staron process where rape meal is fermented, is of a high biological value and could be added to charcuterie, soups and baked goods with satisfactory results. This process is as yet undeveloped but perhaps more will be heard of it in the future.

Leaf protein products have met with only limited sucess in trials in this country carried out by Pirie, but more extensive testing has been done in India where the material seems to be more acceptable. It may be significant that the experiment lasting two years at Coimbatore was conducted using children. Perhaps such an LP fortified diet would not be so acceptable to their parents. Humphries[12] feels that this acceptability is not a problem in Eastern diets which are normally strongly spiced, and that the flavour of LP is a disadvantage only in the West. Reports of such trials, including one in Nigeria where maize gruel was successfully fortified with 38% LPC, are discussed in a review by Bingham[13].

In order to remove the flavour and colour from the product, a process of ultrafiltration must be used which separates the protein fractions in the concentrate. There is a significant loss of yield and only about 20% of the protein is recovered in a totally bland form. This is a comparable product to oilseed and SCP isolates and is expensive

TABLE III

Protein Efficiency Ratio of a Range of Protein Products

		PER
Oilseed Products		
(1)	Unico Textured Protein	2.2
(2)	Soya Flour	2.3 - 2.6
(2)	Soya Protein Isolate	1.97
(3)	Rape Textured Protein	3.1
(3)	Rape Protein Concentrate	3.0 - 3.3
Leaf Protein Products		
(4)	LP Concentrate	1.84
	LP Isolate	2.40
	Fortified LP Concentrate	2.83
	Fortified LP Isolate	3.06
(5)	LP Concentrate	1.54
	LP Isolate	2.68
SCP Products		
(6)	Yeast	0.9 - 1.7
	Yeast + Methionine	2.0 - 2.3
	Yeast Protein Concentrate	2.1 - 2.3
	Yeast Concentrate with Nucleic acids removed and methionine fortified	3.19
	Casein	2.5

(1) Unimills Publicity literature.

(2) Roszkowski, W., et al. Nutritive Value of new protein sources in: Alimentation et Travail. 2nd Symposium, May 1974, Vittel.

(3) Cichon, R. Nutritional Evaluation of Rape Protein Concentrate. Proceedings of the 5th Int. Rapeseed Conference, Malmo, Sweden. 1978. Vol. 2, p. 147.

(4) Betschart, A.A. Leaf Protein in Human Diets. BGS Symposium No. 9, p. 83, 1976.

(5) Bray, W.J. Processing of Leaf Protein to obtain food grade products. BGS Symposium No. 9, p. 107, 1976.

(6) Lovland, J., et al. SCP for human food - a review. Lebens Wiss Technol 9, p.131, 1976.

to produce.

The amino acid profile shows a methionine deficiency in the leaf protein concentrate but this is not a problem in the isolate type product.

Table III shows some values for Protein Efficiency Ratio for various protein products obtained by different researchers. These give some idea of the value of proteins relative to each other. Casein is often used as a standard in such tests and has a PER of 2.5 in this table. As can be seen by the values, all three novel products can be improved by processing and fortification.

Political Aspects.

The introduction of any new technology or product is a process which takes a long time to reach fruition. It is certainly not something which is dependent on any single factor but may be accelerated or suppressed by a variety of events in the changing political climate.

SCP production seems to provide an example of just such a new technology which has had its share of setbacks. Conceived in the early 1960's, SCP technology was acclaimed as a new, cheap source of protein, capable of relieving the growing problem of malnutrition in the Third World and not unlikely to make a profit for the oil companies. The changing oil prices in the early 70's showed that massive profits from oil based proteins were unlikely and the first sign of difficulty in marketing the product was seen. In Japan the Kanegafuchii Chemical Co. had licensed a process for producing SCP from paraffins, but in 1973 was refused a licence to operate a plant to produce this new protein. There was growing concern by the government in Japan that environmental disaster could follow irresponsible industrial activity. The terrible Minimata disease had already crippled many people in Japan through uncontrolled disposal of mercurial waste. Similar disfigurements were to be seen in that country caused by radiation from the atomic bomb.

There was a growing awareness by the government that the new SCP products just might cause cancer through mycotoxin or hydro-carbon residues, and they were not prepared to risk taking the responsibility for permitting such materials to be produced. The reaction of the Kanegafuchii corporation was to try to build the plant somewhere else as their plans had been thwarted at home. They concluded an agreement with Liquichimica, an Italian company, to use Japanese technology to build an SCP plant in Southern Italy in 1974. This was initiated at about the same time as BP were agreeing with ANIC, the Italian oil company, to build a similar SCP plant on Sardinia. Here again a series of events built up which were to defeat the efforts of these four large companies.

First of all BP, it is rumoured, refused to enter into any irregular financial arrangements, ie. bribery of an official over a planning objection. This had the effect of angering the authorities as, it is said, such bribes are considered normal practice in Italy(14). BP were particularly reluctant to offer any payments to officials, as there were allegations in the UK of BP sanction-busting in Rhodesia, and the BL Slush fund affair was in the headlines at the time. Coinciding with these events was the Seveso disaster in Italy, in which an explosion at a chemical works had spread a cloud of poisonous dioxin over a large area. The possibilities of some kind of disaster arising from the widespread use of Toprina or Liquipron in animal feeds had not escaped the minds of the authorities.

It is not unlikely that Italian soya importers saw the completion of two large SCP plants as potentially damaging to their trade. There may have been fears that the reduced imports resulting from the SCP plants' operations might have been reciprocated by reduced olive oil exports to the USA. Also much of the pulp which remains after pressing olives to remove the oil is used in the animal feed trade. Indeed, there must have been many who saw the SCP products as having a potentially depressing effect on some sectors of the olive industry. It can only be surmised what influence this lobby could have had on events.

Additionally, Liquichima were suspected by the police of some type of misuse of the generous grants made to developing projects in Italy, perhaps even of Mafia involvement in the company's affairs. As a result, there was a clamp down on the activities of Liquichimica which resulted in the arrest of the company president in July 1978 on a charge of fraudulent use of public funds[15]. This climate of events indirectly meant the closedown of both Italian SCP plants through licence suspension based on health authority objections, the bankruptcy of Liquichimica, and the withdrawal of BP from the SCP field.

Here can be seen the cumulative effect of public opinion and a series of apparently unrelated events which have led to the closedown of both companies' operations in this field, despite their displaying a high level of technical competence in the setting up of production facilities.

The political intrigue behind the development of the oilseed crop in the UK is not as complex as the SCP story, but, nevertheless, its expansion is governed by more than agronomic factors. Perhaps the first indication that the USA was beginning to dominate world oilseed supply was the US soya export embargo in 1972. This initiated an awareness of EEC dependence on US supplies and indirectly led to the current policy of price support for oilseed rape to encourage a larger domestic supply of the crop. This has to some extent succeeded, as the UK acreage has risen by 90% since 1974, but EEC production as a whole has dropped from 537,000 H in 1974[3] to 506,000 H in 1978[16]. This decline is largely attributable to the problems in France with pests and disease, leading to a change to sunflower cultivation in 1975.

Perhaps the forces of international politics will not come into play to change current EEC policy on oilseeds unless the crop expands much further. More will be said about this in Chapter 6.

Leaf protein production has perhaps never got into full swing because no government or organisation has given it full backing. The UN supported research using Pirie's equipment for evaluation of suitable crops but at the end of that project no official development followed. A lack of certainty as to the appropriate level at which leaf protein technology should be applied has led to hesitance by large organisations to take the process into the field. Recent support by Unilever and Meals for Millions at opposite ends of the technology spectrum is still essentially of an evaluative nature.

6

THE INTRODUCTION AND EXPANSION OF NOVEL FOOD PRODUCTION

In this chapter emphasis will be placed on areas which would be of importance if all or any one of the chosen processes were to be introduced on a large scale in the UK. Having already examined the current state of technology and found a wealth of information pertinent to the production of novel foods and feeds, it is proposed to show how these basic systems may be modified by forces which would come into play only when an attempt is made to scale-up production to a significant level in terms of the nation's economy. One of the most powerful forces is that of legislation; also there are several aspects of the introduction of new foods related to their acceptability, as well as technical and economic constraints brought about by increased production.

Legislation and Safety.

There are many regulations which touch upon the use of single cell proteins in foods and feeds in the UK but few of these cover the industrial manufacture of these products for commercial use. At present the law is based upon various regulations and amendments. The Fertilizers and Feedingstuffs Regulations (1973) and their Amendments (1976) attempt to define dried yeasts and state that they are an acceptable ingredient of animal feeds. The Food and Drugs Act (1955) permits use of yeast and yeast products in human foods but controls the type of substrate from which they may be produced. With regard to hydrocarbons, there are the Mineral Hydrocarbons in Food Regulations (1966) which permit the incorporation of mineral hydrocarbons in certain foods only: in dried fruit; in chewing gum; on skins of citrus fruits; in sweets at a rate of 1/5th of one per cent by weight; in preserving eggs; and on the rind of hard cheeses like Edam and Gouda. The regulations also permit white mineral oil as a contaminant in processed foods, provided it does not exceed 1/5th of one per cent by weight of product. This is allowed as the oil is often used as a release agent to prevent foods sticking to machinery.

However, in 1975 the Food Additives and Contaminants Committee produced a Review of Mineral Hydrocarbons in Food and suggested that levels of mineral oil permitted should be halved and urged the food industry to seek alternatives.

The Food Standards Committee report on Novel Protein Foods (1974) reviewed the use of all unconventional sources of protein in food and came up with several recommendations regarding SCP products. These included the need for consultation on a continuous basis between manufacturers and the departments responsible for control measures. The report also called for safety assessment of novel proteins by independent experts and said that new foods must be brought under control by regulations when developments make this necessary; there are provisions regarding labelling and the proviso that the words "single cell" or "microbial" should not be used. It is recommended that replacement of meat by novel proteins should not exceed 30% by weight and stressed the need for control, particularly in the catering trade. Finally it was suggested that the question of novel proteins be reconsidered again within 5 years[1]. No legislation has yet resulted from this report.

It must have been a mixture of legal and human prejudice which led to the licence refusal of BP's SCP plant in Sardinia. The reason stated for refusal was that the fat of pigs fed on Toprina contained 70 ppm of N. Paraffin[2]. The level of paraffin tolerated in bread by the USFDA is 1,500 ppm, as oil is used to grease the baking tins. Ironically, other EEC countries have sanctioned Toprina for use, so theoretically if the plant had been built on Corsica for example, the French authorities would have been happy to license it and the present SCP situation might have been quite different.

There are other fears regarding SCP production apart from traces of residual substrate. The product must be guaranteed true to type and must not deviate in its analysis. Any change in amino acid profile may indicate a change in organism and a risk of toxic or allergenic by-products. The risk of mutation is also a remote but frightening one. A large, continuously operated fermentor such as ICI are operating has no precedent in any other industry, so to some extent its operation must be a step into the unknown. So important is it to ICI that the fermentor operates cleanly, that during its construction all the welding was carried out at a specialist factory in France. The fermentor was then transported in one piece to Billingham to reduce the number of on-site welds to be made. An independant company is performing a microbiological audit on the plant to ensure a clean start for the process. The presence of any stray micro-organisms may not mean a dramatic failure or the production of toxic material, but equally damaging to industry, it may mean a lengthy period of teething troubles involving complete shut down of the plant for sterilisation before restarting.

Acceptance.

To discuss the problem of acceptability of novel foods is a complex task. To be successfully marketed a new product it must be physically and economically attractive as well as convenient and fitting to the culture of the society. It must, in short, be able to compete with foods already available on the market. Examples of successful innovation of food products are fish fingers and breakfast cereals; these, however, are new products made from traditional materials. When the market for completely new products derived from new materials is surveyed, the examples are less numerous. Perhaps textured protein products made from soya have been moderately successful, but sales have not matched early predictions.

These novel proteins can be processed by animals in order to gain acceptance as foods; this is the preferred route by most manufacturers. If the novel product can be sanctioned for animal feed then the resulting meat or milk product is in a readily accepted form with none of the food processing problems associated with human food products.

If SCP or oilseed proteins are processed into an isolate product, they can then be incorporated into existing foods to improve their nutrient balance. It has been suggested[3] that the rising volume of confectionery consumed is responsible for nutritional disorders due to their imbalance of nutrients. Most snack foods are high in carbohydrate and fat and low in protein; this imbalance could be offset by enrichment with protein concentrates or isolates. This, of course, does not approach the problem of nutritional insufficiencies at its root, but raising the quality of popularly consumed foods has its merits.

Notwithstanding the hard facts of legislation, there are more human aspects to acceptance of new foods. Pirie[4] has found that the strongly flavoured leaf protein foods which he has prepared are acceptable in Eastern diets where people are accustomed to strong spices, yet are rejected by Europeans who find such a taste objectionable. Hopes that leaf protein could be incorporated into biscuits were dashed when it was found that baking tends to intensify the leafy flavour of the protein.

Psychologically too, the origins of food are important. There is a connection in people's minds between hydrocarbons and cancer which is difficult to overcome when presenting a yeast grown on paraffin to the public[20]. Many SCP's are associated with allergies too, and there are fears that these allergeric factors could be passed on to man via the meat of an animal which has consumed such novel feeds. Synge[5] of the Food Research Institute points out that any danger to man may not be detected in animal feeding trials, as their life span is so much shorter than ours. He also urges conservatism both in the choice of protein sources and in the choice of processing routes through which these foods must be passed. He suggests that oilseed meals are more likely to be successful than single cell protein in the introduction of novel foods.

Technical and Economic Constraints.

In this section it is proposed to elucidate areas where the production technologies of SCP, oilseed and leaf protein could be expanded, and place limits to that expansion.

(i) Single Cell Protein

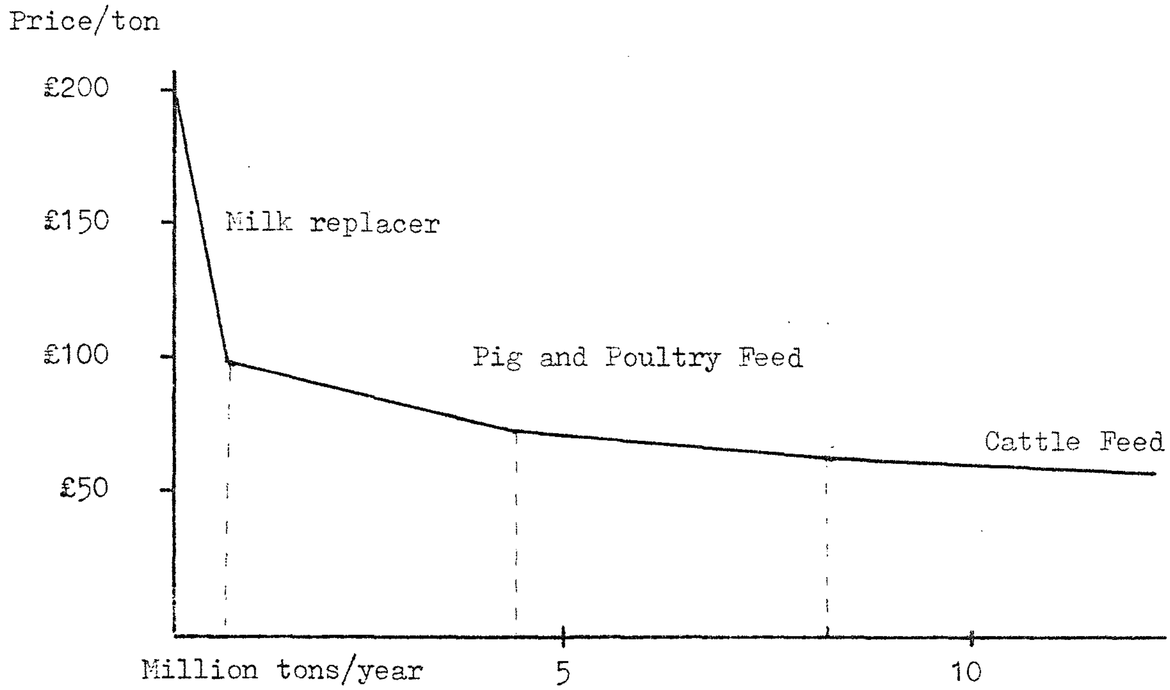
Single cell protein technology offers the greatest range of possibilities, especially in the field of effluent treatment. The latest development of this type in the UK is a project by Tate and Lyle to develop a process for SCP recovery from any dilute organic waste. A plant is being tested in Sheffield at Bassetts, the confectionery company; it will convert sugary effluent from sweet manufacture into animal feed grade SCP by fermentation. The company are currently paying £92,000 a year to the water authority for treatment of this discharge[6] [7]. So far Tate and Lyle have made no claims for the success of the process, but if it operates as planned it could be applied to many food industry effluents and could see the start of widespread application of SCP technology in this new field.

The Wolfson report on conversion of organic wastes into marketable protein[8] is an extensively researched document investigating many presently untapped effluent resources. These range from forestry wastes, to domestic refuse, sewage sludge and various animal waste products. A general conclusion is drawn that there is no reason to doubt the technical feasibility of producing SCP from waste. Also the report stresses that such conversions must be made on large scale plants; for example, domestic refuse could only be treated from a catchment of 1½ million people.

Among the many points made by the report is that the potential for production of SCP from wastes is so great that development will be limited by demand. Total production of lower grade products could reach 8 million tonnes per year, while demand for such feedstuffs is only 4½ million tonnes per year. The report goes on to say that such SCP could become a seller's market only if grain and soya prices rise faster than SCP production costs. Since 1974 this has not been the case: grain and soya prices have approximately doubled; SCP production costs on the other hand were estimated at £10 million for a 50,000 tonne plant in 1974, but ICI have paid about £50 million to construct their 70,000 tonne plant, and it is estimated that it would cost £100 million to build another(9).

Figure 1 shows the approximate volume of sales and its relationship to price per ton in the SCP market in 1974. It can be seen that above £200 per ton no sales are envisaged, and between £100 - £200 a small market is seen for SCP as a milk replacer in calf diets. Below £100 per ton, however, the market opens up, as pig and poultry diets could economically include SCP, and below £65 per ton even cattle food may contain SCP. Since 1974, of course, market prices have risen but not as much as production costs, so the market is only active in the low volume, high value, left-hand side of the graph. Recent down-turn in veal production in Europe has made the share of the milk replacer market even smaller, with a consequent reduction in sales potential.

Fig. 1 MODEL OF SCP MARKET[10]



From: Wolfson Report 1974. Vol. 1, p. 20.

The high cost of SCP production has prevented any movement of the market into the volume sales for pig and poultry diets. The optimism of the manufacturers even in 1975 is surprising; Wells[11] predicted potential world wide SCP production by 1980 to be 1½ million tons (see Fig. 2). As far as can be ascertained, the 1979 world production is only 40% of this figure and seems unlikely to expand dramatically in the foreseeable future. The mistaken optimism reported by Wells did not anticipate the rising costs of raw materials and plant which have occurred in the last five years, nor did it imagine the role that government authorities would play in shaping the development of SCP technology.

Research to improve production efficiency has led to improvements in growth rate of the micro-organisms and selection of new strains with lower nucleic acid levels. Much of this type of information is only available through patent registration, as many companies will apply for a patent as soon as a technique seems valuable; in this way any

Fig. 2 WORLD OUTPUT OF SCP PRODUCTS

	Tons 1980 - Wells' Estimate	Tons 1979 - actual*
Czechoslovakia	160,000	160,000
Finland	10,000	10,000
France BP	100,000 40,000	- -
Germany	pilot	pilot
Italy	300,000	-
Mexico	pilot	pilot
Rumania	60,000	60,000
China	1,000	1,000
Switzerland	1,000	-
Taiwan	100,000	100,000
UK		
BP	100,000	-
ICI	100,000	60,000
Shell	1,000	-
RHM	1,000	-
T&L	4,000	pilot
USSR	200,000	200,000
USA		
Amoco	5,000	5,000
Louisiana State University	10,000	10,000
US Army	10,000	10,000
Japan	300,000	-
Total:	1,503,000	616,000

* figures obtained by literature search only.

subsequently developed process will be protected from an early stage. For example, British Patent No. BP 1500 163 describes the effect of a chemical 5 Fluoro-uracil in increasing the mutation rate of yeasts; it was registered by Liquichimica, but no published information is available to say what use may have been made of this technique. Similarly BP have registered a patent concerning the mutation inducing effects of Ethyleneimine on a yeast, Candida-tropicalis.

Work by Lewis(12) examines the feasibility of producing SCP from newspaper by enzymatic hydrolysis of the cellulose to sugars which could then act as an SCP substrate. Lewis talks of a plant requiring 300,000 tonnes per year of newspaper, or sugar cane, or straw, which would yield 160,000 tonnes of sugar, which could be fermented to produce 70,000 tonnes of SCP. The gross energy requirement of such a product is over 300 MJ/kg of protein - "a distinctly unfavourable figure" says Lewis.

Zermeno(13) also discusses the utilisation of agricultural residues as a basis for SCP production. He shows the fermentation route for enzymatic hydrolysis to convert cellulose to sugar to be too energy intensive, as the straw must be reduced to a small particle size by ball milling. Zermeno's main study is of the chemical hydrolysis of straw as an SCP substrate; this is found to be less expensive than SCP from any other source.

		£/ton
SCP from straw by enzymatic hydrolysis		298
SCP from straw by acid hydrolysis -	large scale	194
	small scale	308
Direct fermentation		240
SCP from hydrocarbons		233

From: Zermeno, R.G. M.Sc. Thesis UMIST, 1977. P.

However, what at first glance seems to be a good choice of SCP route is not so favourable on close examination. The cost of £194 per ton is only obtained on a theoretical plant processing 500,000 tons of straw per year. The risks of storage and supply failure would be very high for such a plant. Present straw processing units have a capacity of only 20,000 tons per year and even on this scale transport and storage of straw can be problematic. Zermeno also points out that such a plant would generate, in addition to 100,000 tons of SCP, 155,000 tons of lignin effluent and 145,000 tons of decomposed sugars. Again the economies of scale create their own particular problems here. Zermeno concludes that the only efficient answer to the question of utilisation of such resources is an integrated approach in which all components are converted into useful products.

Goldstein(14) also proposes an integrated system for processing wood in which the cellulose and lignin are reduced to a range of useful chemicals such as ethanol, furfural and phenols.

In summary two main points stand out in the expansion of fermentation techniques into the waste treatment field: one is the sheer size of plant needed to obtain the necessary economic viability, requiring enormous catchment areas; the other aspect is that of the non standard nature of many effluents and secondary raw materials. Most proven SCP routes are based on primary raw materials of high quality. The use of residues and wastes introduces many unknown variables into the fermentation, making it much more difficult to control. For these reasons the likelihood of successful transfer of SCP technology to the recovery of protein from secondary raw materials on a large scale seems remote.

That is not to suggest that fermentation has no place in waste treatment; the most likely application is in non-food products, including the now widely reported prospect of fermentation alcohol for fuel use. Also the detoxification role of some micro-organisms is valuable in the treatment of toxins in sewage sludges, so that they can be made safe for application to the land as a fertiliser. Finally, of course, protein recovery may be an attractive proposition in some cases; this is most likely to be in the food processing industry, where large quantities of dilute effluent of relatively constant composition are produced on a regular basis. Here the cost of disposal of such effluent will be a large factor in the decision to install the necessary plant for SCP production.

(ii) Oilseeds

It has been made clear in Chapter 4 that the range of oilseed crops available for cultivation in the UK is very limited. In fact, only oilseed rape has any prospect of expansion; all other oilseed crops tried have been generally disappointing, despite interest shown by university and commercial research to find suitable plant types for Britain. The main problem with crops introduced from other regions into the UK is the nature of the climate. The climatic requirement of such crops has been quantified into a concept known as heat units (HU), whereby each day that the air temperature exceeds 10° C the number of degrees by which 10° C is exceeded is the number of heat units accrued. For example, if the air temperature reaches 15° C then 5 units are counted; then if the temperature reaches 17° C three days in a row, 21 units are added to the total. The system operates on the basis that a certain crop will reach maturity if it is exposed to a critical number of HU in a season. This method has been successfully used to identify regions suitable for growing peas and to predict the date they will attain maturity. This has been particularly valuable in making successional plantings of peas, spreading the harvesting period in order to ease congestion at freezing plants during the busy season.

A development of this technique has been the Ontario Unit (OU), which operates in a similar way but is a function of both day and night temperatures. This has been used in the USA in the development of the soya crop and has been applied to maize(15). It could also be used in identifying regions suitable for other corps such as outdoor tomatoes or sunflowers.

Work at the Meterological Office has led to the production of maps showing the number of heat units in different areas of England and Wales. Figures 3 and 4 show areas which exceed 2,500 OU 9 years in 10, and areas which receive 2,900 OU respectively. The original purpose of this work was to identify areas suitable for maize growing. 2,500 OU is considered a threshold value for sweet corn production, but for grain maize 2,700 OU are necessary. The climatic requirements of sunflower are similarly exigent, so the cultivation of this crop would probably be restricted to the areas shown on Fig. 4 if any expansion in current production were to occur.

Climatic factors are only one part of the limits to expansion of a new crop; the susceptibility of the plant to pests and diseases can play a large role. With an increased acreage of oilseed rape being grown in the UK, the consequences of a disease outbreak are becoming apparent. It is a characteristic in the development of any new crop that any setback results in a retrenchment to traditional techniques, followed by a slow renewal of interest taking several years. This is clearly seen in an examination of the expansion of the sunflower crop in France, illustrated in Fig. 5. The introduction of productive Russian varieties attracted more French farmers to the crop in the early 60's; then in 1963 a serious outbreak of botrytis resulted in many crop failures and the area planted dropped to below half the 1963 figure and remained there for 5 years. Then with the arrival of better varieties and better prices in 1968, plantings began to rise again. This was particularly boosted when crop failure in oilseed rape caused by widespread canker encouraged farmers to adopt sunflowers instead. A peak of 60,000 hectares in 1975 was

Fig. 3 METEROLOGICAL DATA FOR ENGLAND AND WALES

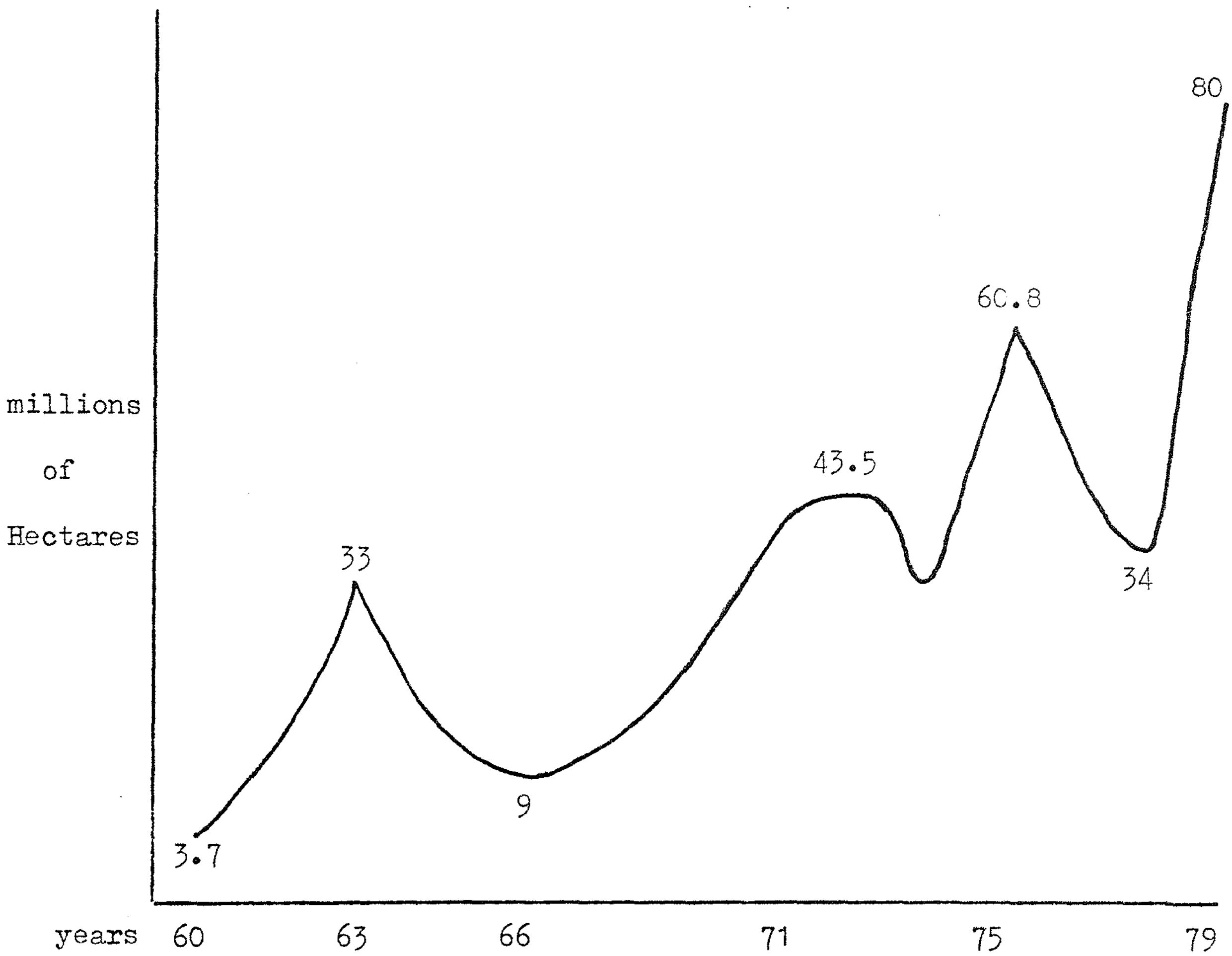
Exceeds 2,500 Ontario Units 9 years in 10.

Fig. 4 METEROLOGICAL DATA FOR ENGLAND AND WALES

2,900 Ontario Units

almost halved by 1978, the crop succumbing to its share of disease problems. But good prices and new varieties have put the 1979 crop up to 80,000 hectares as it continues to expand[16].

Figure 5



Area of Sunflowers planted 1960-1979 in France.[16]
From: Taille, G. Bulletin C.E.T.I.O.M. No. 74. 1979

This pattern of disease build-up with intensification is bound to result in crop failures in the UK acreage of oilseed rape before long. Serious setbacks have already been reported in oilseed rape in Australia, Germany and France, all caused by stem canker[17]. There have been numerous cries of alarm about UK disease and pest outbreaks, but the introduction of new varieties like Jet Neuf, which is canker resistant, could delay a widespread breakdown of the crop to this disease.

The current expansion of the oilseed rape acreage in the UK is made possible by the displacement of such crops as sugar beet, potatoes, barley, and even grass, from present cropping patterns. Unlike lupins and sunflowers, there are no major climatic limitations to the expansion of rape, but it is likely that the need for good management of the crop to ensure a profitable yield would prevent it from becoming more than a valuable break crop in arable regions. The forecasting study detailed in the Appendix revealed a potential for expansion of the oilseed rape acreage up to around 500,000 acres, but none of the experts consulted could see the crop taking on an unlimited expansion. The increasing acreage of oilseed rape is a result of many factors, including profitability of rape compared to other crops, demand for the crop by feed compounders, and quality and availability of imports. This last factor is one of the most critical, as the development of Canadian varieties low in glucosinolate and erucic acid has been accomplished more quickly in North America than in Europe. These "double zero" varieties are more versatile in their application in the animal feed industry. If European compound manufacturers find them cheaper and more useful this may mean the end of the UK crop, unless suitable double zero varieties become available for domestic production. Economic yields from UK grown double zero rape will not be seen before 1985[18], which may be too late to compete with Canadian imports.

Alternatively, if the flood of Canadian rape does not materialise and the UK crop continues to grow, there could be new problems on the horizon. Rapeseed contains 40% oil, while soya has only 20%; the current level of imports of US soya beans for crushing in Europe means that there is a surplus of oil in the EEC. If the soya imports were reduced and replaced with home-grown rape, this surplus would become larger. Added to this, even if suitable double zero rape were available, Europe could not grow enough to replace present levels of protein imports.

1 ton Soya

0.2 tons oil		0.35 tons protein

1 ton Oilseed Rape

0.4 tons oil		0.21 tons protein

It can be seen in the diagram above that a ton of soya has 50% less oil and 66% more protein than a ton of rape, so by replacing soya imports with rape, protein supply would fall short and oil supply go into surplus. It was for this reason that the pea and bean scheme was introduced to boost home-grown protein supply, but due to the unreliability of many bean crops this scheme has not worked as well as was hoped. The pea and bean scheme also seems to have become one of the areas for swindling over subsidy payments. There are rumours that subsidy is paid for crops grown for racing pigeons, and subsidy is claimed on large quantities of peas rejected from the human market, and even that successful claims have been made on shipments of imported chick peas[19]. All of which is defeating the object, as the intention is to pay the subsidy on crops grown in the EEC for animal feed use. Returning to the replacement of soya imports by home-grown rapeseed, this may prove to be an unsound move on political grounds, regardless of the physical limitations already discussed. Europe is a major customer for US soya beans and any serious move to reduce this trade could evoke a flexing of economic muscles.

US authorities are already protesting at the EEC purchase of soya from Brazil by the use of export refunds to that country. The US claims that they suffered damage to traditional export trade in 1978 and requests a less aggressive EEC policy. This is backed up by the prospect of trade retaliation, made quite real by the recent legislation passed in Washington which states that under such circumstances the US could and should retaliate(19). Obviously, if the US thought that EEC moves to reduce dependence on soya imports were capable of affecting the stability of the US export market, then there would undoubtedly be a reciprocal reduction in US imports from the EEC, with damaging results to the economy.

Ironically, the other consequence of such a move would be a flooding of the world markets with oilseeds, which could only bring down world prices as the US tried to off-load its crops to the less developed countries. The price of such independence from US trade is evidently high.

(iii) Leaf Protein

Since the early 1960's when N.W. Pirie first developed the necessary hardware for leaf protein extraction, research has broadened considerably. Having accepted the basic premise that there is a certain biological advantage to be gained from fractionating the protein in forage, then feeding some to animals and some directly to man, several workers have tried to make clear the best technique for exploiting this advantage.

In trying to clarify the most energetically and economically efficient route to be taken, there has been much diversity of approach and end results.

First of all the choice of crop to use as a raw material is variable. Lucerne and cocksfoot, as well as other grasses, are favoured, as are water weeds and crop residues which have a lower cost of production as they are not specifically cultivated to be processed.

Having chosen a crop, it must be decided how best to manage it for optimum protein yield. Fertiliser rate and harvest frequency are critical, as well as the choice of perennial or annual crops in sequence. The main aim of this crop management is to extend the length of the harvesting season as well as maintain high yields.

The choice of machinery used to process the crop once harvested is now an area of considerable research. The early techniques of screw presses and hammer milling are now superceded by rotary beaters and extruders which consume less power. The pressing of the forage to express the juice is now a problem being solved both by BOCM-S and work by Pirie on the rotary belt press.

The most energy intensive part of the fractionation is the coagulation and drying of the juice and forage. Some economies can be made by using a heat exchanger to recover the heat from the end products. To produce LP isolate suitable for human use requires yet more processing to separate the flavour and colour from the cytoplasmic protein, but the final bland isolate is of high nutritional quality.

Pirie rightly says that "physiological efficiency is no longer the only factor controlling profitability" and this leads us to consider the possibility of a subsidy on leaf protein production. The current level of price support for oilseed rape is approaching £100/tonne, which clearly demonstrates the level of commitment by the EEC to the expansion of the oilseed acreage. Since May 1978 there has been a subsidy for dried grass producers, which in July 1979 was about £7/tonne. This low level of support for a grass drying industry together with current rises in fuel costs is leading to predictions of a 25% cut back in the 160,000 tonnes per year of dried grass produced in the UK(19). Similarly, the future for leaf protein production is not encouraged by fuel price increases, but the fact remains that if a larger subsidy for forage products were introduced, the economics of fractionation would improve. However, current price support policy favours more conventional agricultural practices.

Many different options are open to the future of forage fractionation: as a farm-based operation to provide feed for ruminants and monogastrics, or as a fully developed industrial plant producing food grade products plus other forage fractions for animal feed. Alternatively, the answer may lie in the integration of forage fractionation with some other activity like grass drying or straw processing, such that plant overheads can be spread. Much depends on both technical developments to streamline the process and economic changes which could make each fraction valuable to the food and feed industries. If a fodder subsidy were to boost forage fractionation into an economically attractive position, then a successful UK industry would probably be based on the following premises:-

1. Large scale production units integrated with straw processing or grass drying plants.
2. Capable of year round operation.
3. Capable of processing a range of crops and crop residues.
4. Capable of producing a range of food and feed grade products.
5. Forage crops supplied by local farmers on a contract basis.

Undoubtedly, a fractionation plant with all these characteristics would be in a strong position to supply food and feed ingredients at competitive prices. But its success would also depend on the market price of more conventionally produced proteins such as soya. Perhaps the success of agricultural techniques in producing such crops as rape, soya and cereals will always ensure that they are relatively cheap sources of food and feed. Under such circumstances forage derived products such as leaf protein are unlikely to capture a very large share of the market.

7

THE INTEGRATION OF NOVEL FOOD PRODUCTION WITH A CROPPING PLAN

In recent years there have appeared several publications which express concern over the environment which our society creates by its intensive methods of industrial production. More specifically, there have been criticisms of agricultural techniques and the debasement of our food by processing, with detrimental results to human health[1]. This type of thinking has led to proposals by various writers of alternative techniques for food production, often with detailed examination of the effect of such alternatives on diet and health. It is intended to review some of these proposals in the context of this thesis, with the aim of placing the new technologies of food production discussed in the preceeding chapters in perspective with current thinking on the possible future agricultural situation in the United Kingdom.

Blaxter (1975)[2] reviews the possibility of nutritional self-sufficiency in Britain; he begins by pointing out that the UK is able to produce only about 63% of its needs in temperate foods. This figure is arrived at by calculating the value of home produced foods in proportion to the value of food consumed. It is interesting that a similar degree of self-sufficiency is shown by calculating the area of land needed to produce all our food needs in proportion to the area of land actually in production. Home production of all foodstuffs accounts for only 53% of the total consumption, when foods which cannot be produced in Britain are taken into account.

Blaxter sees three possible ways of improving this situation.

1. An increase in agricultural land available for food production.
2. An increase in the technical efficiency of food production.
3. Changing the diet of the population. Evidently the first possibility is not likely, in fact the reverse is true, with land being taken for development of roads, houses and factories at a rate of 20,000 hectares each year in the United Kingdom(3). As far as the second proposal is concerned, there has been a dramatic increase in agricultural productivity in the last thirty years, but it is unlikely that the next thirty years will see such a continued improvement. As the limits of production are reached the rate of improvement is slower, unless new technical advances can improve output without profligate use of resources. So it seems likely that, in order to attain self-sufficiency, our diet must change, and with it the policies which shape our agricultural industry. An examination of the extent to which our existing diet provides our nutritional needs reveals that protein consumption exceeds recommended levels by 25%, based on 1972 figures. As our main source of protein is from animal products, Blaxter suggests a reduction in meat consumption. He also shows that 40% of our energy needs come from fat and 11% from sugar, and points out that we obtain as much of our energy from bread as from butter, and that current thinking on diet and health would imply that we spread our butter too thickly.

Overall, Blaxter's proposals for self-sufficiency in food require a reduction in meat, fat, fruit and sugar consumption, and a rise in dairy products, potatoes, vegetables and cereals. This could be achieved by reducing the beef herd and producing meat only as a by-product of an enlarged dairy industry. The arable acreage would have to be enlarged to accommodate larger acreages of potatoes, cereals, sugar beet and oilseed rape; this would not cause problems as land would not be a limiting factor with a reduced livestock population.

Mellanby (1975)[4] also shows how much food Britain could produce if it did not have the benefit of cheap world food prices. He anticipates that future supplies of food on the world market may become more expensive and that a greater degree of self-sufficiency is desirable. He shows that our minimum requirement of protein and energy could be met by cereals alone if we were prepared to accept an uninteresting diet. Mellanby comes up with similar conclusions to Blaxter: a reduction in the beef herd, continued production of dairy products, increased use of cereals and reduced sugar consumption.

Watkin-Williams[5] evaluates UK food production in the future and sees three alternatives, all based on a reduction in meat production as this is seen as the most inefficient aspect of modern agriculture. A first choice is to provide protein by milk and egg production - a less inefficient route for food production than a beef enterprise. This would involve a 60% increase in the dairy herd and a doubling of egg supply. The second alternative is to expand the acreage of peas, beans and oilseeds to provide more protein as the meat and dairy industries contract. Here the author mentions single cell protein and leaf protein as possible inputs to a revised agricultural system, as such novel proteins could support pig and poultry units so that these animals did not compete with man for traditional protein crops. Finally, the favoured alternative is a combination of the two choices, which involves an increase in milk and egg production with a similar rise in output of vegetable protein crops. Such a system would require less land than is at present used for agricultural production, and Watkin Williams suggests that this could lead to a return to less intensive methods with lower yields but larger acreages, with considerable potential for savings in fertiliser and fuel.

A recent work by Tudge[6] discusses the concept of a "rational agriculture" providing greater "self reliance" in the UK economy. Both these terms are introduced by the writer in order to bring a new approach to the ideas discussed - a national agriculture would not have its base in the capitalist system, but would value the land, the farmers' labour and the food produced in an attempt to create a food production system less dependent on external supply of feedstuffs and chemicals. Tudge believes that this would bring not "self sufficiency" but "self reliance" - an ability to depend on our own resources without ignoring the existence of some need for trade. If these values were applied to the development of each nation's agriculture, then this could contribute to a more stable world. It is interesting to see here a discussion of agricultural reorganisation with economic and nutritional changes, being extrapolated by Tudge into a formula for a more equitable world. Perhaps this writer more than others brings out the essentially political nature of the reforms which are discussed in this chapter. Rational agriculture is characterised by a return to traditional techniques of crop rotation and a reduction in meat production with only beef and sheep on hill land. The resulting diet would be based on cereals, potatoes and vegetables, with meat playing a minor role.

A medical view on dietory change is expressed by Passmore et al[7], who draw up a prescription for a better British diet in which sugar, meat, fat and alcohol consumption are reduced, while potatoes, vegetables and cereals form a larger part of the diet. This "better British diet" would contain fewer of the so-called empty calories - fat, sugar and alcohol, and would be replaced by energy foods containing protein, vitamins and fibre. The changes involved are summarised in figure 1.

This paper does not differentiate between saturated and unsaturated fats in the diet - an emphasis on reduction in the former would be in

Figure 1

Recommended Changes in Consumption of Foods

by Passmore et al.

Foods Consumed	kg/person/year		
	National Diet 73-77	Target Diet	Change %
Dairy Products excluding butter	26	26	0
Meat	56	48	-15
Fish	8	8	0
Eggs (No.)	252	252	0
Oils and Fats	22	19	-15
Sugar	48	40	-15
Fruit	55	63	+15
Potatoes	96	111	+15
Vegetables	65	75	+15
Pulses and Nuts	6	6	0
Grain Products	73	87	+20
Alcohol (MJ/day)	0.67	0.50	-25

From: British Medical Journal, 24 Feb. 1979, p.529.

Figures based on Consumption Level Estimate - which is derived from agricultural production and food import figures.

line with current thinking. Also the value of whole grain bread and cereal products is not stressed, though this would undoubtedly be important, as a rise in consumption of white bread would not produce the desired increase in fibre. In discussing the role of cereals in human nutrition, Ulbricht(8) points out that on a world scale, over-nutrition is approaching under-nutrition in significance. The UK nutritional status is summarised as containing too much saturated fat, too much refined carbohydrate, eg. sugar, white flour, and too little dietary fibre. This could be corrected by a reduction in consumption of meat, milk and milk products and an increased consumption of unrefined cereals. A livestock industry based on grass fed animals would result in meat with a lower saturated fat content than the grain fed beef produced under current conditions. Ulbricht summarises by predicting that cereals may become more expensive on world markets and be in short supply, so a modest increase in self-sufficiency is desirable in the UK, though a siege economy is an unlikely event. The resulting changes in our diet would mean a reduction in meat, sugar and refined carbohydrate consumption, with increased use of unrefined carbohydrate and vegetables. Such a move would reduce our dependence on world food supplies, save on imports and improve the nation's health. The topic of health cannot be left without reference to a recent HMSO publication(13), "Eating for Health", in which the different views of the modern diet are discussed. The booklet concludes in favour of a prudent diet containing less visible fat such as cream and butter, as well as less invisible fat which is consumed in cakes, biscuits and puddings. Less sugar is recommended, with an increase in bread, potatoes, fruit and vegetables. Wholemeal bread is advocated, as is porridge, to increase the consumption of dietary fibre. A final comment is made of moderation being necessary in the consumption of any food. This useful booklet gives valuable advice to members of the public seeking information on dietary matters.

Mellanby (1979)[9] in a more recent work on the future of agriculture predicts a changing structure away from intensive livestock rearing to a forage based meat industry. Such a swing may come partly as a result of cost pressure on feed prices but also from the environmental lobby which opposes intensive farming methods. The resulting drop in meat production and consumption will lead to a higher level of self-sufficiency in agricultural products. Mixed farming will predominate in the lowlands with wider use of leguminous crops and farmyard manure. The uplands may see a kind of revival as they will prove ideal for extensive beef and sheep rearing. Mellanby feels that if pig and poultry enterprises are to survive, they may need inputs from single cell protein or leaf protein, as imported soya or fish meal will prove too expensive in the future. Whilst acknowledging vegetarianism as healthy, he anticipates that the demand for meat and animal products will continue.

Thompson[10] constructs a cropping plan for England and Wales which is designed to provide the basic nutritional needs of the population entirely from plant sources, in effect a vegan diet. This is done by drawing up a cropping plan and estimating the output of nutrients from that system. Based on the 1973 arable area and categorising each crop by its ability to produce nutrients suitable for human food, however humble, a table of energy and protein output was obtained.

The plan was characterised by the following working assumptions:

1. Utilised only proven crops.
2. Working area of 5,641,098 Hectares - the 1973 arable area of England and Wales.
3. Assumed size of population to be 49 million, as of England and Wales 1973.
4. Some crops re-categorised as human food, ie. turnips.
5. Some crops in the plan were not for food use. They either constituted amenities, ie. flowers, or were for rotational

purposes, ie. grass and legume leys. These were designated a fixed acreage.

6. Consideration was given to grades of land available for each crop - this is critical with some crops, ie. wheat, potatoes. In this way special crops could not exceed the area of land suitable for their cultivation.

7. Annual protein and energy requirements for the population were calculated from World Health Organisation data to be:

Energy	186.2 MGJ
Protein	700,000 tonnes.

An initial plan was drawn up and shown to produce 125% of energy needs and 230% of protein needs. These nutrients were entirely derived from existing crops, producing a diet predominant in cereals, potatoes and vegetables, with no meat. A simple type of linear programming technique was applied to the initial plan in order to optimise energy and protein production. Using an index of energy yield from each crop, optimum production was found to give only a 4% improvement, raising output to 129% of calculated energy need. This could be considered insufficient as Roy(11) suggests that wastage on the food supply chain could be as high as 30% overall. Such a reduction in energy output could reduce self-sufficiency to 90%. Thompson explains that this need not be critical, as any deficiency in energy crops could be compensated by either increasing the area of these crops at the expense of others, or increasing the area of cultivated land which, as this study reveals, would not be a limiting factor under a vegan regime.

The maximisation of protein production in the plan was calculated using an index based on both chemical score and yield of protein from each crop. This optimisation produced an increase of 17% to yield 247% of calculated protein need. This, even with a generous wastage factor, is more than enough for the nation's requirements.

The results of this work show that a dramatic change in diet, which a meatless agriculture would certainly provide, surprisingly need not be a nutrient deficient one. It can be safely stated, however, that the variety in such a diet would be restricted and the menu rather dull.

In order to evaluate the impact of increased oilseed production and the development of a leaf protein industry on a plant based agriculture, modifications were made to the plan devised by Thompson. This involved the following changes to the structure of the cropping plan:

1. Sunflowers are added and maize removed, as these crops compete for the same climatic regions.

   Maize 1,686 H. Sunflowers 2,000 H.

2. 300,000 Hectares of grassland are removed from the fixed acreage in order to be used as a source of leaf protein.

3. 29,365 Hectares of lucerne in the fixed acreage are transferred to the plan in order to be used for leaf protein production.

4. The oilseed rape crop is increased to 200,000 Hectares, displacing 100,000 H from barley and 52,431 from wheat.

It is important to realise that these modifications do not include the protein from a single cell protein industry, the output of which would be considerable. This is because the process is not based on any land using agricultural activity, so its expansion is not dependent on the constraints of the plan. As the main inputs to such an industry would be oil derived feedstocks or agricultural and food processing effluents, its eventual size would be influenced by factors other than the availability of land. It was therefore decided to apply those processes which required land to the plan and discuss the contribution of SCP separately. With these modifications applied to Thompson's cropping plan, new totals for energy and protein output were obtained and these are summarised in Figure 2. The results for energy output are similar to the initial plan at 125% of needs, but the results for protein show a very high figure of 280% of needs. As these revisions provide adequate supply of energy and protein it was not thought necessary to optimise output by a linear programming technique, however figures 2 and 3 show each crop with its energy and protein index, which permits the reader to see which crops to increase in order to boost output. Figure 4 lists the crops included in the fixed acreage which play no nutritional role in the plan but provide amenities such as flowers, and gastronomic inputs such as herbs and hops. The following table summarises the results of the three solutions to the plan.

	Self-Sufficiency %	
	Energy	Protein
Thompson Initial Plan	125	230
Thompson Optimised Plan	129	247
Modified Plan	125	280

The principal foods produced by this modified plan would be potatoes, cereals and vegetables. Criticism regarding the palatability of this diet could be made of the level of fat which is very low.(12) The preparation of many vegetable based meals is made more attractive with sufficient fats and oils. Thompson suggests 0.15 kg. per person per week as a reasonable level, which is half the present consumption, but this could only be achieved by boosting the 200,000 Hectares of oilseed rape up to around 700,000 Hectares. In order to raise the level of energy in the diet above the 125% which may prove insufficient after losses in the production chain, the acreage of potatoes or cereals could

Figure 2.

ENERGY AND PROTEIN YIELD FROM A REVISED CROP PLAN

CROP	HECTARES	ENERGY PRODUCED (GJ)	INDEX	PROTEIN PRODUCED (TONNES)	INDEX
1. Wheat	1325839	72788561	6	662919	2.5
2. Barley	1465130	80435637	6	586052	2.4
3. Oats	305573	19403885	7	152786	3.0
4. Rye	41549	1695199	5	12464	1.5
5. Maize	1686	117008	7	674	2.0
6. Early Potatoes	24597	1465981	6	12298	1.99
7. Main Potatoes	176669	18726914	10	88334	2.0
8. Field Beans	82978	2497637	4	49786	1.8
9. Turnips	24510	696084	3	7353	0.9
10. Cabbage	22407	557934	3	8962	1.6
11. Oilseed Rape*	200000	6500000	4	60000	1.6
12.-25. Vegetables	254057	5589000		120000	
27. Sugar Beet	202012	19999188	10		
29. Orchards	57446	769775	2		
30. Small Fruit	13317	79902	1		
36. Lucerne for LP	29000	290000	2	17400	3.6
39. Sunflowers	2000	65000	4	1200	3.6
40. Grass for LP	300000	3000000	2	180000	3.6
Fixed Crops	1112328				
TOTAL:	5641098	23467764		1960228	

Annual need: 18726000 700000

Plan supplies: 125% energy and 280% protein

Protein and Energy content of crops obtained from:

Paul, A.A., and Southgate, D.A.T. McConce & Widdowson's "The Composition of foods", 1978.

*Energy is that obtained from oil only, and protein that obtained from seed meal only.

Figure 3.

OUTDOOR VEGETABLES IN THE PLAN, SHOWING ENERGY AND PROTEIN INDEX

		Energy Index	Protein Index
12.	Brussell Sprouts	2	1.5
13.	Celery	2	1.6
14.	Cauliflower	2	2.5
15.	Carrots	4	1.2
16.	Beetroot	4	2.4
17.	Parsnip	5	1.2
18.	Broad beans	3	1.8
19.	Runner beans	2	0.8
20	French beans	1	0.8
21.	Green peas	2	1.8
22.	Dried peas	4	3.6
23.	Onions	4	1.2
24.	Lettuce	1	1.2
25.	Leeks	3	1.2

The area devoted to each vegetable crop was not itemised as a broad variety of combinations of all these crops will provide the protein and energy totals seen in the plan, from a total area of 254057 Hectares of vegetables.

Figure 4.

FIXED CROPS IN THE PLAN

		Hectares
26.	Mustard	6410
28.	Hops	6900
31.	Watercress	470
32.	Other vegetables	10300
33.	Glasshouse crops	2000
34.	Flowers	15118
35.	Others	12478
37.	Temporary Grass	1001652
38.	Fallow	57000
		1112328

These crops were considered essential although they play no nutritional role in food supply.

be increased. These are the two improvements which could be made from a dietary point of view within the constraints of a plant based agriculture and, indeed, both of them could be incorporated into the plan without disturbing the overall levels of production. There is greater flexibility in a plant based agriculture, as the area of land needed to provide the necessary nutrients is much less than that needed for conventional food production. Consequently, it would be quite feasible to raise the area of oilseed rape and potatoes in order to increase the fat and energy content of the diet, as a corresponding reduction in the turnip or cabbage area, for example, would still result in higher overall energy and fat yields. Thompson also notes that the arable area under consideration does not include permanent pasture(14) and that the plan, if insufficient, can expand to take in uncultivated land currently classified as permanent pasture. Of course, the lack of variety in the diet from the plan could be relieved to some extent by the ability of the food processing industry to produce textured vegetable products from oilseeds.

It must be remembered that of the novel processes in the modified plan single cell protein plays no role. It seems easy to include oilseed crops and to divert grass and lucerne to leaf protein production, but with such a surfeit of protein it is difficult to justify SCP as a valid input. In some respects all three technologies could be said to be energetically inappropriate and nutritionally superfluous to a vegan agriculture. On the one hand they add a small amount of variety and could be applied to the quantities of crop residues and, indeed, crops not used due to the absence of animals, to produce additional protein. But on the other hand a plant based agriculture would need to compost all its crop residues and return them to the land in order to maintain soil structure and fertility. Variety in such an agriculture could easily be obtained by introducing chickens, milk production, and perhaps hill sheep rearing, without a significant loss in efficiency.

It is in discussing the need for animal production that the roles of single cell protein and leaf protein come into a better perspective. Pigs and poultry in particular need protein feeds of good quality, such as fish meal and soya bean meal, and it is in this way that livestock compete directly with humans for their nutritional requirements. The new protein foods discussed in this thesis were designed to improve the supply of protein to humans and animals, and thus to reduce the undesirable competition which has built up as a result of the intensification of meat production to satisfy our needs. The change to a plant based agriculture effectively does away with this competition between man and animal by eliminating the use of animals for food. Equally effectively it does away with the need for the sophisticated protein production systems developed in response to high demand for food and feed. So whilst a plant based agriculture will provide a dull diet of cereals, potatoes and vegetables, it has no difficulty in producing sufficient nutrients from the arable area of England and Wales. But as Blaxter[2] points out, the area of land necessary to produce all our food and feed needs under the current regime is approximately 50 million acres, whilst the area of land available in the UK for food production is only about 30 million acres, the difference in available land area being made up by imported foodstuffs. Clearly, the plant based system has much to offer in terms of import saving to the benefit of the balance of payments. But equally clearly, the diet which this plan provides would be intolerable to the majority of the population, and there would be little that single cell protein or leaf protein products could do to improve it. Both these processes have been developed to provide concentrated, even purified proteins which are mainly of value as inputs to food processing or animal feeds - they are designed to provide the very nutrient which would be adequately supplied by an agriculture without animals. Oilseed crops fall into a different category, as they produce nutritionally desirable oil which can be converted into gastronomically desirable margarine, and processed into textured vegetable protein. The structure of this plan, though a useful enquiry, is based on two unlikely assumptions: one, that Britain will adopt a totally plant based agriculture and thus a vegan diet; and two, that the novel protein production systems here discussed will attain a commercially significant share of the market.

In order to explore other possible routes for the evolution of UK agriculture and the role of novel technology within it, the following three scenarios will be discussed:

1. No animals or animal products.

Single cell protein Leaf protein Oilseeds	Commercially developed

2. Present level of animal rearing.

Single cell protein Leaf protein Oilseeds	Commercially developed

3. Low level of animal production.

Single cell protein Leaf protein Oilseeds	Limited development in appropriate circumstances

Scenario 1 is the situation already discussed in the plan; it would produce a vegan diet with little variety but at low cost to the exchequer. The existence of novel proteins would be unnecessary and innappropriate.

Scenario 2 presumes a high level of animal production with large supplies of novel proteins. This would, at first glance, look like a good combination, but in fact the problem would be cost. The energy crisis is going to ensure that SCP at least remains one of the most expensive sources of protein. The only exception is those processes based on effluents from processing industries, which could provide a cheaper source of animal feed if the technology is developed. The likelihood is, however, that agriculturally produced proteins such as oilseeds are going to be cheaper than those derived from hydrocarbons. Leaf protein could also make a contribution if suitably versatile plants were set up, able to change their mix of products to suit market conditions. But generally speaking the technology necessary to produce novel proteins on a large scale, and the cost of meeting stringent safety standards, will ensure that a growing livestock industry is more likely to base its feedstuff supply on the cheapest proteins, which are likely to be provided by cereals and oilseeds, with some contribution from waste derived SCP.

Scenario 3 is an intermediate situation in which there is a lower level of animal production than at present with a more vegetarian type diet. That is, milk, eggs and cheese would be included but meat eating would be reduced, as advocated by several writers and reviewed in the early part of this chapter. It could be said that if the animal population were low enough, the necessary feedstuffs could be provided from indigenous agricultural production at reasonable prices, such that the system would not require expensive imports. However, I see here a role for a carefully structured novel protein industry. The solution lies in not allowing such an industry to grow beyond its natural size, and I suggest that that size is a small one. Take, for example, the ICI SCP production facility at Billingham. It is based on the ready availability of methanol derived from North Sea Gas; it is bought in sufficiently large quantities by ICI to obtain a generous discount; and it is produced at a site where large chemical installations are the norm and the expertise to operate them is readily available. The degree of technical and design innovation is high and the result is potentially the most efficient possible production facility. Here, I suggest, is an appropriate innovation, but it is not reasonable to suppose that because the process works in Billingham it will work in Southampton or Liverpool or Sardinia. Perhaps it will be shown that Billingham is the only appropriate development of SCP in this country. Similarly, the development of protein recovery from effluent by fermentation could provide large quantities of novel protein, but in reality it may prove cheaper to detoxify an effluent for land disposal than to develop a full protein recovery process. Exceptions to this will obviously be processing facilities such as dairies or canning plants, which regularly produce large quantities of relatively standard effluent which would lend itself to the continuous fermentation process which is a feature of these systems. Another aspect of the development of single cell protein is that it is unlikely to be economic to produce SCP for human food use. More conventional proteins will always be cheaper than SCP for food use, principally because of the cost of establishing the safety of these products.

Leaf protein under this scenario could be developed under suitable conditions; already mentioned is the necessity to maintain flexibility in the mix of products to suit the market. Also the ability to process a range of crops and by-products would add versatility, as discussed in Chapter 6. Siting of such an enterprise could be critical to minimise transport costs; the integration of forage fractionation with straw processing could provide the necessary reduction on overhead costs to keep such a unit viable. The mix of products it could provide would certainly be of value to the pig and poultry industries.

Finally, an indigenous oilseed industry would make the most efficient use of its products if, as at present, the oil is directed to the human food trade and the seed meal used to provide animal feed.

There is ample processing capacity in the UK to deal with home grown oilseeds, producing oil for conversion to margarine and the seed meal incorporated into animal feeds to supplement supply to an essentially forage based dairy, pig and poultry industry. Such an oilseed industry would be able to grow to meet demand but would not need to exceed 500,000 Hectares, as this provides adequate fat in the diet and, with the contribution made by SCP and LP would provide adequate animal feed for the reduced livestock population.

This third scenario is, I believe, a favourable combination of traditional and novel techniques of food production, with rational use of resources to provide a diet dominant in plant foods but including dairy products and eggs with a small amount of meat. Whilst it has already been established that self-sufficiency in nutrient supply can be attained without animals and without novel proteins, it is apparent that such a solution does not make the most efficient use of the available resources, as not all the agricultural land would come into production. By using animals to utilise fodder crops and the less productive upland areas, and by using SCP, LP and oilseeds to provide animal feed, thus increasing the crops available for human use and saving imports, a simple but adequate diet can be provided without excessive exploitation of any sector of the food supply industry.

8

SUMMARY AND CONCLUSIONS

Three emerging technologies have been considered in this thesis and their impact, both present and potential, assessed in the context of UK agriculture and food supply. The chosen technologies are single cell protein production, leaf protein and oilseed crops; all three are characterised by an ability to provide useful protein for human or animal consumption if suitably developed for that purpose. The three technologies are also characterised by providing novel proteins, that is foodstuffs not having a traditional role in our diet. The particular problems associated with the introduction of such novel processes and products are a key aspect to the discussion of their development. Taking each process in turn, their main characteristics will be summarised.

Single cell protein production has been the object of a large number of research programmes in the past twenty years. Of the many companies which embarked on such research and development during that period, only a very few have achieved technical and commercial success. The principle behind the process is to culture micro-organisms on any suitable substrate and harvest the rapidly multiplying biomass; isolate it from the substrate on which it grew; and dry it to produce a protein-rich product suitable for animal feed or possibly human food. The diversity of suitable organisms is only exceeded by the range of possible substrates. The organisms are bacteria, fungi, yeasts and algae, and may be cultured on several different hydrocarbon fractions such as paraffin and methanol; primary food products like molasses; as well as a wide range of wastes containing carbohydrate and effluents from intensive animal rearing units (see chapter 2, fig. 1).

Big investments have been made by leading companies to develop the hydrocarbon route, notably ICI using bacteria on methanol, and BP using yeasts on paraffin. Such projects depended upon economies of scale to ensure the cheapest possible end product. Plants producing 100,000 tonnes per year of SCP are considered the optimum for such units. However, the technology necessary to ensure efficiency and safety has proved expensive, and legislative difficulties have proved so insurmountable to BP that they have now closed down all their commercial projects and are not now active in the SCP market. Similarly, Rank Hovis MacDougall developed technology using fungi on starch, hoping to produce a human food grade product, but they have never commercialised this process. Success in this field has become more elusive because of the cost increases brought about by the energy crisis, in addition to the not insignificant expense of establishing product safety now mandatory for any new food or feed ingredient put on the market.

Waste derived SCP is, of course, attractive because it produces a protein product in addition to reducing the polluting burden which effluents place on the ecosystem. Here, in principle at least, is an opportunity to recover a valuable product from a cost incurring by-product. Several attempts are being made to perfect such a system, but each one must be tailored to suit the particular effluent to be treated and may require extensive monitoring and control to ensure that a consistently safe product is obtained from what may be an unpleasant and even noxious substrate. Processes to recover SCP from potato processing and paper mill effluents have met with some commercial success and present attempts to treat food processing effluent in the UK look promising.

Energy analysis of these processes reveals a very high requirement of energy for SCP production, especially when considering the processes using primary resources (see chapter 5, Table 1). The high energy requirement and high cost of the hydrocarbon based processes militate against their success. Effluent derived SCP is more attractive energetically and economically, but has its own particular problems of acceptability and safety. Success for this type of process is dependent upon judicious application of the technology and careful evaluation of the product.

The principle of the technique of leaf protein production (or forage fractionation as it is also known) has been acknowledged as correct for forty years. Essentially it involves the removal of the protein-rich juice from harvested grass by application of great pressure. In this way the protein content of the forage is divided or fractioned between the extracted juice and the remaining fibrous material. The attraction of this technique lies in the fact that the pressed forage can be fed to ruminants as an adequate diet, while the juice fraction can be dried to provide a protein for animal or human use. In this way, much more efficient use is made of the protein available in green crops which is normally wastefully consumed by ruminants. This elegant nutritional theory is, however, proving very difficult to realise in practice. Many refinements to the original pulper and press have been made, notably by N.W. Pirie; other workers have concentrated on identifying the most suitable types of green crop to be used and the best size of plant for such a process. Workers in America and India as well as in Britain have not yet come up with a workable system for producing leaf protein in quantities suitable for commercial use. Plants in Eastern Europe and one in France are said to be operating successfully, but the French process is only viable because it is able to sell the lucerne based product at a premium as an ingredient in poultry rations.

Problems with this technology lie in the efficiency with which the forage and juice can be separated and the energy needed to dry the resulting fractions. More development is needed at all levels of LP production, from the choice and management of the crop, to the design and operation of the plant; the mix of products resulting from the process, and the market to which they are directed. An attempt to find this right combination is being made by a UK animal feed company which has set up a semi-commercial leaf protein plant integrated with a grass drying and straw processing operation. This combination may be successful, as it reduces overheads and permits greater flexibility in resource utilisation.

The interest in the last five years in the emergence of oilseed crops as a significant acreage in UK agriculture has focussed on to oilseed rape as the only serious contender as the basis for a home-grown oilseed industry. Initial enthusiasm for sunflowers, linseed and lupins have waned, as even two favourable seasons failed to produce hoped for yields in various trial sites throughout the UK. Only oilseed rape has shown the necessary consistent yield and profitability to attract farmers to an oilseed break crop. The acreage has risen dramatically from 34,000 acres in 1973 to a predicted 250,000 in 1980. Early problems with high erucic acid levels in the seed oil were solved by plant breeding and the crop became a valuable one for salad oil and margarine production. Problems relating to the level of glucosinolates in the seed meal limit its use in animal feeding, so its import saving role is not complete as soya from the USA and rapeseed from Canada are more suitable for the feed compounders. Plant breeders' efforts to reduce glucosinolate levels is continuing and EEC support for the crop is increased annually; current target prices are about £50 tonne above world market prices. Continued success for what has been described as an oilseed revolution in the UK depends upon several factors:- Canadian rapeseed is low in glucosinolate and erucic acid, the so-called double zero varieties; these are not yet available for growing in the UK, so if the compound manufacturers prefer the double zero, the British farmer will not be able to provide them for two or three years. This could lead to a price differential based on rapeseed quality, to the detriment of the UK crop. Also the rapid expansion of rape in Britain has so far not met with any significant outbreak of disease. Some observers feel that a breakdown is inevitable, particularly if, as at present, much of the crop is down to one variety only. Such an outbreak could seriously reduce yields and deter many farmers from trying the crop again, for a few years at least. Finally, there is always the possibility of reduced support for rape from the EEC; if the guaranteed price were not increased as it currently is every year, then farmers would be discouraged by the lower returns. I estimate that this reduction of support is unlikely, however, until the acreage goes much higher, say 500,000 acres, at which level there would be a possibility of rapeseed oil going into surplus in the community. Overall, oilseed rape provides the cheapest animal feed of the three sources and has additional benefits to the food and agricultural industries in the form of oil supply and a useful break crop, respectively.

The contribution of the novel proteins to a plant based, vegan agriculture is examined and found to be innappropriate. Essentially a vegan agriculture would produce adequate protein and energy from the current arable area of England and Wales to feed the population. The diet, it is stressed, would be dull, consisting principally of potatoes, cereals, vegetables and pulses, with no meat or animal products. Of the novel products, only oilseed rape would be valuable, and then only by the oil it could contribute. A modified version of this plan incorporating a leaf protein and oilseed industry, provides 280% of the protein needs, and 125% of energy needs of the population. Clearly, under this type of regime only oilseed rape would be of any value in contributing to human food needs.

It is only when animals are introduced into the system that SCP and LP begin to look more attractive and then, it must be stressed, only under particular conditions. In a situation where milk production is carried out and limited rearing of sheep, beef, pigs and poultry, the latter animals could have a contribution to their high protein requirements provided from novel sources. Even this contribution would only be feasible if the SCP production plant were carefully sited and efficiently run for optimum output; similarly, protein recovery from effluents could contribute but only in the specific circumstances discussed in chapter 6. Leaf protein systems would also need to be carefully sited and designed to meet market needs by building flexibility into the process.

If, as this study reveals, single cell protein in particular appears to have only limited potential in vegan, vegetarian, or even conventional agricultural futures, then, is this a good example of scientific advance not heeding the needs of society? On the one hand, it is easy to say that it is an inappropriate technology, requiring excessive energy to produce a product more easily obtained by traditional methods. But I suggest that even if SCP fulfills none of the claims made for it in the 60's to "feed the starving millions", the impetus which its development gave to research in the field now becoming recognised as Biotechnology, will be reflected in many different ways as fermentation science solves some of the problems created by the energy crisis. Without the basic research carried out by ICI, BP and other transnational companies and continued by more recent entrants to the field like Hoechst, there would not be that body of scientific knowledge which is now being directed into new applications such as fuel alcohol production; enzyme technology; cellulose conversion, and bacterial leaching, all of which have their base in a new understanding of the possibilities of Biotechnology.

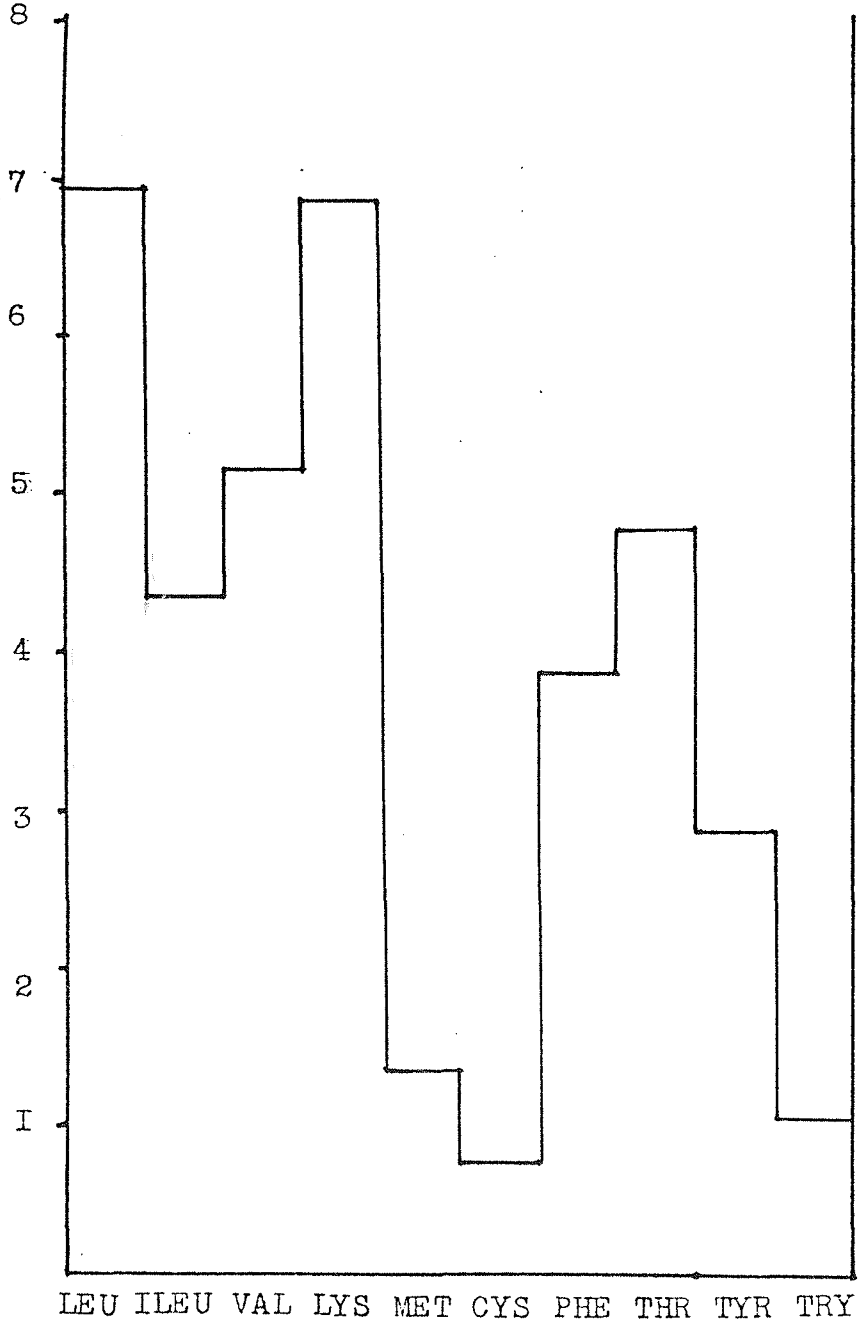
To a similar extent, the development of leaf protein extraction processes can be attributed to the efforts of a small number of individuals and a similarly small number of companies prepared to put capital at risk in order to fully explore the potential of this technology. It looks unlikely to make a large impact on food supply unless new developments enable the fractionation to be achieved more efficiently than at present. But this in itself is not sufficient reason to condemn the process. It is important that new ideas are fully explored and the large companies which dominate modern industry are in the strongest position to finance research which is not guaranteed to bring high returns. The fact that leaf protein production has not taken off does not detract from the theoretical advantage which it offers. If research reveals a new technique to exploit that advantage, then the system could be much more attractive.

Finally, the contribution offered by oilseed production is of value to the food and agricultural industries. It is not without its drawbacks and, indeed, there could be difficulties ahead if expansion continues at the present rate, but oilseeds do provide a useful agricultural crop, giving good returns to the farmer and useful products to the food and feed industries. Of the three sources of novel protein examined it requires the least energy in its production and is consistently the cheapest product. The low cost of oilseed protein is one of its strongest points, as to some extent the development of SCP was encouraged by the notion that agriculturally produced proteins would become more expensive than they have. Agriculture still offers the feed manufacturer the safest and cheapest protein ingredients. Modern agricultural techniques, blended with the technology of plant breeding, seem to be the most successful method of producing food. The more sophisticated technology of SCP will never replace agriculture but it may have formed the base of a new movement vital to our survival in the post-oil era.

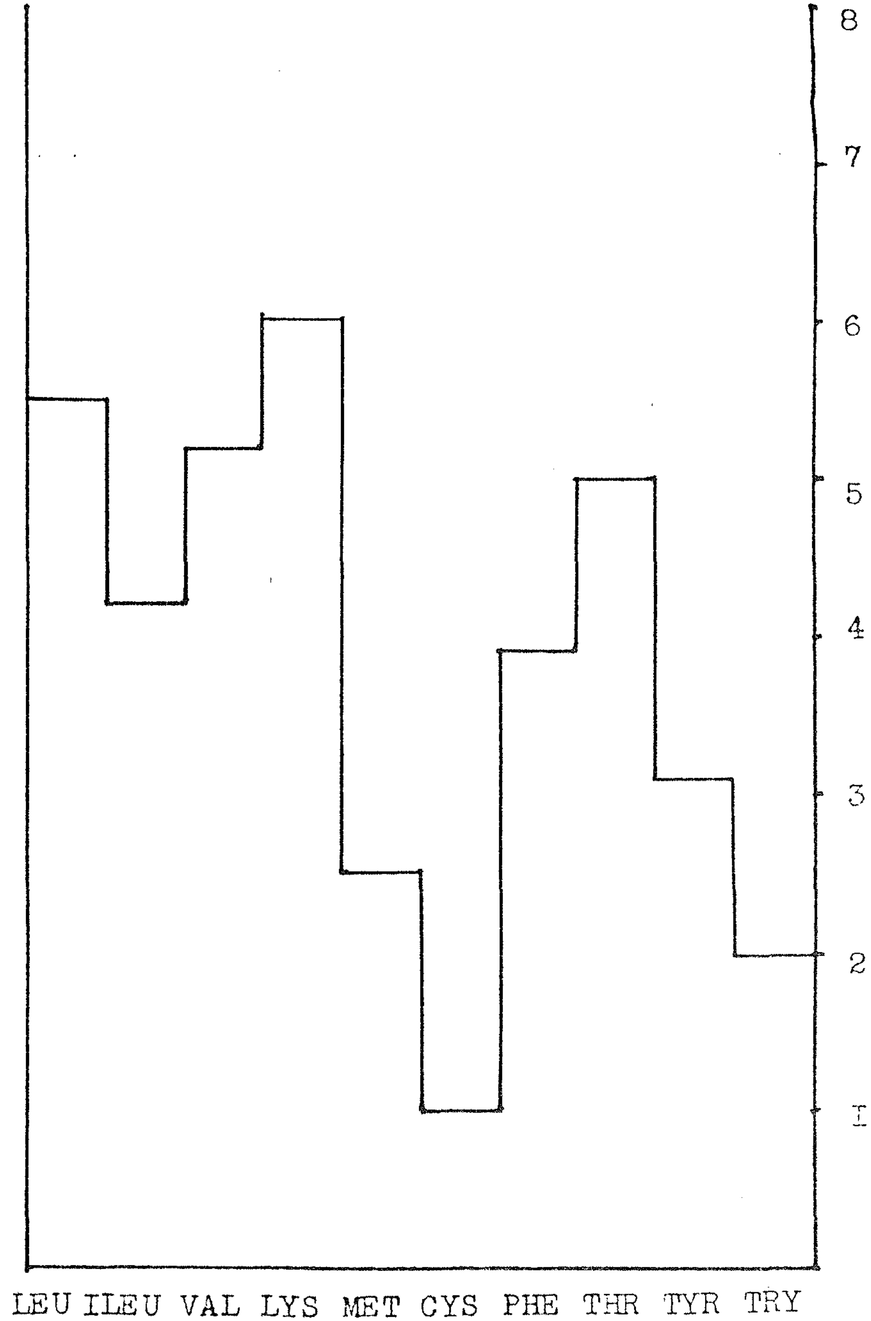
APPENDIX I

AMINO ACID PROFILES OF PROTEIN PRODUCTS

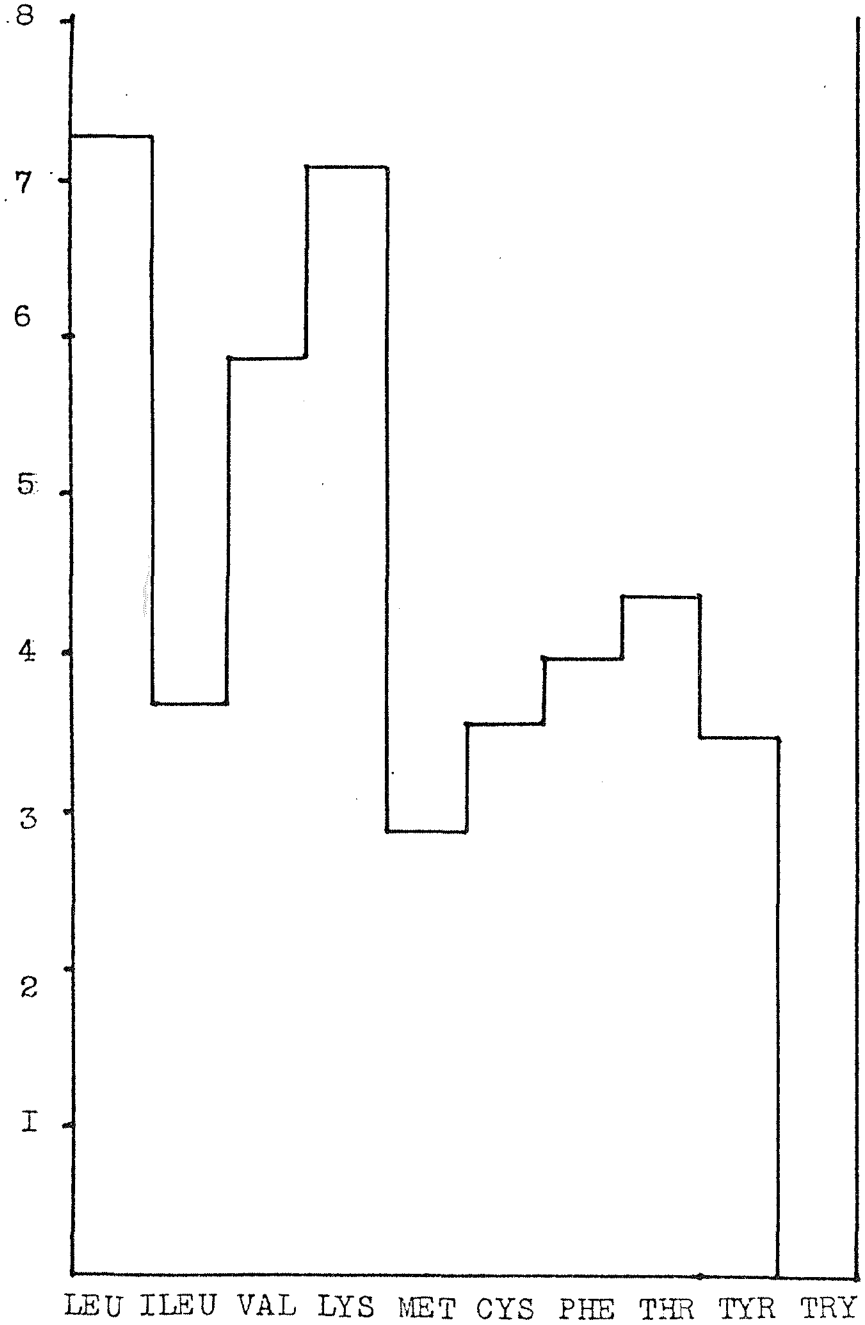
Units g/16gN.



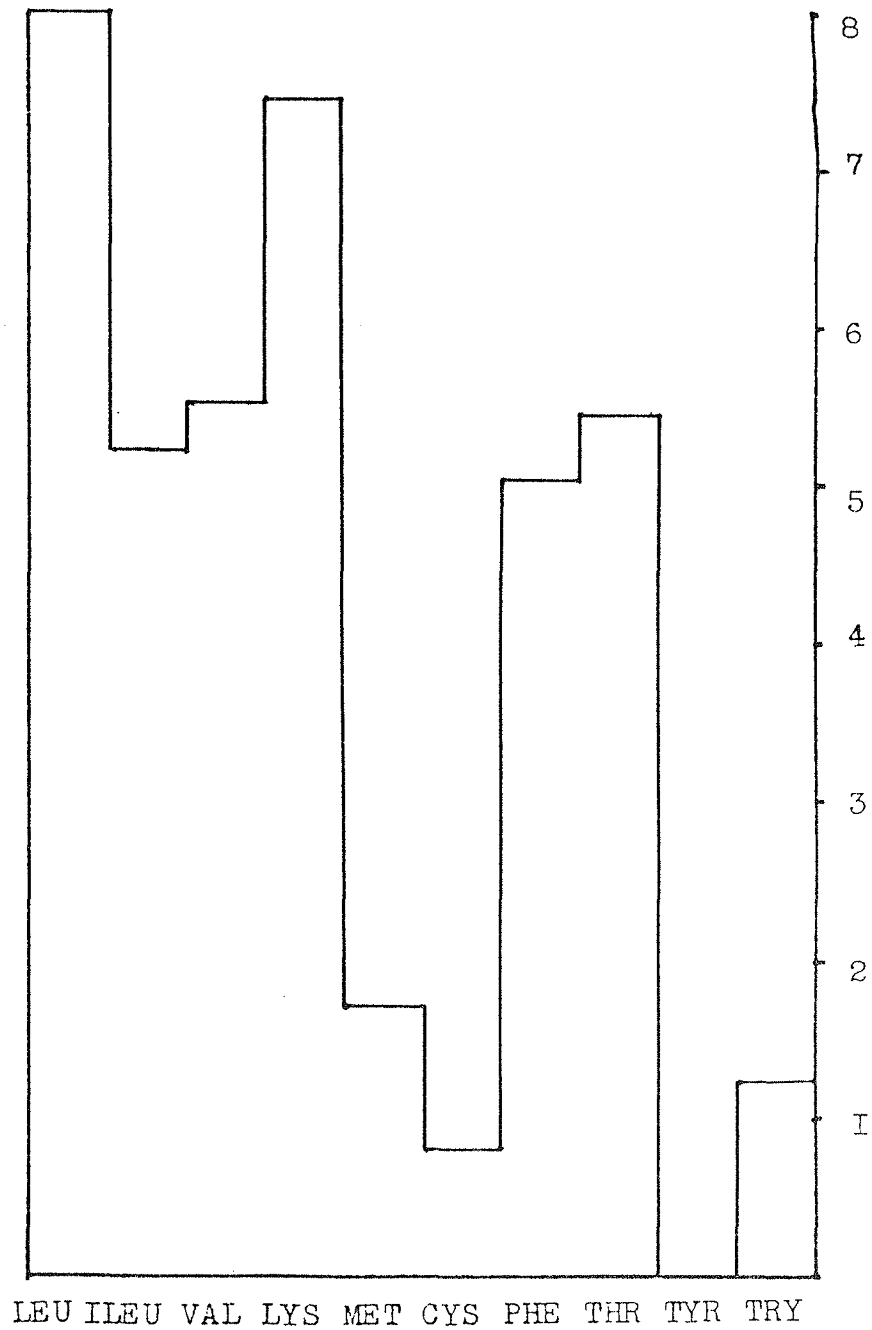
AMOCO TORUTEIN



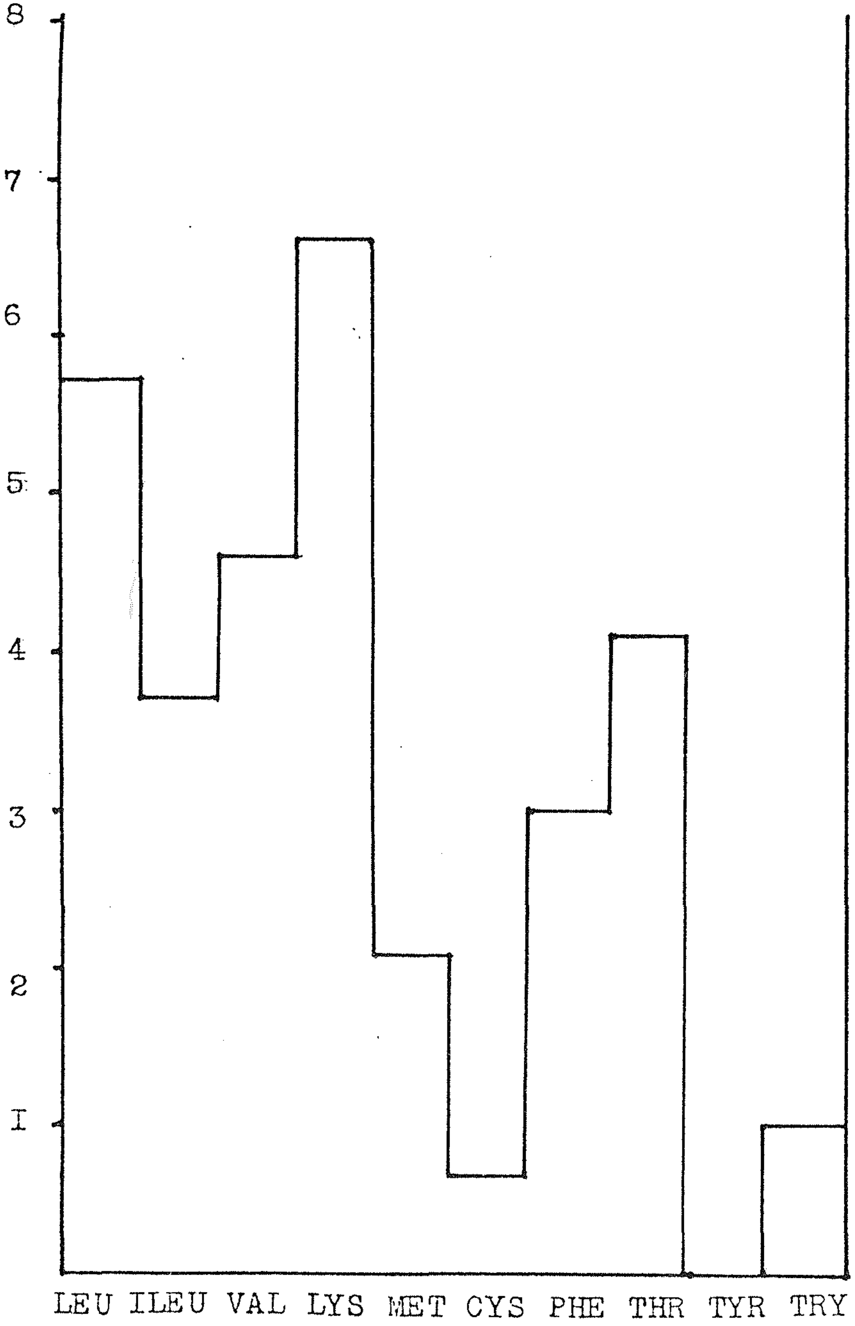
ASPERGILLUS NIGER



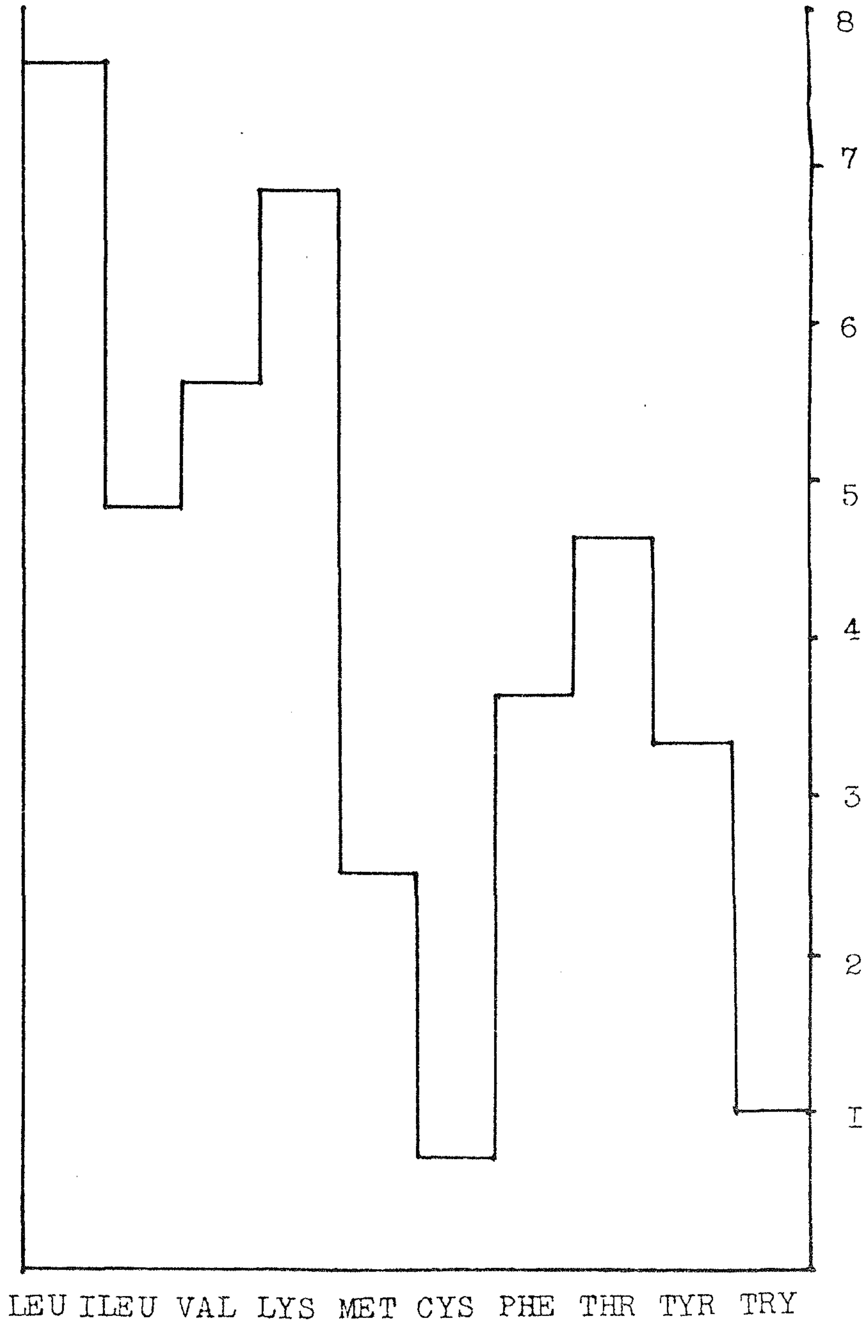
RHM FUNGAL PROTEIN



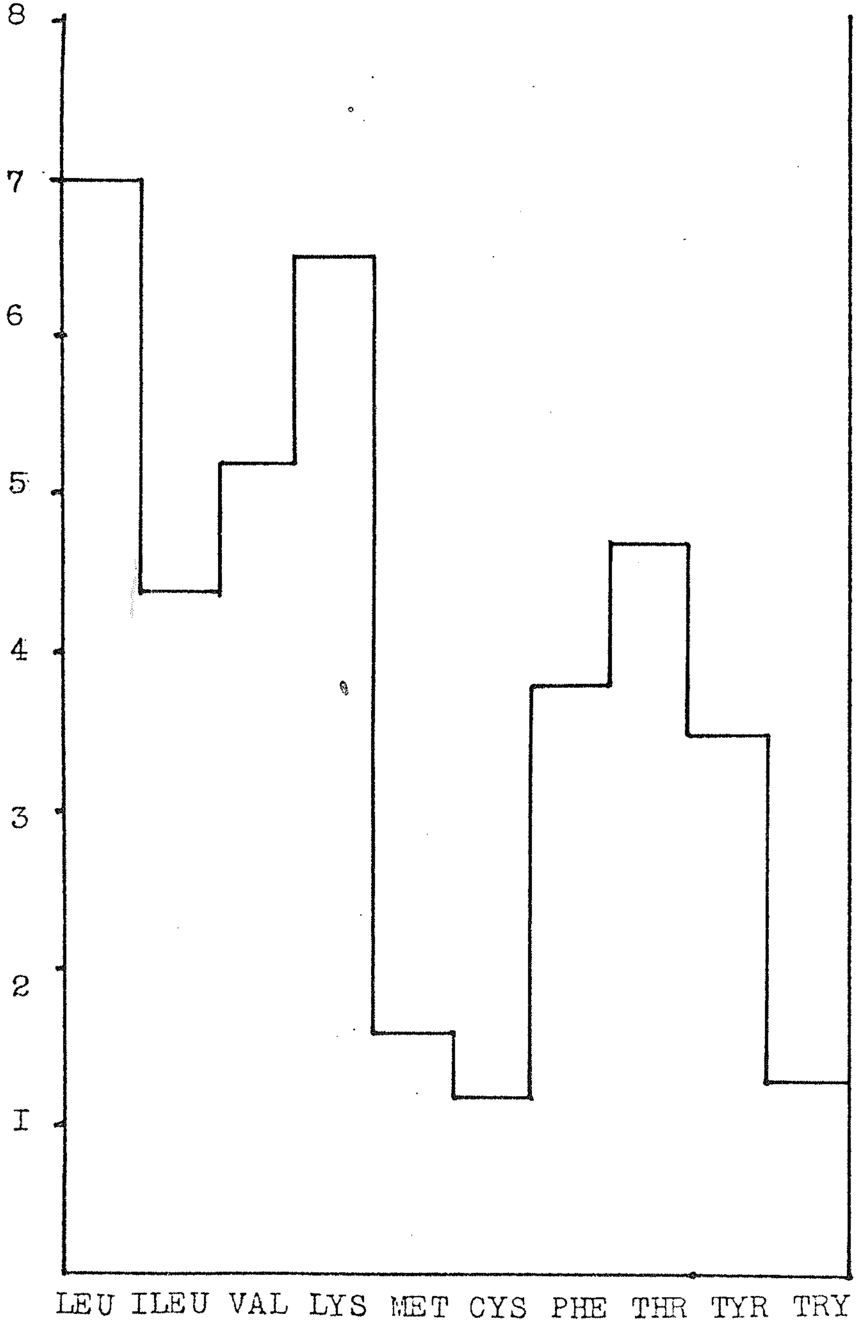
BP TOPRINA



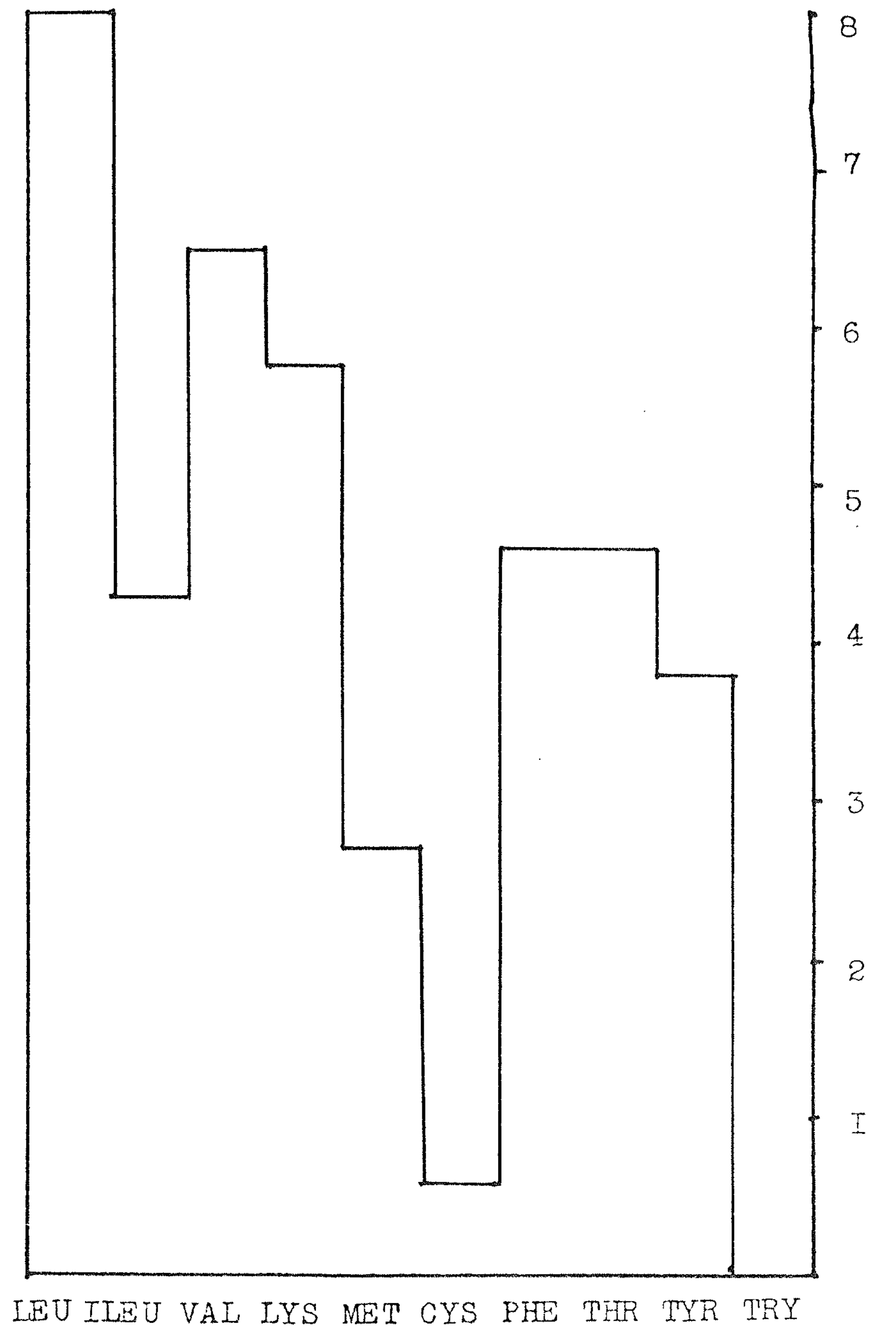
EXXON-NESTLÉ BACTERIA



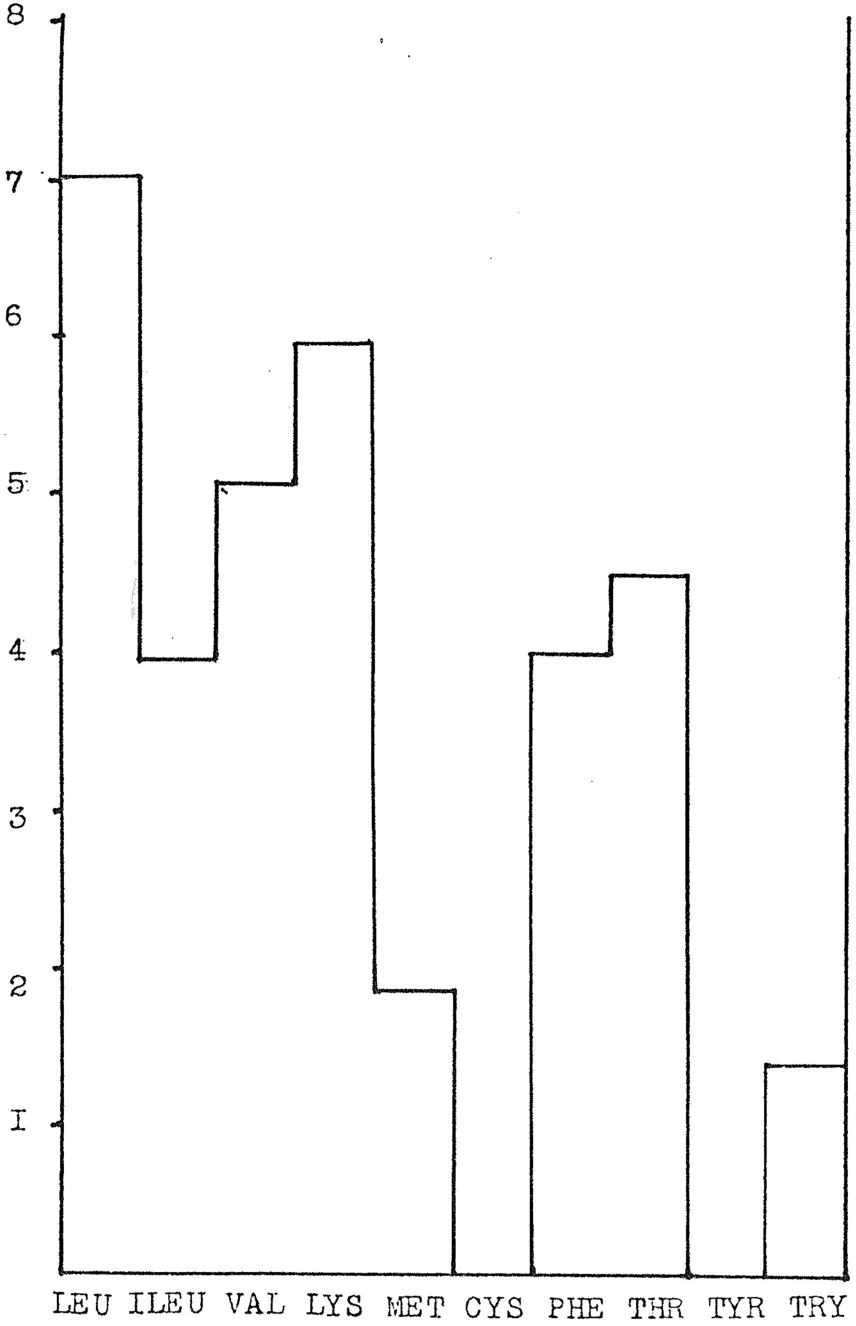
ICI PRUTEEN



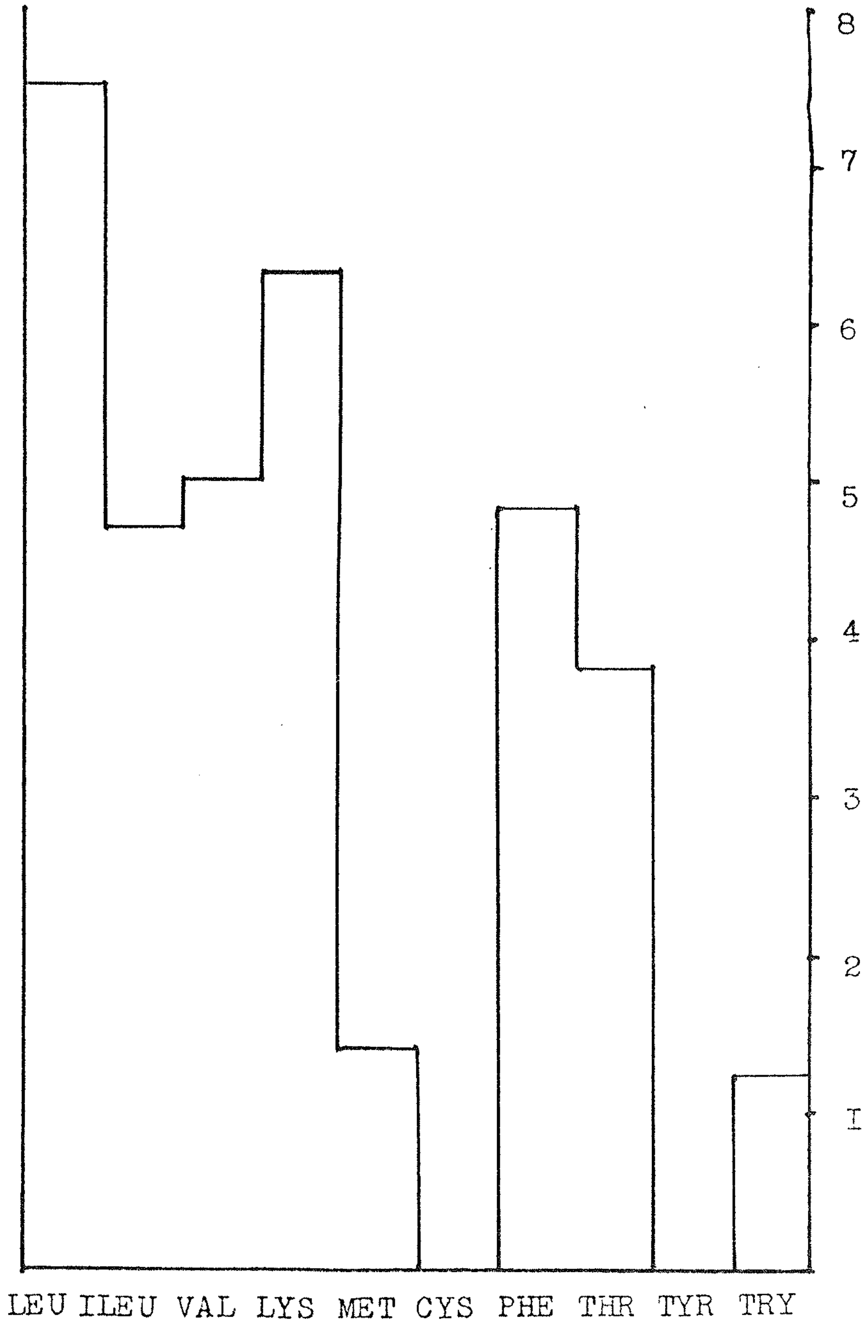
PEKILO PROTEIN



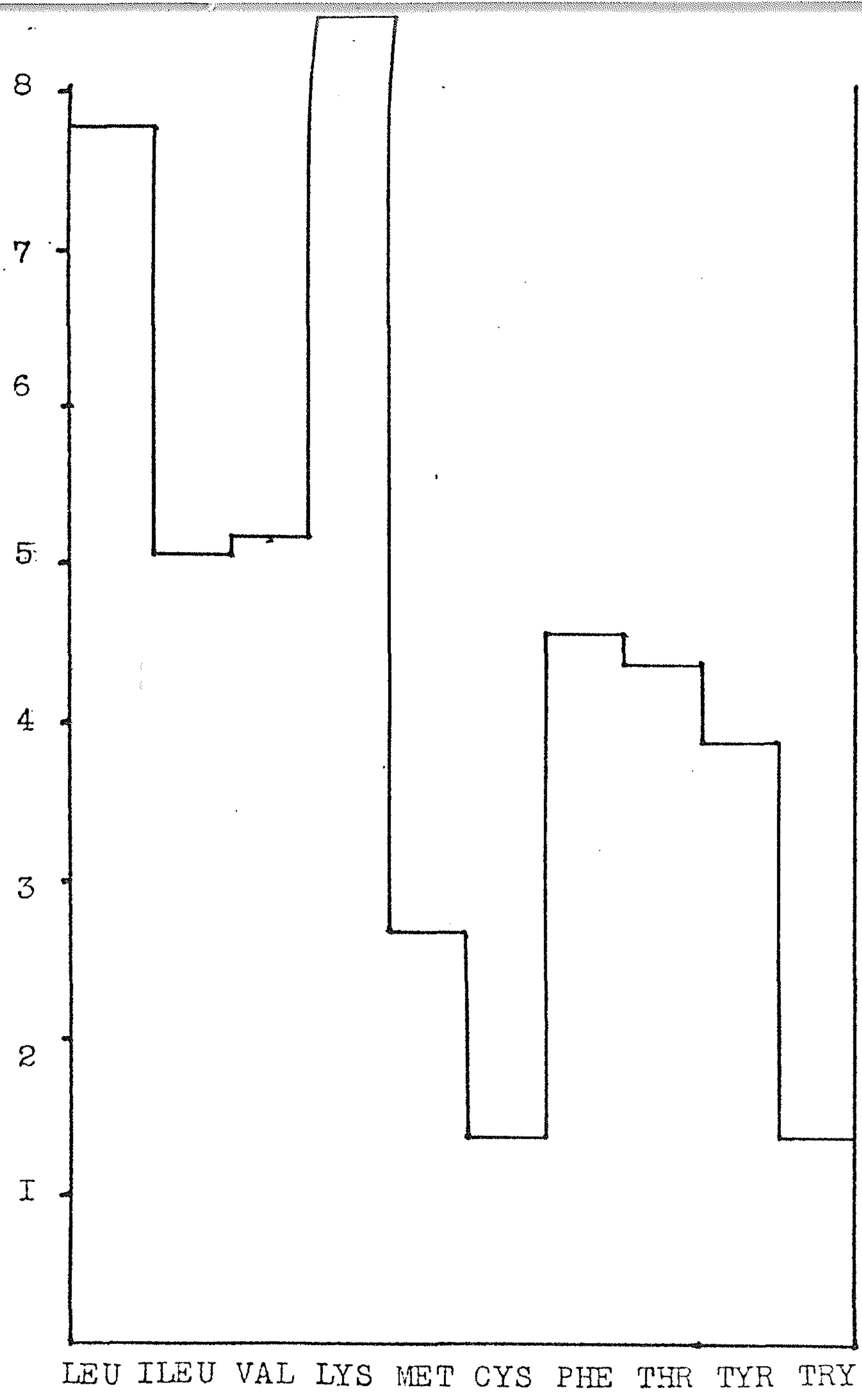
SHELL SCP PRODUCT



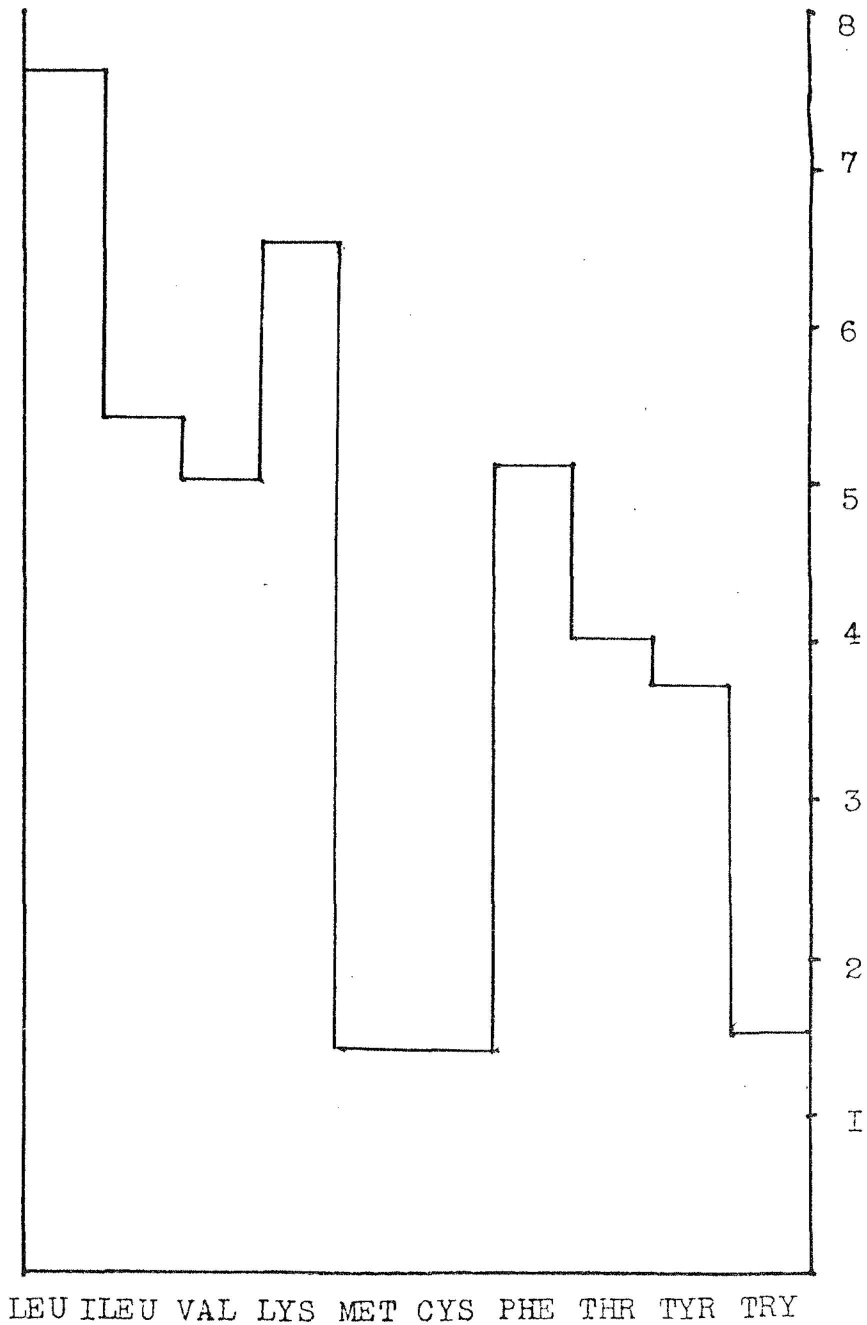
RAPESEED MEAL



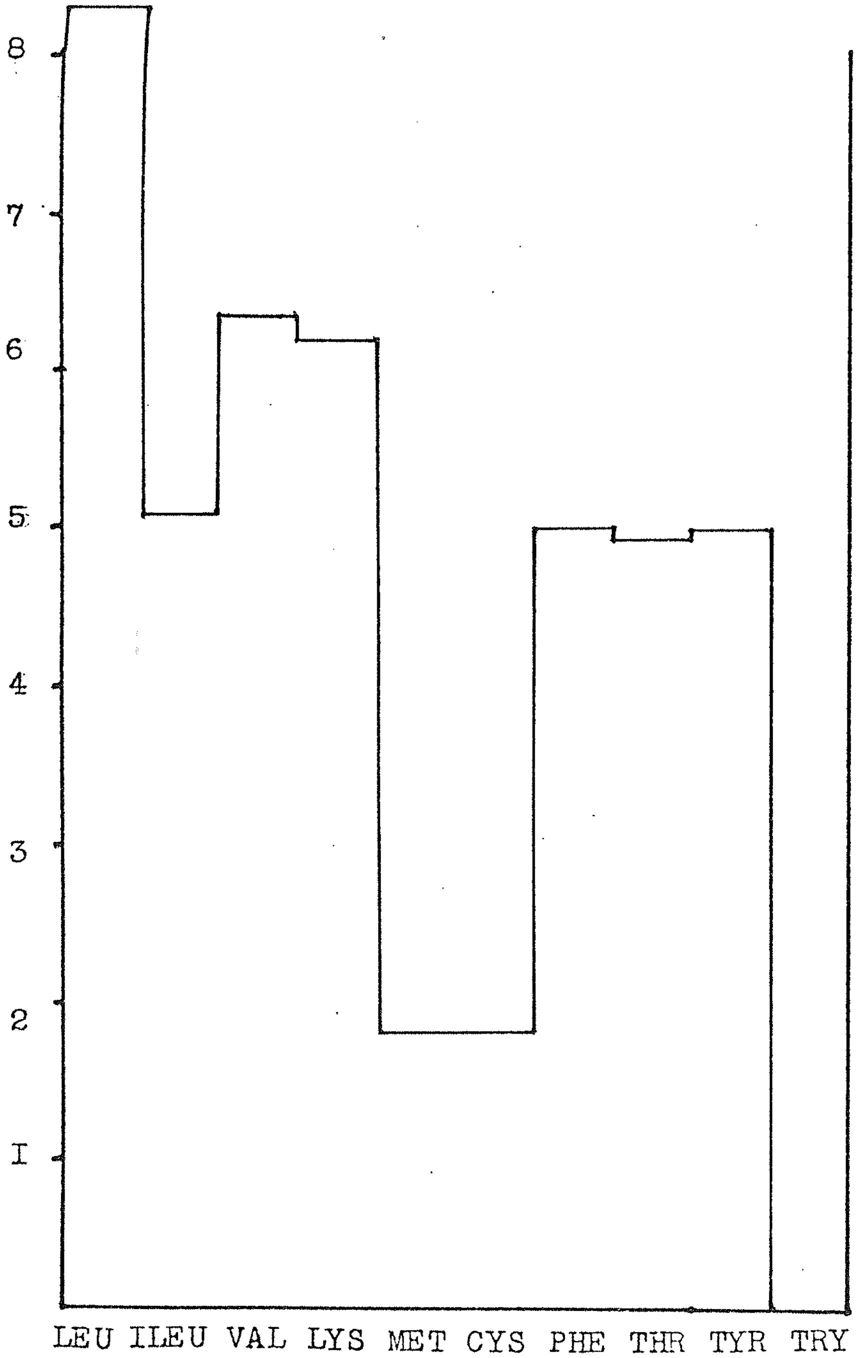
SOYABEAN MEAL



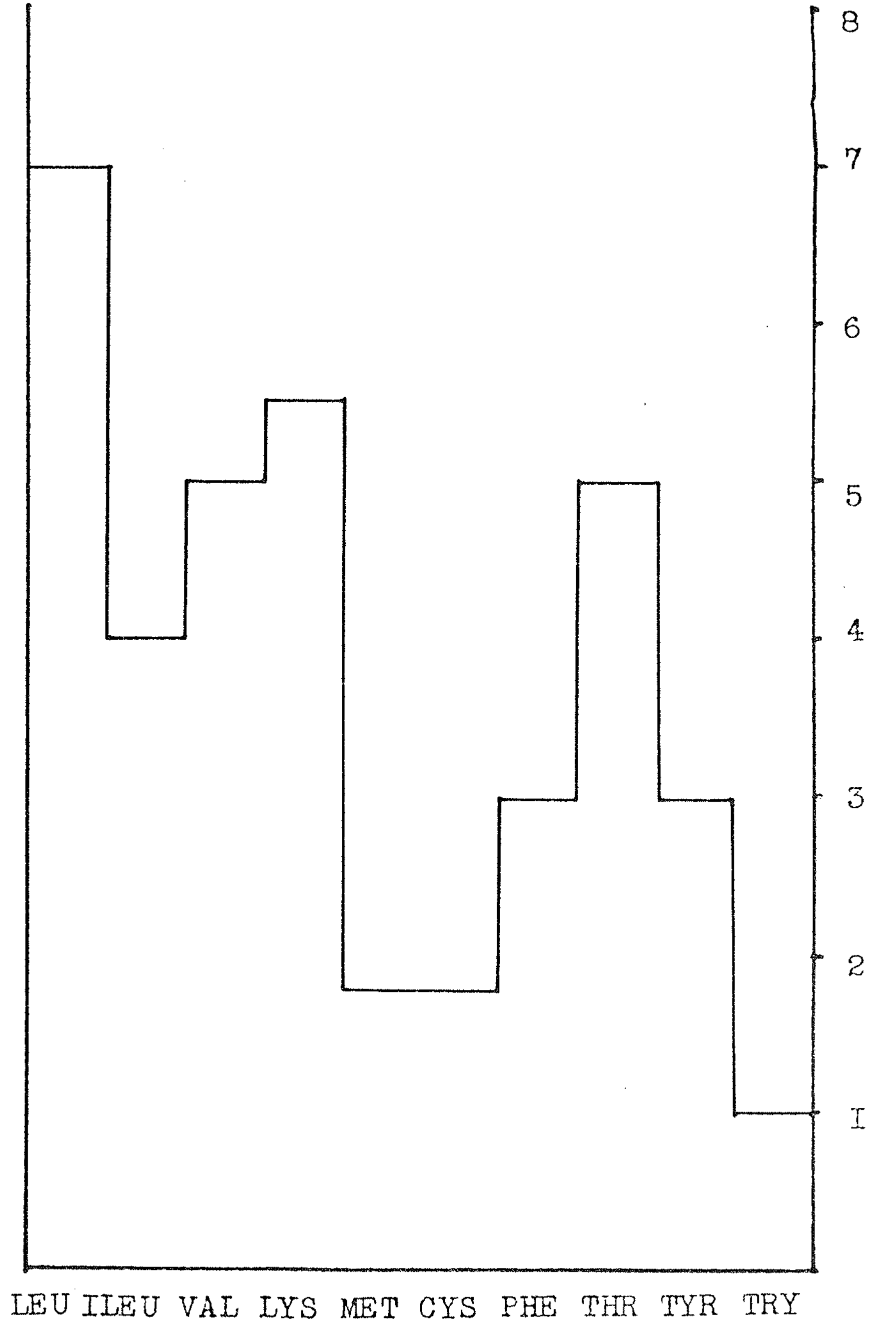
BEEF



EXTRACTED SOYA MEAL



LEAF PROTEIN CONCENTRATE



FAO/WHO SCORING PATTERN 1973

APPENDIX II

FORECASTING STUDY ON OILSEEDS

MARCH 1978

DISCUSSION OF FORECASTING STUDY

My reading on the scope for development of oilseed crops in the UK made clear to me the fact that the introduction of new crops into an agricultural system is influenced by a very wide range of constraints.

These range from the more obvious biological facts of crop species and climate variation to economic incentives to interest growers and government policy regarding the future areas of agricultural growth. Plant breeding is an active area of development with several crops, notably oil seed rape, lupins and sunflowers being carefully studied in this country. The basic material for this breeding work is varieties taken from plant breeding stations in countries as far afield as Russia, Canada, France, Germany and Australia. These must be adapted to UK conditions and bred to produce a new variety of crop plant resistant to disease, giving an economic yield of a product of sound nutritional quality in the UK climate.

In order to truly assess the state of development of oilseed research it became evident that I should carry out some form of survey among specialists involved in this field. Again, the people working on oilseeds are from many disciplines; plant breeding, oil extraction technology, agronomy and are found in industry and in government research establishments.

To carry out a survey of opinion, I formulated a questionnaire covering the three principle oilseed crops being developed in the UK; oilseed rape, sunflower and lupin. One of the problems I encountered in composing the questions was the fact that no one person would be likely to be qualified to answer expertly every one of the whole range of questions which needed to be posed. It became necessary to add a self assessment of expertise in answering each question. This would enable the specialist to confidently answer all the questions at the same time, varying his assessment of his own ability to give an opinion.

It was difficult to select people with expert knowledge of this broadly based questionnaire, so I considered research workers in plant breeding, oilseed processing, oilseed sales and development in seed companies and academic institutions.

I contacted a total of 19 specialists, of whom 15 participated in the questionnaire and three declined to take part, saying that they felt their knowledge was not sufficient to offer informed opinions. One offered to discuss with me the many points if I cared to visit him, as he felt that the information was too complex to deal with in a brief reply.

Of those replies in which the questions were qualified by an expertise rating

42 questions were answered with a rating of 1

21 " " " " " " " 2

26 " " " " " " " 3

15 " " " " " " " 4

11 " " " " " " " 5

Of these, there was a solid body of participants who replied at some length to the questions and rated themselves expert in six or more of the eight replies which they gave.

The answers to the first question concerning the introduction of double low varieties of oilseed rape showed a concensus of opinion that they could be introduced within 2-3 years. Some answers pointed out that there are already some Canadian spring varieties of double low material on the market but economic yields will not be seen until winter varieties are grown which could be by 1980.

The questions on reducing linoleic acid and fibre with a view to modifying rape to produce a more suitable analysis for human consumption was thought to be a long term project, anything up to ten years.

Question three was difficult for some people to answer, as there was some difference of interpretation of its meaning. Some said that rape could never be used for on-farm processing or if it could, then it would be a long time before it became practical. At the same time, other replies felt that if the necessary research were carried out, then it could become feasible very soon.

Question four was on lupins and here there were a wide range of opinions varying from three people who said that lupins could become commercial within three years and one who thought they may never succeed in the UK. A body of replies settled on a 3-5 year period - others said 10 and 15-20 years.

Question five invited the same opinion on sunflowers and here three people thought that they would not succeed at all and four felt their development may take another 10 years. Only five people thought that sunflowers would be commercially viable in less than 10 years.

For me, question six on the projected acreage of oilseed crops in the UK was the most surprising of all, in that 8 people thought that the oilseed acreage would not reach 500,000 acres in the foreseeable future and 4 of these gave themselves an expertise rating of 1. Those who thought that the acreage may rise this high thought it may occur within 5-10 years with qualifications, depending on the prices of competing crops such as cereals.

Of the replies to question seven, five people thought processing of oilseeds is best suited for removal of antinutritional factors whilst four thought breeding is best. Two thought there is an equal opportunity for both. The final question on the possibility of other oilseeds becoming important showed only linseed as a possible contender.

The overall results of this study were the belief that oilseed rape has a secure place in UK agriculture and that plant breeding interest in its performance is high. Generally, the prospect for lupins and sunflower is less bright, though the more far-seeing of the participants felt that both these crops have a role to play in future oilseed policy. Despite the apparently considerable potential for import substitution, there was no prospect of a dramatic expansion of acreage beyond half a million acres. Although climatically there are many limitations on sunflower and lupin cultivation, oilseed rape can be economically viable in many parts of Britain, but it was not thought likely that it will displace a significant acreage of barley for example.

THE UNIVERSITY
OF ASTON
IN BIRMINGHAM

Gosta Green, Birmingham B4 7ET/Tel: 021.359 3611 Ex 755

Technology Policy Unit
Professor Ernest Braun

12 January 1978

Dear Sir

I am a research student at Aston University engaged in a project to assess the potential for novel protein sources in the UK. My work is particularly concentrated upon the study of an increased contribution from non-animal protein sources and I am looking at such developments as single cell protein, leaf fractionation and oilseeds.

I propose to carry out a study on the oilseed industry in this country and in view of your special knowledge of these crops, I am writing to you to ask for your help in this area of my work.

My questionnaire is an attempt to see how long it may be, if ever, before oilseeds play a more significant role in UK agriculture. I am only really concerned at this stage with biological barriers to progress and in answering the questions I would ask you to consider only the delay necessitated by technical developments, not political or economic factors.

Please answer all the questions and qualify your answers using the expertise rating in the right hand columns. Category 1 implies a considerable knowledge of the topic and category 5 suggests limited knowledge, whilst category 3 classifies a participant with an adequate understanding of the subject.

I would also welcome any comments you may wish to make on the future of oilseeds in this country.

Thank you for your help in this matter.

Yours sincerely

Richard Stanley

Telex 336997

	Your Estimate	Expertise 1	2	3	4	5
1. Within how many years do you think double low varieties of oilseed rape could be commercially available?						
2. Low erucic acid and glucosinalate have been clearly defined as breeding objectives of oilseed rape and are currently being attained. Further development may be the reduction of fibre and linolenic acid - could these be attained by breeding and if so, how long would it take?						
3. How long do you think it will be before oilseed rape could be used as a home-grown component of animal feed rations for on-farm processing?						
4. Within how many years could lupins become commercially viable as a protein crop in UK?						
5. Within how many years could sunflowers be developed as a viable crop in the UK?						
6. 1977 saw a harvest of 140,000A / 60,000H of oilseeds in UK, mainly oilseed rape. Do you think that this acreage will reach 500,000A / 200,000H and if so, within what time period?						
7. Plant breeders are working on eliminating more antinutritional factors from oilseeds. Do you think that these could be more easily removed by processing?						
8. Do you think that other oilseed crops will gain importance in the UK and if so, which ones?						

Comments

LIST OF PARTICIPANTS

Dr K F Thompson
Plant Breeding Institute
Maris Lane
Trumpington
CAMBRIDGE

Dr H W Howard
Plant Breeding Institute
Maris Lane
Trumpington
CAMBRIDGE

Mr C S Elliott
Assistant Director
National Institute of Agricultural Botany
Huntingdon Road
CAMBRIDGE

Prof Watkin Williams
Dept of Agricultural Botany
University of Reading
Whiteknights
READING

Dr H G Livingston
Technical Director
Farm Feed Formulators Ltd
Darlington Road
NORTHALLERTON
North Yorkshire

Mr L Malin
Group Technical Director
Croda Premier Oils Ltd
Ann Watson Street
STONEFERRY
HULL

Mr David Dow
Technical Manager
Hurst Gunson Cooper Taber Ltd
WITHAM
Essex

Mr Mike Bearman
Regional Oilseeds Manager
Quenby Price Ltd
TURVEY
Bedfordshire

Mr B G M Gill
Group Products Manager
Kenneth Wilson (Grain) Ltd
Morwick Hall
York Road
LEEDS

Mr J H Baldwin
Agricultural Development and
Advisory Service
CAMBRIDGE

Mr Peter Groome
Mommersteeg Seed Company Ltd
Station Road
Finedon
WELLINGBOROUGH
Northants

Mr Peter Goetz
General Manager
United Oilseeds Ltd
Parnella House
Market Place
DEVIZES
Wilts

Dr R D Rice
Chambers and Forgus Ltd
189-197 Wilcolmlee
HULL

Mr I Low
Technical Manager
Spillers Newgrain Ltd
Finsbury House
HALSTEAD
Essex

Mr Lars Eskilsson
Hurst Gunson Cooper Taber Ltd
WITHAM
Essex

REFERENCES

INTRODUCTION

1. Mayer, J. The dimensions of human hunger. Scientific American, Sept. 1976, p. 40, V. 235, No. 3.

2. George, S. How the other half dies. Part 1, pp. 1-23. Penguin Books, 1976.

3. Bleasdale, J.K.A. Britain's Green Revolution. Lecture at British Association conference, Sept. 1977, Aston University.

4. Wortman, S. Food and Agriculture. Scientific American, Sept. 1976. pp. 31-39, V. 235, No. 3.

5. Pirie, N.W. Food Resources conventional and novel. Penguin Books, 1969.

6. Bull, D.A. "Protein and the food and nutrition policies of the United Nations agencies." M.Sc. Thesis, Manchester University, 1974.

7. Altschul, A.M. New Protein foods. V. 2, Part B. Technology Academic Press, 1976.

8. Richardson, W.N. Plants, Agriculture and human society. Chap. 17. W.A. Benjamin Inc., 1978.

General Reading on protein supply in Jones, A. World Protein Resources. Medical and Technical Publishing, 1974.

CHAPTER 2

1. Shibasaki, K., and Hesseltine, C.W. "Miso Fermentation", Journal of Economic Botany (1962) 16 180.

2. Lockwood, B., and Smith, A.K., "Fermented Soy Foods and Sauce", pp.357-361, (1950) Yearbook of Agriculture.

3. Tannahill, R., "Food in History", ch. 7, Paladin (1975).

4. Gray, D., "Use of Fungi as Food", p.51.

5. Spicer, A., "Proteins from Carbohydrates", (1973) Chemistry in Britain 9.

6. Hawker, L.E., Linton, A.H., "Micro-organisms - Function, Form and Environment", ch. 20, (1971).

7. Langrish, J., et al., "Wealth from Knowledge", p.136, Macmillan (1972).

8. Hesseltine and Wang, "Traditional Fermented Foods", (1967) Biotech. and Bioeng. 9.

9. Clement, G., "Production of Spirulina with CO_2", ch. 24, Single Cell Protein II Ed. Tannenbaum, S., and Wang, I., MIT Press (1975).

10. Romantschuk, H., "Operational aspects of the first fullscale Pekilo SCP mill application." Process Biochemistry, March 1978, V.13, No. 3. p.16.

11. Tannenbaum, S.R., "Single Cell Protein II", p.31, MIT Press (1975).

12. Pringle, W., "Novel Food Sources", lecture at conference on World Food Supplies, May 1974, organised by Financial Times.

13. Clement, G., "Production et Constituents Characteristiques des Algues Spirulines", (1975) Annales de la Nutrition et l'Alimentation, Vol. 29, No. 6.

14. Tannenbaum, S.R., op. cit., p.223.

15. Tate and Lyle Group Research and Development Annual Report (1975).

16. Righelato, R.C., et al., "Production of SCP from Agricultural and Food Processing Wastes", Resource Recovery and Conservation, (1976), pp.257-269.

17. Jones, A., "World Protein Resources", ch. 25, M.T.P. (1974).

18. Pringle, W., "Novel Food Sources", lecture given at Financial Times conference on World Food Supplies, May 1974.

19. Tannenbaum, S.R., op. cit., p.314.

20. Spicer, A., "Proteins from Carbohydrates" (1973), Chemistry in Britain, 9, pp. 100-103.

21. Westbury, J., "Straw: Food for Fires or Livestock", Esso Farmer, Vol. 28, No. 2 (1976).

22. Eggins, H.O.W., and Seal, K.J., "Biodegradation of Waste Agricultural Products using Recycled Nutrients", Biodeterioration Information Centre, Aston University.

23. "British Farmer and Stockbreeder", 23rd April, 1977, p.14.

24. Litchfield, J.H., Microbial Cells on your Menu", Chemtech., April 1978, p.218.

25. Dr. J. Abson, Simon Engineering, Stockport, Cheshire. Personal Communication, March, 1979.

26. Church, B.D., et al., "Fungal Digestion of Food Processing Wastes", Food Technology, February 1973, Vol. 27.

27. Pannel, S.D., and Greenshields, R.N., "Biomass Fermentation in Relation to Dairy Effluent Treatment" (1977), in print.

28. Stockbridge, P.J., "Continuous Fermentation of Food Process Effluent", First Year Postgraduate report, 1976.

29. Herrington, J.J., "Reduction of the Effluent Stream from a Brewery by Fungal Growth in Selected Brewery Wastes", Birmingham University M.Sc. thesis, September, 1976.

30. Baines, T., "Stock Feed from Pig Effluent", Farmers' Weekly, 22 April 1977.

31. Horne, Dr. D., Manager of Technical Development Division, BP Proteins. Personal communication.

32. "Economist", 10 April 1976. "Let them eat Oil", p.107.

33. Laine, B.M., et al., "Production of Single Cell Proteins from Normal Paraffins - Biochemical Engineering Problems", April 1976, BP Proteins Ltd., Brittanic House, London EC2.

34. "The Toprina Cycle", BP Publication.

35. Tannenbaum, S.R., op. cit., ch. 18.

36. Craden et al., "Substrates for SCP Production Single Cell Protein", Ed. Davis (1973).

37. Tannenbaum, S.R., op. cit., ch. 17.

38. Lublin, J.S., "High Protein Yeast from Petroleum", Wall Street Journal, 24 September, 1975.

39. MacCormick, R.D., "New Chocolate Flavour Enhancers in Food Products Development", February 1976.

40. Flannery, R.J., "Non-Agricultural Sources of Food", Food Technology, August 1975.

41. Mauron, J., "Technology of Protein Synthesis and Protein-Rich Foods", Nutrition Dietic No. 18 (1973), pp.24-44.

42. Jones, A., op. cit., Ch. 26.

43. Tannenbaum, S.R., op. cit., p.41.

44. Endozien, J.C., et al., "Nature" 228, p.180 (1970).

45. Tannenbaum, S.R., op. cit., Ch. 7, p.158.

46. Maul, S.B., et al., "Nature" 228, p.181 (1970).

47. Statement issued by Protein Advisory Group at its 17th meeting in New York, May 1970, reprinted in "Proteins from Hydrocarbons", op.cit.

48. Tannenbaum, S.R., op. cit., Ch. 31, p.564.

49. Gounell de Pontanel, "Proteins from Hydrocarbons". Proceedings of the 1972 Symposium at Aix en Provence, Academic Press.

50. "Financial Times", 20 July 1978, p.22.

51 Litchfield, J.H., Adv. in Appl. Microbiology, V.22, 1977, pp.267-301.

52. "Financial Times", 9 August, 1978.

53. "Soviet Bioprotein's industry continues rapid progress." European Chemical News, 2 April 1979, p.8.

54. Lewis, C.W., Report No. 2 to Systems Analysis Research Unit, Single Cell Protein Production, 1975.

55. Rout, M., ICI. Personal Communication.

56. Wolfson-Interplan, "Conversion of Organic Waste into Marketable Protein", 1974, p.64, v.2.

57. Worgan, J.T., Ch. 11, p.191, "Protein Production by Micro-organisms", in Plant Proteins, ed. Norton G., Butterworths 1978.

58. "Big Farm Weekly", p.15, 19 April 1979.

59. Lovland J., et al. "SCP for Human Food" - a review, Lebens Wiss Technol, 1976. 9. p.131.

60. Slesser, M., Lewis, C., and Edwardson, W., "Energy Systems Analysers for Food Policy". Food Policy, May 1977, pp.123-129.

61. Leach, G., "Energy and Food Production", International Institute for Environment and Development, 1975.

CHAPTER 3

1. Wilson, P.N. Biological Ceilings and Economic Efficiencies for the production of Animal Protein AD 2000. Chemistry & Industry, 6.7.68, pp. 899-902.

2. Pirie, N.W. Leaf Protein, its agronomy, preparation, quality and use. IBP Handbook No. 20. Blackwell Scientific Pub. 1973.

3. Jones, A.S. The Principles of Green Crop Fractionation - in Green Crop Fractionation. Ed. R.J. Wilkins. British Grassland Society Occasional Symposium No. 9, 1976.

4. Bentall, E.H., & Co. Ltd. Sales Literature for "Protessor" screw press.

5. Koegel, R.G., Bruhn, H.D., Formin, V.I. Forces needed to rupture cells. Transactions of the American Society of Agricultural Engineers, Vol. 16, p. 712, 1973.

6. Pirie, N.W. Op. cit. p. 53.

7. Koegel, R.G., Bruhn, H.D. Requirements for the expression of plant juice. B.G.S. Symposium No. 9, p. 23, 1976.

8. Thring, J.M. The BOCM-Silcock Green Crop Fractionation Process. Ibid. p. 171.

9. Arkoll, D.B. Agronomic aspects of LP production in Great Britain. IBP Handbook No. 20, p. 9.

10. Heath, S.B. Production of LPC from forage crops. Chap. 10, p. 71. Plant Proteins, Ed. G. Norton, Butterworths, 1977.

11. Arkoll, D.B., Festenstein, G.N. Journal of Science, Food and Agriculture. Vol. 22, p. 49, 1971.

12. Bray, W.J. Processing of leaf protein to obtain food grade products. BGS Symposium No. 9, p. 107, 1976.

13. Report on leaf protein feeding trial conducted at Coimbatore, South India, 1975-77. From Carol Martin, "Find Your Feet", 13-15 Frognall, London, NW3.

14. Pirie, N.W. Leaf Protein and other aspects of fodder fractionation. Cambridge University Press, 1978.

15. Betschart, A.A. Leaf Protein in human diets. BGS Symposium No. 9, p. 83, 1976.

16. Kohler, G.O., Bickoff, E.M. Commercial production of leaf protein from Alfalfa in the USA. IBP Handbook No. 20, p. 69, 1973.

17. Thring, J.M. BOCM-Silcock fractionation process. BGS Symposium No. 9, p. 171.

18. Heath, S.B., Wilkins, R.J., Roberts, W.P., Foxell, P.R. A theoretical economic analysis of systems of green crop fractionation. Ibid. p. 131.

19. New Scientist Vol. 66, 1975, p. 388.

20. Lewis, C. Leaf Protein Production Report No. 10 for Systems Analysis Research Unit, October 1976.

21. Bruhn, H.D., et al. On farm forage protein - the potential and the means. Paper No. 3. Conference of Institute of Agricultural Engineers, London, May 1977.

22. Kohler et al. Leaf Protein concentrate from Alfalfa - new developments of an old idea. 2nd International Symposium "Alimentation et Travail", Vittell, France, May 1974.

23. Lucerne gives up its protein. "Big Farm Weekly", 19.8.77.

24. Heath, S.B., and King M.W. Production of crops for green crop fractionation. BGS Symposium No. 9, p. 9, 1976.

25. Boyd, C.E. IBP Handbook No. 20, p. 44, 1971.

26. Bray, W.J. The processing of leaf protein to obtain food grade products. BGS symposium No. 9., p. 107, 1976.

27. Ref. 2, p. 63.

28. Bingham, W.J., 1976. Leaf Protein Technology and Forage Fractionation, Science Policy Research Unit, University of Sussex.

29. Abson, Dr. J. Simon Engineering, Stockport. Personal Communication 15.3.79.

30. "Big Farm Weekly", 17.5.79, p. 3.

CHAPTER 4

1. Parris, K., and Ritson, C., EEC Oilseed Products Sector and the Common Agricultural Policy, CEAS occasional paper No. 4.

2. Wilkins, R.J., Increasing Crop Protein Production for Animal Feeding in the UK. Paper for annual conference of the Institute of Agricultural Engineering, May 1977.

3. Agriculture Economic Development Council. Agriculture into the 1980s. Report on Animal Feeding Stuffs, 1977.

4. Food from our own Resources. Government White Paper, April 1975, ISBN 01 01 602006.

5. Downey, R.K., Tailoring Rapeseed and other Oilseed Crops to the Market. "Chemistry and Industry", 1 May 1976, p.401-406.

6. Nieschlag, H.J., and Wolff, I.A., "Industrial Uses of High Erucic Oils", Journal of American Oil Chemists Society, 1971, 48, p.723-727.

7. Downey, R.K., and Harvey, B.L., Canadian Journal of Plant Science, 1963, 43, p.271.

8. "Big Farm Weekly", 1 February 1979, p.9.

9. "Big Farm Weekly", 20 April 1978.

10. NIAB Farmers Leaflet No. 9. "Oilseed Rape 1978."

11. Baldwin, J., "Growing Oilseed Rape in 1977". Paper presented at Conference on Oilseeds, Stoneleigh, February 1977.

12. Ministry of Agriculture. ADAS short term leaflet No. 76, Oilseed Rape.

13. Daybell, H., "Why spray Rape at all?" "British Farmer and Stockbreeder", 29 April 1978, p.32.

14. Jones, J.D.,"Preparation and Tests on Rapeseed Proteins". Canadian Federation of Biological Sciences,Eighteenth Annual Meeting, Winnipeg, Canada, June 1975.

15. Jones, J.D., "Rapeseed Flours, Concentrates, Isolates, Status and Prospects". Rapeseed Association of Canada, Tenth Annual Meeting, Vancouver, Canada, March 1977.

16. Shah, B.G. et al.,"Beneficial Effects of Zinc Supplementation on Young Rats fed Protein Concentrate from Rapeseed". Nutrition Reports International, January 1976, Vol.13, No.1.

17. Staron, T., "Propriétiés Physico-Chimique et Valeur Nutritionelle des Proteines de Colza Extraite par Voie Fermentaire", Symposium Alimentation et Travail, May 1974, Vittel, France.

18. Jones, J.D., Personal Communication, November 1977.

19. University of Reading, Wolfson Oilseed Group, Fourth Report, 31 March 1978.

20. Dickie, P.G., "Breeding Progress in Soya, Lupin and Sunflower". Paper presented at Conference on Oilseeds in UK, NAC, February 1977.

21. Green, T.B., Personal Communication, November 1977.

22. "Big Farm Weekly", 24 March 1978 and 17 February 1978.

23. Ministry of Agriculture, Short term leaflet No.183, 1976. "Linseed for Seed."

24. Cutting, O., "Arable Farmer", October 1977, p.74-75.

25. Fletcher, S.M., "Oilseed Rape: 1976", University of Reading Agricultural Enterprise Studies Economic Report No. 53.

26. Financial Times Supplement - "Soya Beans", 21 November 1977.

27. Financial Times - "Chambers to quit Soya Foods", 31 May 1978.

28. "The Guardian", 30 May 1978, p.5.

29. Canadian Department of Agriculture, "Sunflower Seed Production, 1972."

30. Ministry of Agriculture, "Soya Beans - Crop for the Future?"

31. Lees, P., "Sunflower Expansion in UK?" Milling Feed and Fertilizer, July 1977.

32. "Farmers' Weekly", 2 March 1979, p.61.

33 "Big Farm Management", May 1979, p.25.

CHAPTER 5

1. Bray, W. Personal Communication.

2. Wilkins, R.J., et al. Report No. 19, Green Crop Fractionation, p.49. Grassland Research Institute, Hurley, Nov. 1977.

3. Lovell, J. Big Farm Weekly 1.3.79. p. 12.

4. Downey, R.K. Tailoring Rapeseed and other Oilseed crops to the Market. Chemistry & Industry, 1 May 1976, pp. 401-406.

5. Hollow, J. Tendances de la technologie des huiles vegetale. Revue Française des Corps Gras, March 1977, pp. 137-143.

6. Slesser, M. Energy Subsidy as a Criterion in Food Policy Planning. Journal of Science, Food and Agriculture, V. 24, p. 1193, 1973.

7. Lewis, C.W. Report No. 2 to Systems Analysis Research Unit, 1975.

8. Litchfield, J.H. Review of SCP Processes. Advances in Applied Microbiology, V. 22, pp. 267-301, 1977.

9. Spicer, A. Protein production by microfungi. Tropical Science, V. 13 No. 4, p. 239 (1971).

10. Unimills protein department: Refined Soya Proteins, p. 6.

11. Weigand, J.G. Processing of rapeseed and its products. Proceedings of 5th International Rapeseed Conference, Malmo, Sweden, pp. 314-333, Vol. 2, 1978.

12. Humphries, C. Personal communication 18.6.79.

13. Bingham, W.J. Leaf Protein technology and forage fractionation. A short review with an extended bibliography. Science Policy Research Unit, Sussex, 1976.

14. "Big Farm Weekly", 24.8.78.

15. "Guardian", 10.8.78, p. 16.

16. Fletcher, S.M. Oilseed Rape, 1976, Report No. 53. Reading University Department of Agricultural Economics, 1977.

CHAPTER 6.

1. Ministry of Agriculture Fisheries and Food. Food Standards Committee Report on novel protein foods. FSC/REP/62 LONDON H.M.S.O. 1974.

2. Chemical and Engineering News. March 20, 1978. p. 12.

3. Report of the study group on vegetable proteins. European Commission. Appendix III, part 1. 1978.

4. Pirie, N.W. Leaf Protein and other aspects of fodder fractionation. Cambridge University Press. 1978.

5. Synge, R.L.M. "The problems of assessing safety on novel protein rich foods." Proceedings of the Nutrition Society, 1977. V. 36, pp. 107-111.

6. British Farmer and Stockbreeder. 26 May 1979.

7. Farmers' Weekly. 27 July 1979.

8. Wolfson/Interplan Conversion of Organic Wastes into Marketable Protein, 1974. ?

9. Big Farm Weekly. 19 April 1979, p.15.

10. ref. 8. V. 1, p. 20.

11. Wells, J. New Scientist. V. 66, p. 459. 1975.

12. Lewis, C. Report No. 2 to SARU. Annendum 2, 1975. ?

13. Zermeno, R.G. Considerations on the industrial application of the chemical hydrolysis of Straw. M.Sc. Thesis UMIST, Feb.1977.

14. Goldstein, I. New Scientist, 3 Feb. 1977.

15. Hough, M.N. Meterological Office, Bracknell, Berks. Personal Communication, 13 July 1978.

16. Taille, G. Bulletin CETIOM, No. 74, 1979.

17. Cook, R.J., and Evans, E.J. Proceedings of the 5th International Rapeseed Conference, 1978. Malmo, Sweden. Vol. 2, p. 333.

18. Arable Farming, May 1979, p. 27.

19. Big Farm Weekly, 19 July 1979.

20. Ferrando, R. Conventional and Unconventional foods in Protein from Hydrocarbons. Academic Press, 1972. p. 83.

Chapter 7

1. Hall, R.H. Food for Nought. Harper & Row 1974.

2. Blaxter, K.L. Can Britain Feed Herself? New Scientist, 20.3.75, p. 697.

3. Land for Agriculture. Centre for Agricultural Strategy, Report No.1, October 1976, p. 84. University of Reading.

4. Mellanby, K. Can Britain Feed Itself? Merlin Press, 1975.

5. Watkin Williams. UK Food Production: Resources and Alternatives. New Scientist, 8.12.77, p. 626.

6. Tudge, C. The Famine Business. Pelican, 1979.

7. Passmore, R., Hollingsworth, D.F., and Robertson, J. Prescription for a better British diet. British Medical Journal, 24 February 1979, pp. 527-531.

8. Ulbricht, T.L.V. Cereals, the world food problem and UK self-sufficiency. Proceedings of the Nutrition Society, 1977 (36), p. 121.

9. Mellanby, K. Farming in the 21st Century - paper at conference on Developing Technology of Alternative Farm Systems. N.A.C. Stonleigh, 6 Feb. 1979.

10. Thompson, S.E. The Potential for and limitations of a shift from animal based to plant based agriculture and food production in England and Wales. PhD. Thesis Aston University, 1979. Part 2.4, page 253.

11. Roy, R. Wastage in the UK Food System. Earth Resources Research, 1974.

12. Thompson, S.E. op. cit. Table 2.7, p.272.

13. Prevention and Health, Eating for Health. A discussion booklet by the Health departments of Great Britain and Northern Ireland. HMSO, 1978. Dept. of Health and Social Security.

14. Thompson, S.E. PhD. Thesis, op. cit. p.263.