THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

Volume 30 Autumn 1975 No 3

THE INSTITUTION TIE

Members of the Institution are entitled to wear the Institution tie. As well as being an attractive emblem of membership in its own right it is also a particularly useful means of recognition at meetings, exhibitions, agricultural shows and other events at which members are likely to congregate. The tie is made of crease resisting and hard wearing terylene to a pleasing design displaying in silver the Presidential Badge of office on a background of navy blue, dark green or wine, according to individual taste. Institution ties are available strictly to members only and cost £1.50 each; any number may be obtained in any of the three colours mentioned. Remittances should be made payable to 'I Agr E' and crossed.

THE AGRICULTURAL ENGINEER

The December 1975 issue of THE AGRICULTURAL ENGINEER will report the Autumn National Meeting of the Institution of Agricultural Engineers, which will include papers on the guarding of mowing machines; stone-throwing problems with small rotary machines; and ventilation of farm buildings.

Display advertisement space for this issue should be ordered now.

A rate card can be supplied on request to The Advertisement Manager, The Agricultural Engineer, PO Box 10, Rickmansworth, Herts WD3 1SJ (tel Rickmansworth 78877).

INSTITUTION AUTUMN CONFERENCE

14 October 1975

THE FUTURE FOR OPERATOR EFFICIENCY & SAFETY IN THE AGRICULTURAL INDUSTRY

VENUE: National Agricultural Centre, Stoneleigh, Warwickshire.

This conference, organised by the Institution in support of National Farm Safety Year, will seek to deal with this important subject in an every-day and practical manner, and particularly to interpret and highlight the effect of the 1974 Health and Safety at Work etc Act on the responsibilities of machinery and equipment designers and manufacturers.

The chairman will be J H Wilder OBE BA FRAgS HonFIAgrE Past President of the Institution, who is well known throughout the agricultural industry for his support of sound design principles in relation to operator safety.

Anyone requiring further information should write to the Secretary, The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU. Tel: Silsoe (0525) 61096.

THE
AGRICULTURAL
ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

Volume 30 AUTUMN 1975 No 3

Institution and Editorial Office:
West End Road, Silsoe, Bedford MK45 4DU
Tel: Silsoe 61096

Advertisement Manager:
LINDA PALMER

Production Manager:
NORMAN STUCKEY AIAgrE

Advertisement and Production Office:
PO Box 10, Rickmansworth, Herts WD3 1SJ
Tel: Rickmansworth 78877

The AGRICULTURAL ENGINEER is published quarterly by the Institution of Agricultural Engineers

ABC
MEMBER OF THE AUDIT BUREAU OF CIRCULATIONS

Price: £1.20 per copy, annual subscription £4.80 (post free in UK)

Printed by Studio Trade Plates Ltd, Watford WD1 8SA

CONTENTS

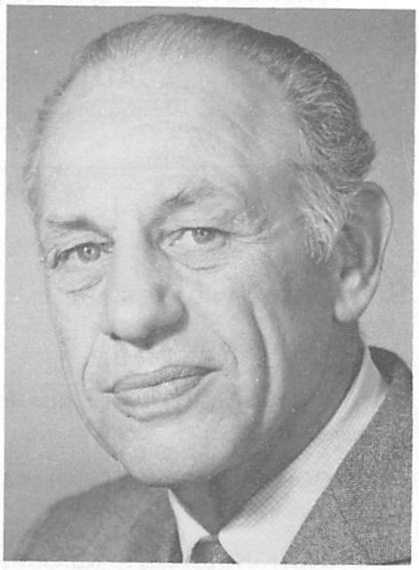
Cover: Energy from the sun powers a sunshine hours recorder. What does the future hold for other forms of energy used in agriculture?

Energy use in agriculture

TCD Manby BSc MSc CEng FIMechE and
Dr DJ White BSc DIC PhD CEng MIMechE

T C D Manby BSc MSc C Eng FIMechE, Joint Conference Convenor.

Prof J R O'Callaghan BE MSc CEng FIMechE, Conference Chairman.



Dr H C Periera DSc FRS FIBiol, Luncheon Guest of Honour.

THE conference papers summarised in this Journal bring together the details of energy use in agriculture, existing and potential sources of energy and means of reducing its use while maintaining output. Of more importance may be the views of authors on means of dramatically increasing food production albeit with increased energy use particularly in the form of nitrogen, supported by improved management skills and modern computing aids. Warnings are also given that attempts to save energy which put crop quality after storage at risk should be carefully considered.

Professor O'Callaghan first remarked when opening the Conference that it is never pleasant to have to tell the family that the inheritance is practically spent and that before too long they will have to earn their needs by their own efforts. In the case of energy and raw material resources the experiences of 1973 brought home to us that the extraordinary prosperity of the developed world in this century was due as much to cashing in on accumulated resources as to any particular skill of this generation. The non-renewable resources are held in trust for future generations and it is expected of us that we husband them carefully.

It was evident from much that followed that this generation must increase its efforts. The number attending the Conference confirmed the interest in doing so. Engineers of many disciplines have, first, the vital task of introducing improvements so that short term gains may provide time for long term achievements to be realised by, for example, biologists, botanists and physicists. It may be argued that because almost twice as much energy as the four per cent of the national total spent on the farm, is expended in processing and distributing food outside the farm gate the agricultural engineer's role is nationally relatively unimportant. This would be an irresponsible attitude for individuals to adopt. I was a little surprised however that no-one commented that, because of this ratio, there is need to reconsider certain aspects of our life style, for example, the food marketing and distribution practices we accept from large chain retailers. In Pembrokeshire recently I bought potatoes grown in the Fens and in Bedfordshire, at a different season, we have cauliflowers from Pembrokeshire! Not all families care to pay for packing and grading produce to close size limits and are happy with an assortment of sizes. Lettuce at Christmas time are enjoyable but not essential! Recently it was stated that 25% of food is wasted after leaving the farm. These are complex issues which will slowly be reappraised.

Although agriculture would most likely be in a high priority category if energy rationing were introduced in the future, this is no excuse for insensitivity to efficient methods of use. The farmer is unable to take account of idealogical considerations regarding use of irreplaceable energy resources because he must first and foremost make a profit. The greatest responsibility for finding ways of reducing energy must lie therefore with the policy makers influencing future developments and legislation. The Vice-President of the USA when addressing the Society of Automobile Engineers Annual Conference stressed that it was far better for the administration to spend money within the USA on research, development and engineering to reduce fuel usage rather than have to find the same or perhaps even less money to purchase imported fuel. He was discussing the aim to reduce fuel consumption rates for road transport by approximately 40% by 1980. In exchange for this pledge from industry the administration were preparing to relax the time scale for legislation on emissions, at least to the extent where health would not be significantly impaired.

Because agriculture's share of the nation's energy consumption is small and produces in return a little over half of the nation's unprocessed food, many believe that studying ways of improving efficiency should have a lower priority than seeking ways of expanding production to reduce our import food bill and safeguard our future. It is a strong argument at a time when resources for research and development are being trimmed and when sterling continues to decline in value so that our import bill rises without improvement in our standard of living. It is, of course, equally true that the import bill for fuel continues to rise for the same reason. Therefore I believe that because questions concerning efficiency of production and efficiency of systems are fundamental to the engineer's training, he has a special responsibility to see that energy wasting deficiencies in construction or functioning of machinery are eliminated. Maximum economies must also be achieved in the distribution of high energy input materials, such as fertilisers and in reducing crop losses.

Professor O'Callaghan reminded the Conference that renewable energy resources are all derived from the sun, are free flowing and in general do not create environmental problems, that crop photosynthethis is the main way of capturing solar energy. He questioned how much of the solar collector ie the agricultural land, which we are losing to urban development, we could really afford to dispose of in this manner. Could we improve the basic plant process and then having converted solar energy to carbohydrate could we reduce the wastage of further processes so that a larger proportion is retained for human food? He also believed that reduction of losses, which may be all that can readily be achieved in the short term, must not be dismissed as not worthwhile. In the longer term he believed there was much that the biologist could do to help.

In fact the underlying impression left in the minds of many was the enormity of the research and development still to be completed. This was not the venue to attempt to enlarge on nuclear power research or similar resource aspects, but possible solutions to the basic food problems seem most likely to emerge from long term research and discussing these was the unique and valuable contribution to the Conference made after lunch by Dr H C Pereira, the Chief Scientist of MAFF. As the man carrying the main responsibility for government support for research and development in agriculture his remarks are worth quoting at length. First, with reference to the immediate future, he pointed out that the White Paper proposal for a ten per cent increase in cereals, 30% increase in sugar beet and 20% increase in milk would increase energy requirement, but the amount would depend on whether ways can be found of increasing yield, for example, by reducing loss from existing crops. He mentioned the machinery developments already in hand to reduce energy in cultivating soil, the inefficient loading of tractors and the reduced need to pulverise soil as a means of weed control now that herbicides are available. Dr Pereira claimed, "we have a lot of fuel and a lot of soil structure to save." These and other points are mostly referred to at length in the papers.

His remarks on the longer term prospects offered most hope to a hungry world and were especially opportune for a Conference at which the members of the Association of Applied Biologists were invited to attend.

His forecast for 1980 and beyond, based on many years of study and travel in the tropics and on current work with the World Bank Consultative Group, was that in five years time the trend in the world food situation will be giving us more rather than less concern, and that the effort to grow more food in the UK will be intensified.

To many of those present he felt that the last war did not seem all that long ago. We have however less time than that to double the world's total food production since there is now no prospect of the world's populations stabilising at under twice the present numbers. Estimates of fossil fuel reserves did not suggest that there was any probable stability to be achieved on the basis of doubling the rate of use throughout the world.

He looked towards the really exciting aspects of biological and chemical research rather than engineering, although he was quite certain that every new biological or chemical achievement will involve the engineers in solving further problems.

The first major advance will, he believed be to eliminate the severe energy costs of fixing nitrogen by the high-temperature, high-pressure Haber-Bosch process, which accounts for 87% of the energy used in fertiliser manufacture. Nitrogen is fixed in nature by bacteria, which employ enzymes, called nitrogenases. This was essentially a rather complex chemical process. The challenge to biochemistry was to master this process and to employ it on a larger scale. Dr Pereira said that Professor Chat and his team from the ARC Unit of nitrogen fixation at Sussex University had already made a flying start. Using a complex molecule based on three atoms of tungsten; they have reached an astonishingly high conversion efficiency of 80%, but in minute quantities. He believed it would certainly take ten years and might well take 20 to bring this advance to a practical development, but he believed that we may well have it available by the end of the century.

This would enable nitrogen fertiliser to be made more cheaply at a small fraction of the present energy cost, but we would still need to ship it and to spread it. Here the biological solution could be more direct. Legumes harbour colonies of nitrogen fixing bacteria and absorb their output directly. Dr Pereira said that we must make fuller use of these legumes. They have diminished in our agriculture as the result of cheapness of nitrogen fertiliser, but a more exciting prospect would be to develop cereals or even root crops, capable of coming to the same comfortable symbiotic arrangements with colonies of nitrifying bacteria as do peas and beans and clover.

An outstanding advance has been the recent discovery by a woman microbiologist in Brazil, that a third type of nitrogen fixing bacterium, different from both the free-living soil types and the nodule forming rhizobia, existed in a tropical grass, a Digiteria. The bacteria lived in the cortex of the root. These not only fixed nitrogen almost as well as rhizobia but they were prepared to do so in a test tube. Dr. Pereira thought this gave rise to prospects of a type of industrial brewing in which we might be preparing nitrates instead of alcohol. An even more far-reaching and exciting possibility was the actual transferring of the genes which confer a capacity for nitrogen fixation from a nitrogen-fixing bacterium to one of a different species. The ultimate triumph of molecular biology could be to transfer the nitrogen-fixing capacity to the cells of crop plants themselves, so that wheat would manufacture its own nitrogen compounds.

Another biological avenue towards energy conservation was the increasing use of plant hormones or of chemicals which simulate them to control the growth, size, flowering and fruiting of crops. The short strawed wheats which put more of their simulates into the grain and less into the straw, had already become the basis of the "green revolution" which in spite of its difficulties was still a major contribution to the feeding of the tropical world. The transformation of the traditional apple orchard from the production of timber to the production of fruit was a very good example, said Dr Pereira. The first stage in reducing tree size was the handsaw, followed by the powersaw and the pneumatically operating pruning tool, but the biological method by which strains of root stocks were found in which plant hormones restricted the size of the tree, had brought the apple orchard of the future down to small shrubs about a metre high and a metre square, which began to crop in only three years instead of the seven to ten years of the bigger trees. In this way the fruit, exposed in a shallow horizontal layer to full sunlight, collected far more of its energy direct and quality was improved.

Data in the Conference papers showed, said Dr Pereira, that in terms of energy costs, proteins from animals were far more expensive than from plants. In the long term he was confident that plant breeders, aided by the cell biologists, would have developed cereal varieties which yielded amino acids of a type and quantity much closer to those for which we at present rely upon meat. This would save enough grain for survival, even in our crowded island. However, the prospect of a vegetarian diet would, he hoped, fire the agricultural industry to feed more cattle from its grass, a side of agricultural development in which we were sadly behind at present. Forage harvesting and conservation processes still had much for the engineer to contribute. The pressure-dewatering of forages separated enough protein from fibre to offer a viable supply digestible by non-ruminants, such as pigs and poultry. This would help to stave off the grim day of the vegetarian subsistence diet.

Finally, peering well ahead into the future of a crowded world, engineers would, he believed, design better devices for collecting and fermenting food wastes of all sorts for the production of methane — not to burn — but to provide the energy for single-celled cultures. Yeasts, bacteria and fungi had all been used successfully to the stage of established techniques held back only by the massive capital investment required. These would provide variable feedingstuffs for animals and eventually would contribute directly to our own diet. The energy feed stocks used at present were the paraffin waxes or North Sea gas, but in the long run Dr Pereira was sure that we should use biological sources of methane also.

In every new development which changed the pattern of agriculture and of food production, there was a call for yet more machinery and energy transformation and he was confident that the Institution had an important part to play in the development of future food supplies.

Until the possible benefits from longterm research are available it was the philosophy highlighted by Professor O'Callaghan which seems to summarise one of the most important technical needs of the present. He pointed out that one of the great lessons from agriculture is that if you have to work under constant energy input it is not the end of development. The two main inputs in applied science are energy and control. When energy is a limiting factor, you have to pay more attention to control and this is mainly the road along which agriculture has progressed — improved genetic control through breeding, improved control of plant growth by closer attention to timeliness, control of nutrient supply which may involve additional small inputs of energy. However because the energy input to agriculture is variable from one year to another variations in production must be smoothed by storage in the system (and the means developed of doing so efficiently!).

Energy in agricultural systems

by D J White BSc DIC PhD CEng MIMechE

Synopsis

AN analysis is made to identify the relative importance of those factors contributing to the use of energy in agriculture and to give perspective to agriculture's use in relation to national consumption. It is shown that the principal contributors are direct use of petroleum fuels (23.5%), the manufacture of fertilisers (23%), off-farm feedstuff processing (14.6%), the manufacture of machinery (14.3%) and direct use of electricity (9.1%). Up to the farm gate, agriculture uses about 4% of national energy consumption and produces, in return, a little more than half of the nation's unprocessed food. When food processing and distribution are taken into account, about 11% of national energy consumption is used to make indigenous and imported foods available to the consumer.

An introduction is given to the concept of energy budgets for commodities and the conclusions that may be drawn from these. They have, for example, an important role to play in indicating ways in which energy is used in the production of various commodities and permit alternative systems to be studied. It is shown that some farm products are more expensive in energy terms than others. For example, on a basis of energy input compared with the metabolisable energy or protein in the commodity, animal products and some horticultural crops are more costly than those based on arable crops. While it is not suggested that this currently provides any basis for determining policy in respect of the foods we should eat, it is certainly a factor that must be borne in mind in a climate of finite and diminishing energy reserves. For the present, the expenditure of energy is recognised as an admissible means of giving us varied foods to satisfy all our needs and to maximise food production in relation to land area and men employed.

1 Introduction

In the developed countries of the world, agriculture is becoming more and more energy intensive as mechanisation of operations is increased to do more work with fewer men and more extensive use is made of manufactured fertilisers to increase crop yields. From figures presented later in this paper, it will become clear that the supplementary energy expended in these forms is often greater than the solar energy captured by the crop from the sun. Thus fossil fuels, on which our present dependence is practically absolute, are as essential to UK agriculture as solar energy but that is abundant whereas fossil fuels are a finite and fast diminishing resource. Although the UK will soon have indigenous oil supplies from the North Sea and by 1980 will be producing as much oil as it uses, it is sobering to record that this self-sufficiency is unlikely to last beyond that decade[1].

Estimates of the lifetime of world energy sources are made very uncertain by the unpredictability of such factors as world resources of energy, the proportion of these that may practicably be recovered, world population trends and the growth of energy consumption brought about by even greater demands in the developed countries and the natural aspirations of under developed countries to follow suit. It is suggested by Rocks and Runyon[2] that world oil and gas reserves will be near exhaustion by 2020 and to satisfy world energy requirements then existing, world reserves of coal would have a 'constant-consumption life-span' of about three to four centuries. At the 1970 rate of world coal consumption, world reserves would last for 1700 years. These are optimistic estimates because they imply little improvement in living standards for much of the world's population. There is perhaps even greater uncertainty in relation to resources of nuclear fissile materials but it is suggested[2] that the USA could satisfy her present total power requirements for nearly 300 years. The ultimate answer to the world's future energy needs is of course nuclear fusion but this source remains tantalisingly unexploited simply because the relevant technologies do not exist. Although they are sources of energy with much lower potential yields than nuclear fusion, the same may be said of wave and tidal power, and the harnessing of geothermal and solar energy in appreciable amounts and on an industrial scale.

The picture that emerges is one in which there is promise of abundant energy at some time in the future but there are formidable problems to be overcome before the promise becomes reality. In the shorter term, within the lifetime of many now living, we are faced with depletion and exhaustion of our most versatile and convenient fuel – petroleum. When that happens, the supply of hydrocarbon fuels could be continued by synthesis from coal. However, unpredictability both in the short and long term provides compelling reasons for all industries to improve their efficiency of energy usage while continuing to balance their productivity requirements. Although agriculture's use of energy is small in the national context, there is no reason to except it from scrutiny. This paper attempts to make such a detailed analysis of energy use in agriculture and gives an introduction to the concept of energy budgets for commodities and the conclusions that may be drawn from these.

2 Analysis of energy use in agriculture

To build up a picture of agriculture's use of energy and to relate it to national consumption an examination is made of the principal contributory items and justification is given for the values deduced. Throughout this paper, the International System of Units is used in which the unit of energy is the joule (J). Some useful definitions and conversions are given in a footnote *.

2.1 National energy consumption

Table 1 shows the national energy consumption in 1973 and is taken from the Digest of UK Energy Statistics 1974[3]. Our overwhelming dependence on fossil fuels is illustrated by the fact that 97% of the energy was provided by coal, petroleum and natural gas and only 3% by nuclear and hydro-electricity. The slow growth of energy from nuclear fission is particularly to be noted; 18 years after the first nuclear power station, Calder Hall, supplied electricity to the national grid, nuclear energy accounts for only 2.6% of national energy used.

2.2 Energy of petroleum fuels

The most obvious use of energy in agriculture is in the form of petroleum fuels and in 1973[3] amounted to 1.67 Mt, constituting 1.7% of total petroleum fuels used in the UK, with an energy

Dr White is Scientific Liaison Officer, Engineering and Buildings, Chief Scientist's Group Ministry of Agriculture, Fisheries and Food, Great Westminster House, Horseferry Road, London SW1P 2AE

Paper presented at the annual conference of the Institution of Agricultural Engineers, held at the Bloomsbury Centre Hotel, Coram Street, Russell Square, London, on 13 May 1975.

*The joule (J) is a very small unit of energy and in more familar units, 1 therm = 10^5 Btu = 105.5 MJ; 1 kWh = 3.6 MJ; 1 calorie = 4.187 J. The unit of mass is the kilogramme (kg) and tonne (t) where 1 t = 1000 kg = 0.984 ton. The unit of length is the metre (m) and area the hectare (ha) where 1 ha = 10000 m^2 = 2.471 acre. Crop yields are expressed as tonne/hectare (t/ha) where 1 t/ha = 0.398 ton/acre. The following prefixes are used to denote the multiples indicated.

Prefix	kilo	mega	giga	tera	terakilo
Symbol	k	M	G	T	Tk
Factor by which unit is multiplied	10^3	10^6	10^9	10^{12}	10^{15}

Table 1 National energy consumption in the UK 1973

Resource	*Consumption Mt*	*Energy equivalent TkJ*	*Energy per cent*
Coal	134	3 500	37.8
Petroleum	95	4 300	46.5
Natural gas	–	1 170	12.6
Nuclear electricity	–	240	2.6
Hydro electricity	–	50	0.5
Totals		9 260	100.0

equivalent of 75 TkJ. However, in order to make petroleum fuels available for use, energy has to be expended in refining and transport and it has been established[4] that for every litre of petroleum produced, 1.13 litre must be put in. Thus the energy consumed (75 TkJ) when multiplied by 1.13 gives the primary energy input (85 TkJ).

2.3 Energy of solid fuels

There is a small direct use of solid fuel in agriculture[3] and while some glasshouses are still heated by this means it is also possible that much of this may find its way into domestic consumption. In 1973, the amount of solid fuel used[3] was 0.13 Mt with an energy equivalent of 3.9 TkJ, that is, about 0.1% of national consumption of solid fuels. Energy is required to mine and transport coal and it has been estimated[4] that the energy consumed (3.9 TkJ) should be multiplied by 1.04 to give primary energy input (4.1 TkJ).

2.4 Energy involved in use of electricity

The consumption of electricity on UK farms in 1973[3] was 3.95 TWh which is equivalent to 14.2 TkJ and amounted to 1.8% of national consumption. There is reason to believe[5] that 41% of this electricity is used for domestic purposes and that only 59%, that is, 8.4 TkJ is actually used for agricultural purposes. However, this is the energy used on the farm and it is necessary to convert to its primary energy input. The generating efficiency of UK power stations[3] during 1973 was 30%, 8% of the power generated is consumed at the station and there is a further loss of 8% of that sent out in transmission and distribution. The result is that the amount of energy available for consumption is only 25.4% of the primary energy input at the power station. Thus the power consumed on the farm (8.4 TkJ) must be multiplied by 3.94 to give primary energy consumed (33.1 TkJ).

2.5 Energy equivalents of other commodities and services

While the most obvious energy inputs are the fuel and power used on the farm, of equal importance are the complex network of commodities and services behind the provision of fertilisers, agricultural chemicals, machinery, farm buildings, water, feedstuffs and many other too numerous to mention. All of these inputs demand the use of energy to make them available, as was shown for fuels and power themselves, and may be considered to have primary energy equivalents. In the following, energy assessments are made for fertilisers, agricultural chemicals and machinery as these are the most important items.

2.6 Energy involved in fertiliser manufacture

Considerable energy is expended in the manufacture of fertilisers when account is taken of that in the basic materials plus that demanded by the manufacturing process and in transport. Nitrogen is the most energy intensive nutrient because its manufacture is based on natural gas which is used as the feedstock for the synthesis of ammonia. In subsequent processing, part of the ammonia is oxidised to give nitric acid and this is reacted with ammonia to give ammonium nitrate, the most common nitrogenous fertiliser. The elements phosphorus and potassium are included in many compound fertilisers and both have to be mined and transported. Phosphorus is included as phosphoric acid, often made by treating phosphate rock with sulphuric acid while potassium is added as chloride or sulphate. Estimates are available of the energy to manufacture nitrogen, phosphate and potash[6] and these energy equivalents are shown in table 2 together with the amounts used annually[7] and the energies calculated. The total energy involved in the manufacture of all fertilisers is 83.5 TkJ and 87% of this is due to nitrogen.

2.7 Energy involved in manufacture of agricultural chemicals

Agricultural chemicals, in the form of herbicides, fungicides and insecticides, are petroleum based products and the annual

Table 2 Energy involved in fertiliser manufacture, UK 1972/73 (June to May)

Nutrient	*Consumption kt*	*Energy equivalent GJ/t*	*Energy consumed TkJ*
Nitrogen (N)	946	77.0	73.0
Phosphate (P_2O_5)	481	14.3	6.9
Potash (K_2O)	435	8.3	3.6
Total			83.5

consumption[8] is about 12.4 kt with an energy equivalent[9] of 106 GJ/t. The total energy consumed is thus 1.3 TkJ.

2.8 Energy involved in manufacture of machinery, vehicles and spares

Whenever machinery is purchased an expenditure of energy is necessarily incurred which is the energy that was involved both in the machine's manufacture and in the production of the materials from which the machine was made. Thus the idea arises of capital (money spent on machines) having an energy equivalent and it is possible to make an approximate estimate for a particular industry if both total energy consumption and product value are known. For the manufacturing industries of the UK as a whole in 1973, the total energy used[3] was 3740 TkJ and the gross domestic product[10] was £2.1 x 10^{10}. Thus the energy equivalent of capital for manufacturing industry was 3740 TkJ/£2.1 x 10^{10} = 178 MJ/£. The monetary value of new plant, machinery, vehicles and spares used to support UK agriculture in 1973 has been assessed as £292 million from updated information[11], and involved the assumption that spares and labour each constituted half of the sum spent under the heading 'repairs'. Thus the total energy involved in the production of new machines is £292 x 10^6 x 178 MJ/£ = 52 TkJ.

2.9 Agriculture's use of energy in the national context

The preceding items all contribute to energy consumption in agriculture and are collected together in table 3 where they are compared with corresponding values deduced by Leach[12] for 1968. Bearing in mind that consumption of petroleum, electricity and fertilisers all increased between 1968 and 1973 it is not surprising that the present author's values are higher than Leach's although the present value for machinery looks unduly high in relation to Leach's 1968 value. However, of greater importance is the fact that Leach shows some additional inputs, which the present author has not accounted so far, and some of these such as off-farm feedstuff processing and buildings are quite significant. The author has not been able to assess these items for 1973 so has attempted to make an allowance for them by adding to the 1973 values, Leach's 1968 values for the unaccounted items. The values in table 3 represent primary energy consumption in agriculture in the UK, that is, the expenditure of energy is a part of national consumption within the UK. This point is emphasised because no mention is made of imported feedstuffs which, in effect, provide an energy subsidy to UK agriculture. Their omission is due to the fact that their production is not a charge on the UK's energy usage but is a charge on someone else's. Of course, they would be charged to the UK's account if they were home produced, assuming we had the land area to grow them. Imported feedstuffs are considered further in later sections. Table 3 shows that at 23.5% petroleum fuel is the largest single user of energy, closely followed by fertilisers (23.0%) with off-farm feedstuff processing (14.6%), machinery (14.3%) and electricity (9.1%) also having substantial inputs.

It was shown in table 1 that the total consumption of energy in the UK in 1973 was 9260 TkJ and when this is divided into the total energy consumption of agriculture of 362.7 TkJ, agriculture's share of national consumption is 3.92%, that is, about 4%. It should be appreciated that this is the proportion of energy used to produce food at the farm gate and that further substantial inputs of energy are involved before the food reaches the consumer in such things as processing, transport, packaging, distribution, retailing and household preparation. Leach[12] has made estimates for 1968 of the primary energy consumed in the fishing industry, the food processing industries including any accompanying transport and packaging, and in food distribution. Assuming these values still to apply in 1973. Table 4 shows the primary energy consumed in the UK in bringing all food to the consumer. It will be noted that food production uses 11% of national energy consumption and that the food processing industries use over 5%, a little more than

Table 3 Primary energy consumed in agriculture in the UK

Item	*1968 (Leach) TkJ*	*1973 (present author) TkJ*	*per cent*
Solid fuel	8.9	4.1	1.1
Petroleum	69.7	85.0	23.5
Electricity	29.8	33.1	9.1
Fertilisers	79.5	83.5	23.0
Agrochemicals	–	1.3	0.4
Machinery	31.8	52.0	14.3
Feedstuff processing (off-farm)	53.1	53.1 *	14.6
Chemicals	8.5	7.2 **	2.0
Buildings	22.8	22.8 *	6.3
Transport, distribution, services	16.3	16.3 *	4.5
Miscellaneous	4.3	4.3 *	1.2
Totals	324.7	362.7	100.0

*Note: Values denoted thus * are assumed to be the same as those given by Leach[12] for 1968. ** Leach's value less 1.3 TkJ for agrochemicals*

Table 4 Primary energy consumed in the UK in producing food

Function	*Energy TkJ*	*per cent*	*per cent of national consumption*
Agriculture (to farm gate)	363	36.0	3.93
Fisheries	33	3.3	0.36
Food processing industries	476	47.0	5.15
Food distribution	139	13.7	1.50
Totals	1011	100.0	10.94

agriculture's 4%. Table 4 does not consider the energy consumed in food preparation in the home. It is useful to refer to some figures for the USA where the report[13] of the Council for Agricultural Science on Energy in Agriculture permits deduction of the data presented in table 5. An interesting result is that up to the farm gate, the USA uses about 3% of national consumption against UK's 4% and uses the same amount in food processing. Of particular note is the fact that the total energy in bringing food to the plate accounts for 15% of the USA's energy consumption and is no less than 5 times the amount of energy expended in primary food production (up to the farm gate). Furthermore, these results also reveal that a relatively large energy expenditure occurs in food preparation in the home (4.5%).

To return however, to consideration of UK agriculture, it is pertinent to enquire what we get in exchange for this expenditure of energy. In 1971/72, 53.6% of our unprocessed food was produced in the UK[14], this figure being the monetary value of food moving into manufacture and distribution derived from home agriculture from all sources. Thus, we may say that 4% of national energy consumed produces a little more than half of our unprocessed food but clearly, much more than this is involved in bringing all indigenous food to the consumer (note that the total of 11% in table 4 will include some processing of imported foods). In the light of these figures it must be concluded that agriculture has a claim to receive high priority as an energy user and that even in times of dire energy shortages its modest demands should continue to be met. There is no scope for energy economies to have any effect in reducing national consumption significantly but such economies are desirable where they contribute to minimising the

Table 5 Energy consumption in the USA food system

Function	*Proportion of USA food system energy consumption, per cent*	*Proportion of USA energy consumption, per cent*
Agriculture (to farm gate)	18	2.7
Food processing	33	4.9
Transport	3	0.5
Wholesale and retail trade	16	2.4
Household preparation	30	4.5
Totals	100	15.0

rising costs of food production without putting productivity at risk.

The matter of imported foods has not been considered so far because in production, like imported animal feedstuffs, they present no charge to the UK energy budget. Leach[12] has estimated that in 1968, the energy for growing most imported foodstuffs and transporting them was 400 TkJ and the corresponding value for animal feedstuffs was 53.2 TkJ. If these figures are added to the total in table 4 the energy input to the UK food system is 1464 TkJ, equivalent to 16% of national energy consumption but, of course, 11% is the actual charge to that budget.

3 Energy flows in agricultural production systems

So far, only a broad look has been taken at the main energy inputs to agriculture. It is, however, instructive to look at systems for particular commodities to study the energy flows, to see what goes in and what is obtained in return. Such calculations as these have been done by a number of authors, namely, Slesser[15], Pimental *et al*[16] and Leach[17,18]. Following the general methodology of these authors, the present author has made some assessments[19] for selected arable and horticultural crops and for some animal products and the principal results are summarised in table 6. An explanation is given in the following section of the approach adopted and some examples of energy budgets for wheat, white bread, potatoes, dairy cattle (milk and meat) and poultry layers (eggs and meat) are given in an Appendix.

3.1 The methodology of energy accounting

To estimate the energy input, support energy or energy subsidy as it is variously called all items involving an expenditure of energy from expendable resources must be included. Solar energy is not included as an input because it is abundant. The results given in this paper have been derived taking into account wherever possible the energy inputs due to petroleum fuels, electricity, fertilisers, agricultural chemicals and machinery using the following sources. Due to petroleum fuels and electricity, the energy inputs for a selection of cropping systems were given by Rutherford[20,21] and for poultry production by Hann[22]. Rutherford[20] also gave machinery depreciation values in terms of £/ha for selected enterprises and so energy values may be calculated using the energy equivalent derived in section 2.8 of 178 MJ/£. Fertiliser values for the principal arable crops are the average amounts applied (total amount of fertiliser used on that crop divided by the total acreage of crop, including any acreage receiving no fertiliser) as determined by the Rothamsted Surveys[23,24] supplemented where necessary and for other crops by MAFF recommendations[25]. Fertiliser energy equivalents used were those given in table 2. Amounts of agricultural chemicals were obtained from various sources and the energy equivalent used was 106 MJ/kg as in Section 2.7. Data relating to various systems of animal production were supplied by Frost[26]. Because it has not been possible to assess all items involving energy expenditure, energy inputs are underestimated.

The energy output of the system is generally the metabolisable energy of the food and in some systems the output may be of more than one kind, for example, eggs and meat from poultry and milk and meat from cattle. Crop yields and animal populations have been obtained from various sources[11,22,27,28] and nutritional data relating to metabolisable energy and protein yields from MAFF sources[29]. Apart from the outputs consumable by man as food there are other products such as crop residues, animal wastes, manures, wool and hides all of which have a use to man either directly or indirectly by recycling through the crop-animal food chain. However, primacy is given to food production in the present assessment and so the by-products are not included in the analysis.

3.2 Energy in the production of particular commodities

The results summarised in table 6 may be explained as follows. The first column gives the product or commodity and the second gives the energy input or support energy on a per annum basis in relation to land area employed to raise the crop (GJ/ha year). The third column gives the output energy of the crop per annum in relation to land area (GJ/ha year) and provides a measure of the effectiveness with which land area is used to produce energy from food. For animal products, the relationship to land is established through that required to grow all the feed the animals need. This is easily established for ruminants where the feed consists of combinations of grass, hay, silage and cereals but less readily for pigs and poultry. For pigs, feed may be mainly barley with fish meal and for poultry a compounded feed consisting of grains such as maize

Table 6 Estimates of agricultural use of support energy

Commodity or product	*Energy input or support energy GJ/ha year*	*Energy output or metabolisable energy GJ/ha year*	*E = Column 3 / Column 2*	*Protein output kg/ha year*	*Energy input to produce protein MJ/kg*
Wheat	19.6	61.0	3.11	435	45
Barley	18.1	60.6	3.36	310	58
Oats	18.8	66.4	3.52	480	39
White bread	31.7	47.1	1.48	368	86
Potatoes	52.0	69.3	1.33	460	113
Sugar beet (at farm gate)	25.2	82.5	3.28	Not applicable	
Sugar from beet	109	82.5	0.76	"	"
Sugar, tops and molasses	109	129	1.19	"	"
Carrots	25.1	32.5	1.30	234	107
Brussels sprouts	32.4	10.9	0.34	296	109
Onions, dry bulb	93.4	27.7	0.30	276	338
Tomatoes (glasshouse)	1300	62.0	0.05	945	1360
Milk	17.0	12.0	0.70	145	118
Beef (from dairy herd)	10.4	3.2	0.31	40	257
Beef (from beef herd)	10.6	2.4	0.23	31	348
Pigs (pork and bacon)	18.0	11.4	0.63	76	238
Sheep (lamb and mutton)	10.1	2.5	0.25	22	465
Poultry (eggs)	22.5	6.0	0.26	113	200
Poultry (broilers)	29.4	4.3	0.15	145	203
Poultry (turkeys)	23.6	7.1	0.30	129	184

and barley with fish meal and soya. For these animals, an all barley diet has been assumed to assess the 'energy cost' of the foods they eat and to relate their requirements to land area. Since the imported components of their diets have to be transported large distances this may not be an unreasonable assumption. The fourth column gives the ratio energy output to energy input and is a measure of the 'efficiency' of a food conversion process. The higher the value of E, the greater is the energy output for a given energy input. The fifth column gives the protein output per annum on a basis of land area (kg/ha year) and the sixth column the cost of the protein in energy terms (MJ/kg).

It is necessary to add the cautionary note that unique values of E for particular commodities are not to be expected since these estimates depend on particular agricultural practices and mechanisation systems. However, an attempt has been made throughout to use 'average' values, that is, average fertiliser inputs and average crop yields. It is hoped that this consistent methodology permits meaningful comparisons to be made.

With these reservations in mind, it is apparent from table 6 that in terms of both energy and protein some commodities are produced more efficiently than others. For example, the arable crops cereals and potatoes have E values ranging from 1.3 to 3.5, while animal products have lower E values generally in the range of 0.15 to 0.31 with pig products 0.63 and milk 0.70. More energy is required to produce protein from animal products, generally in the range 184 to 465 MJ/kg, than from arable crops for which energy values range from 39 to 113 MJ/kg of protein. For milk, the corresponding value of 118 MJ/kg was closer to that of the arable crops. In relation to land area employed, both the energy output and protein output were significantly greater for arable crops than for animal products. None of these conclusions should cause any surprise since animals feed on plants and are bound to produce less energy as meat than that contained in the plants eaten. It is as well to remember that some plants cannot be eaten by man directly so are processed through ruminants to produce an edible product.

The horticultural crops in table 6 showed wide contrasts but the various values generally lay intermediate between those for arable crops and animal products. The exception was glasshouse grown tomatoes where the energy supplied to maintain the required growing temperature was by far the dominant factor and resulted in an E value of 0.05.

While estimates based on both usable energy and on protein serve to illustrate our very considerable dependence on energy subsidies to capture the solar energy that goes into producing our food, results such as those in table 6 must be treated with circumspection for yet another reason. Important though they are, energy and protein are not the only things that we get from food or even in some cases the most important. Food also supplies minerals and vitamins and, of course, there is the pleasure that is derived from eating varied foods. These are benefits which are not readily quantifiable but it should be accepted that it is as valid to use energy to produce pleasure foods as it is to use energy for pleasure motoring. The preference of an individual for using energy in one form as opposed to another will of course depend on the monetary economics associated with the various choices in relation to the needs of the situation.

3.3 Energy budget for UK agriculture

The presentation of energy budgets for particular commodities leads to the idea of presenting an overall budget for UK agriculture and this is given in table 7. The inputs are those in table 3 with the addition of energy associated with feeding stuffs imported to aid production of animal products in the UK. This may be regarded as support energy in much the same way as fuel and had equivalent feedstuffs been grown in the UK, assuming we had the land resources to do so, an expenditure of energy would have been involved. Imported feedstuffs comprise[27] nearly 70% cereals (mainly maize, barley and wheat), nearly 20% various oil cakes and the reminder largely molasses and fishmeal. To make a crude assessment of the energy equivalent of the 7.4 Mt of feedstuffs imported[27] into the UK in 1973, it has been assumed that this consisted entirely of cereals and that to produce it in the UK would require an energy input identical to that to produce wheat in the UK (4.65 MJ/kg, see Appendix). Thus the total energy would be 7.4×10^9 kg x 4.65 MJ/kg = 34.5 TkJ. However, Leach[12] has carried out a much more detailed analysis of imported feedstuffs for 1968, taking into account the energy to produce each individual component, and calculates a value of 35.2 TkJ for imports of 7.01 Mt. In addition, he estimates a transport requirement of 18.0 TkJ and these result in a total of 53.2 TkJ to make imported feedstuffs available in the UK. This final value of Leach's is used in table 7.

The outputs in table 7 are the energy equivalents of the crops passing into human consumption. Thus for crops such as cereals which are used to feed both humans and animals, only that portion used directly for humans is included. Similarly, other intermediate outputs such as animal feeding stuffs, wastes and plant residues are not shown because they are recycled (albeit some wastefully) within the system to feed animals or returned to the land to raise more crops. The output values for the plant and animal products were assembled[19] using various sources[22,28,29]. Human food was chosen as the basis for determining output because food production is the primary aim of agriculture but it should not be overlooked that energy is also involved in the by-products that man uses directly such as hides and wool just as energy must be expended in the production, say, of man-made fibres. Thus, in that sense, it may be said that the usable energy is greater than that based on food alone.

Table 7 shows that the overall E ratio for UK agriculture is 0.4. (The output value of 168.2 TkJ for 1973 is somewhat higher than Leach's value[12] of 135.7 TkJ for 1968 which results from a more detailed analysis than that of the present author. However, Leach's input value is correspondingly lower and results in an E ratio of 0.36). Thus to obtain the energy we consume in the 50% of our unprocessed food that is produced in the UK, we put in two and one-half times as much energy in the form of fossil fuels and imported feedstuffs. While this is one way of expressing the use that agriculture makes of the energy that it consumes, it is

Table 7 Overall energy budget for UK agriculture up to the farm gate, TkJ per annum

Input or energy subsidy		*Output or energy available to man*			
Solid fuels	4.1	Cereals	56.8	Arable crops	84.4
Petroleum	85.0	Potatoes	13.0		
Electricity	33.1	Sugar beet	14.6		
Fertilisers	83.5				
Agrochemicals	1.3	Vegetables	2.4	Horticulture	3.2
Machinery	52.0	Fruit	0.8		
Feedstuff processing (off-farm)	53.1				
Buildings	22.8	Milk	38.0		
Transport, distribution and services	16.3	Beef	13.8		
Miscellaneous	11.5	Pigs (pork and bacon)	17.3		
Imported feedstuffs (including transport)	53.2	Sheep (lamb and mutton)	4.5	Livestock	80.6
		Poultry (eggs)	4.5		
		Poultry (chicken)	1.9		
		Poultry (turkey)	0.6		
Totals	415.9		168.2		168.2

$$E = \frac{\text{Output energy}}{\text{Input energy}} = 0.40$$

unfortunate that no realistic common basis exists to compare the 'efficiency' with which various industries or activities use energy. Thus, we are not able to assess agriculture's performance in relation to other users of energy but the author would risk making the judgment that it is energy well spent in producing such a major necessity of life.

3.4 Trends in energy usage, manpower and crop yields

In further consideration of the use that agriculture makes of energy, tables 8 and 9 illustrate some trends over two decades from 1950 to 1970.

In table 8, it will be noted that the increase in primary energy used in the form of fossil fuels and electricity[3,30] was accompanied by a decrease in the number of all types of worker employed on agricultural holdings[28,31,32]. Over the two decades considered, energy use increased by a factor of 1.7 while the labour force was reduced to less than one half. These figures thus contain an indication of the increasing role played by mechanisation.

Table 8 Trends in primary energy usage in the form of petroleum fuels, solid fuels and electricity and number of workers employed on agricultural holdings (full-time, part-time and temporary)

Year	1950	1960	1970
Primary energy used TkJ	67	80	104
Number of workers, thousands	918	693	430

Table 9 Trends in primary energy usage in the form of fertilisers, yields of some arable crops and corresponding energy outputs

Commodity	*Year*	*1950*	*1960*	*1970*
Wheat	Energy input GJ/ha	2.77	4.83	7.69
	Crop yield t/ha	2.72	3.64	4.08
	Energy output GJ/ha	39.2	52.4	58.7
Barley	Energy input GJ/ha	2.76	4.06	6.58
	Crop yield t/ha	2.52	3.25	3.63
	Energy output GJ/ha	37.9	48.9	54.6
Potatoes	Energy input GJ/ha	9.27	13.4	17.2
	Crop yield t/ha	19.1	20.5	26.7
	Energy output	48.1	51.6	67.3
Sugar beet	Energy input GJ/ha	9.16	13.4	16.2
	Crop yield t/ha	26.8	34.8	36.0
	Energy output GJ/ha	59.6	77.4	80.1
Primary energy of all fertilisers used in agriculture TkJ		22	42	72

Table 9 shows for four different arable crops, primary energy usage on the farm in the form of fertilisers[24,33] (nitrogen, phosphate and potash), crop yields[28,31,32] and the corresponding energy outputs calculated as explained in section 3.1. Because of the vagaries of the UK climate, crop yields vary significantly from year to year and to compare one year with another may produce misleading conclusions. To reduce this possibility, the crop yields given are five year averages of the central year named and the two years on either side. For all four arable crops in table 9, increasing fertiliser energy inputs are accompanied by increased crop yields and correspondingly higher energy outputs. By taking differences between adjacent columns for different years, it will be noted that increased energy inputs in the form of fertilisers produced, in general, a greater return in output energy. An exception to this was sugar beet over the decade from 1960 to 1970 and it seems likely that this crop may be already fertilised to achieve near maximum yields. It would no doubt be erroneous to link improvements in crop yield solely with increased use of fertilisers but this achievement can be attributed to the adoption of improved seed varieties coupled with enlightened use of fertilisers and better crop protection chemicals.

4 Conclusions

The principal contributors to use of energy in agriculture are direct use of petroleum (23.5%), the manufacture of fertilisers (23.0%), off-farm processing of feedstuffs (14.6%), the manufacture of machinery (14.3%) and direct use of electricity (9.1%). Up to the farm gate, agriculture uses about 4% of national energy consumption and produces, in return, a little more than half of the nation's unprocessed food. When food processing and distribution are taken into account, 11% of national energy consumption is involved in making indigenous and imported foods available to the consumer. Agriculture has a claim to receive high priority as an energy user and even in times of dire shortages, its modest demands should continue to be met. There is no scope for energy economies to have any effect in reducing national consumption significantly but such economies are desirable where they contribute to minimising the rising costs of food production without putting productivity at risk.

It has been shown that some farm products are more expensive in energy terms than others. For example, on a basis of energy input compared with the metabolisable energy or protein in the commodity, animal products and some horticultural crops are more costly than those based on arable crops. However, energy and protein are only two of a number of benefits that we get from food and while 'energy costs' do not at present determine the foods that we eat, they are certainly a factor that must be borne in mind in a climate of finite and diminishing energy reserves. But at present, it is the monetary economies not the energy economics that dictate the situation and provided monetary economics are favourable it is expected that the production of energy expensive foods will continue.

The expenditure of energy should be recognised as an admissible means of giving us varied foods to satisfy all our needs and to maximise food production in relation to men employed and land area. Land, like fossil fuel, is a limited resource in the UK with many conflicting demands placed upon it, though fortunately it is not exhaustible in the same sense as are fossil fuels. In using supplementary energy to produce food, or for that matter any other purpose, we are expressing a preference for receiving its benefits in that form as opposed to some other. However, our present dependence on fossil fuels and their exhaustibility cannot be ignored and it would be wise to control the rate at which they should be consumed in relation to the various calls made upon them.

Appendix

Energy budgets for selected commodities

All energy values are given in terms of primary energy consumed unless otherwise indicated. Some energy inputs that are likely to be of significance have not been accounted and these are mentioned where this applies.

Wheat

Fertilisers	
Nitrogen, 96.5 kg/ha (Ref 24) x 77 MJ/kg (Section 2.6)	= 7430 MJ/ha
Phosphate (P_2O_5), 46.5 kg/ha (Ref 24) x 14.3 MJ/kg (Section 2.6)	= 665 MJ/ha
Potash (K_2O), 39 kg/ha (Ref 24) x 8.3 MJ/kg (Section 2.6)	= 322 MJ/ha
Herbicides, 2 kg/ha (Ref 34) x 106 MJ/kg (Ref 9)	= 212 MJ/ha
Seed, 188 kg/ha (Ref 34) x 4.65 MJ/kg (result of calculation)	= 875 MJ/ha
Fuel used in field operations (cultivations, harvesting etc) (Ref 20)	= 2331 MJ/ha
Grain drying, 6% moisture reduction (Ref 20)	= 5760 MJ/ha
Machine depreciation and repairs, 11.4 £/ha (Ref 20) x 178 MJ/£ (Section 2.8)	= 2030 MJ/ha
Energy input	19625 MJ/ha
Yield of wheat (Ref 11) at 15% moisture content	= 4220 kg/ha
Energy subsidy for wheat = (19625 MJ/ha)/(4220 kg/ha)	= 4.65 MJ/kg
Energy output = 4220 kg/ha x 14.4 MJ/kg (Ref 29)	= 61000 MJ/ha
E = (61000 MJ/ha)/(19400 MJ/ha)	= 3.11
Protein content of wheat, 10.3% (Ref 29) = 4220 kg/ha x 0.103	= 435 kg/ha
Energy to produce protein = (19625 MJ/ha)/(435 kg/ha)	= 45.0 MJ/kg

White bread

All values given are taken from Leach[17], except where indicated otherwise. The following figures apply to one standard white loaf, 28.25 oz, 0.801 kg

Energy to produce wheat grain = 0.758 kg x 4.65 MJ/kg (see wheat above)	= 3500 kJ
Milling of grain at 73% extraction gives 0.553 kg of flour and requires	736 kJ
Baking requires	845 kJ
Transport; farm to mill, mill to baker, baker to shop requires	330 kJ
Finishing, wrapping etc requires approximately	300 kJ
Energy input	5711 kJ
To produce one loaf requires (0.758 kg)/(4220 kg/ha) = 1.8×10^{-4} ha	
Energy input = 5711 kJ/1.8×10^{-4} ha	31700 MJ/ha
Energy subsidy for white bread = 5711 kJ/0.801 kg	= 7.13 MJ/kg
Energy output = (0.801 kg x 10.6 MJ/kg (Ref 35))/1.8×10^{-4} ha	= 47100 MJ/ha
E = (47100 MJ/ha)/(31700 MJ/ha)	= 1.48
Protein content of bread 8.3% (Ref 35) = 0.801 kg x 0.083/1.8×10^{-4} ha	= 368 kg/ha
Energy to produce protein = (31700 MJ/ha)/(368 kg/ha)	= 86 MJ/kg

Potatoes

Fertilisers	
Nitrogen, 170 kg/ha (Ref 24) x 77 MJ/kg (Section 2.6)	= 13100 MJ/ha
Phosphate (P_2O_5), 177 kg/ha (Ref 24) x 14.3 MJ/kg (Section 2.6)	= 2530 MJ/ha
Potash (K_2O), 244 kg/ha (Ref 24) x 8.3 MJ/kg (Section 2.6)	= 1610 MJ/ha
Herbicides, 13 kg/ha (Ref 34) x 106 MJ/ha (Ref 9)	= 1380 MJ/ha
Seed, 2500 kg/ha (Ref 34) x 1.89 MJ/kg (result of calculation)	= 4730 MJ/ha
Fuel used in field operations (cultivations, harvesting etc) (Ref 20)	= 5439 MJ/ha
Grading and storage (Ref 20)	= 20160 MJ/ha
Machine depreciation and repairs, 16.4 £/ha (Ref 20) x 178 MJ/£ (Section 2.8)	= 2920 MJ/ha
Energy input	= 51869 MJ/ha
Yield of potatoes (Ref 11)	= 27500 kg/ha
Energy subsidy for potatoes = (51869 MJ/ha)/(27500 kg/ha)	= 1.89 MJ/kg
Energy output = 27500 kg/ha x 2.52 MJ/kg (Ref 29)	= 69300 MJ/ha
E = (69300 MJ/ha)/(51869 MJ/ha)	= 1.33
Protein content of potatoes, 1.68% (Ref 29) = 27500 x 0.0168	= 460 kg/ha
Energy to produce protein = (51869 MJ/ha)/(460 kg/ha)	= 113 MJ/kg

Dairy cattle (milk and meat)

All values given are taken from Frost[26], except where indicated otherwise. The following figures are given on a per cow per annum basis and it is assumed that the average cow feed is divided between hay and silage in the proportion 65% to 35%.

Concentrates (assumed to be barley), 1200 kg x 4.48 MJ/kg (Ref 19)	= 5360 MJ
Grass (14 kg dm * for 185 days) = 14 kg x 185 x 1.37 MJ/kg (Ref 19)	= 3550 MJ
Silage (8 kg dm for 180 days) = 8 kg x 180 x 0.35 x 1.82 MJ/kg (Ref 19)	= 917 MJ
Hay (7.7 kg dm for 180 days) = 7.7 kg x 180 x 0.65 x 1.81 MJ/kg (Ref 19)	= 1630 MJ
Total forage and concentrates	= 11457 MJ

* dm means dry matter

A separate calculation (Ref 19) gave an input of 8360 MJ to raise a heifer and if it is assumed that the cow is replaced after five years, then the portion to be accounted per annum is 8360/MJ/5	= 1672 MJ
Energy used in the milking parlour (vacuum pump, milk cooling, hot water etc) is estimated to be about 0.3 kWh per gallon of milk produced (Ref 36) = 0.3 kWh/gallon x 888 gallons x 3.6 MJ/kWh x 3.94 (Section 2.4)	= 3780 MJ
Energy input (total)	= 16909 MJ
The area required to produce the forage and concentrates has been assessed (Ref 19) as	= 0.993 MJ
Energy input = 16909 MJ/0.993 ha	= 17000 MJ/ha
Average milk yield per cow per annum (Ref 11)	= 888 gallon
Energy output of milk = 888 gallons x 4.54 kg/gallon x 2.75 MJ/kg (Ref 29)	= 11100 MJ
Energy output of calf assumed culled at birth (carcass weight, 55% of liveweight of 45 kg = 24.8 kg) = 24.8 kg x 10.17 MJ/kg (Ref 29)	= 250 MJ
Energy output of culled cow per annum (assumed culled after five years with carcass weight 55% of liveweight of 545 kg = 300 kg) = 300 kg x 10.17 MJ/kg (Ref 29) x 0.2	610 MJ
Energy output (total)	= 11960 MJ
Energy output = 11960 MJ/0.993 ha	= 12000 MJ/ha
E = (12000 MJ/ha)/(17000 MJ/ha)	= 0.70
Protein content of milk (3.3%) and beef (12.9%) (Ref 29) = 888 gallons x 4.54 kg/gallon x 0.033 + (24.8 + 300 x 0.2) kg x 0.129	= 144 kg
Protein output = 144 kg/0.993 ha	= 145 kg/ha
Energy to produce protein = (17000 MJ/ha)/(145 MJ/ha)	= 118 MJ/kg

Not accounted above but likely to be significant in the production of milk are energy inputs in feed preparation, delivery of feed from store to animals, removal of animal wastes and buildings to house animals.

Poultry layers (eggs and meat)

All values given are taken from Frost[26], except where indicated otherwise. The following figures are given on a per layer per annum basis (the production life of a bird is about 52 weeks)

Feed to rear layer (6.8 kg) + feed for layer per annum (45.5 kg)	=	52.3 kg
At 1 breeder to 65 layers, the proportion of breeder feed is 52.3 kg/65	=	0.8 kg
Energy input to feed (assumed to be all barley, actually it is a compound of maize, barley, soya, fish meal) = 53.1 kg x 4.48 MJ/kg (Ref [19])	=	237 MJ
For each layer per annum, energy is supplied in the form of electricity, oil and gas as follows (Ref [22])		
Fans and lighting for layers	=	41.5 MJ
Heat, fans and light for layer replacements	=	17.4 MJ
Heat, fans and light for breeding stock and replacements	=	1.3 MJ
Energy input (total)	=	297.2 MJ
Area required to produce feed per layer, if all barley = (53.1 kg)/(4030 kg/ha) (Ref [11])	=	0.0132 ha
Energy input = 297.2 MJ/0.0132 ha	=	22500 MJ/ha
Energy of eggs per annum (234 eggs per layer at 0.31 MJ per 2oz egg) = 234 x 0.31 MJ	=	72.5 MJ
Energy of culled hen (carcass weight 75% of deadweight at 2.08 kg = 1.56 kg) = 1.56 kg x 3.78 MJ/kg (Ref [29])	=	5.9 MJ
Energy output (total)	=	78.4 MJ
Energy output = 78.4 MJ/0.0132 ha	=	5950 MJ/ha
E = 5950 MJ/22500 MJ	=	0.264
Protein content of eggs (10.8%) and chicken (12.1%) (Ref [29]) = 234 x (2 x 0.454/16 kg) x 0.108 + 1.56 x 0.121	=	1.49 kg
Protein output = 1.49 kg/0.0132 ha	=	113 kg/ha
Energy to produce protein = (22500 MJ/ha)/(113 kg/ha)	=	200 MJ/kg

Not accounted above but likely to be significant is the energy input to provide buildings to house the birds with any associated mechanisation for feeding and egg removal.

Acknowledgements

I am grateful to Gerald Leach for making available to me his analyses of energy in relation to the UK food system for 1968, to Brian Frost for advice on systems of animal production and to Bob Little for advice on fertiliser practice.

References

1 Production and reserves of oil and gas in the United Kingdom', May 1974, HMSO.
2 **Rocks L and Runyon R P** *The Energy Crisis,* 1972, Crown Publishers, Inc, (New York).
3 Digest of United Kingdom energy statistics 1974, HMSO.
4 **Chapman P F, Leach G A and Slesser M.** The energy cost of fuels, *Energy Policy,* September 1974, p 231.
5 **Bayetto R A.** Central Electricity Council, private communication.
6 'The energy input to a bag of fertiliser'. Imperial Chemical Industries Ltd, Agricultural Division, Billingham, Cleveland.
7 'Fertiliser Statistics 1973', Fertiliser Manufacturers' Association Ltd.
8 'Current levels of resource use in agriculture', National Economic and Development Office, Report EDC/AG(74)1, January 1974.
9 **Leach G A and Slesser M.** 1973. 'Energy equivalents of network inputs to food producing processes', Strathclyde University, Glasgow, private circulation.
10 National income and expenditure 1963–1973, Central Statistical Office 1974.
11 Annual review of agriculture 1974, HMSO.
12 **Leach G.** Private communication, March 1975.
13 'The Cast Report' *Agricultural Engineering,* March 1974 p 19, April 1974 p 37, May 1974 p 21.
14 Annual abstract of statistics 1973, HMSO.
15 **Slesser M.** 'Energy subsidy as a criterion in food policy planning', *Journal of Science and Food in Agriculture* 1973, Vol 24, p 1193.
16 **Pimental D, Hurd L E, Bellotti A C, Forster M J, Oka I N, Sholes O D and Whitman R J.** 'Food production and the energy crisis', *Science* 1973, Vol 182, p 443.
17 **Leach G A** 1974. 'The energy cost of food production'. Chapter in *Bourne A The Man Food Equation,* Academic Press, London.
18 **Leach G A,** 1974. 'Industrial energy in human food chains'. Chapter in **Duckham A N and Jones J G W.** *Human Food Chains and Nutrient Cycles, Elsevier.*
19 **White D J.** Estimates of energy inputs and outputs for various agricultural products. Unpublished work 1975.
20 **Rutherford I.** Private communication. February 1974. Agricultural Development and Advisory Service, Ministry of Agriculture, Fisheries and Food, Silsoe, Bedford.
21 Report of the Energy Working Party, December 1974, Report No 1. Joint Consultative Organisation for Research and Development in Agriculture and Food.
22 **Hann C M.** Private communication, December 1974. Agricultural Development and Advisory Service, Ministry of Agriculture, Fisheries and Food, London.
23 **Church B M.** (1974). Use of fertilisers in England and Wales, 1973. Mimeographed report prepared for MAFF, ADAS 'Closed' Conference of Advisory Soil Scientists Soil Analysis and Fertiliser Committee (SS/SAF/9).
24 'Fertiliser Statistics 1972', Fertiliser Manufacturers' Association Ltd.
25 Fertiliser Recommendations, MAFF Bulletin 209, (1973), HMSO.
26 **Frost B.** Private communication, January 1974. Agricultural Development and Advisory Service, Ministry of Agriculture, Fisheries and Food, Reading.
27 Output and utilisation of farm produce in the United Kingdom 1967/68 to 1972/73, Ministry of Agriculture, Fisheries and Food.
28 Agricultural Statistics, United Kingdom 1972, HMSO 1974.
29 Food Science Division, Ministry of Agriculture, Fisheries and Food.
30 Department of Energy, private communication.
31 Agricultural Statistics, United Kingdom 1962/63, HMSO 1965.
32 Agricultural Statistics, United Kingdom 1953, HMSO 1955.
33 Fertiliser Statistics 1965, Fertiliser Manufacturers' Association Ltd.
34 **Austin R B.** Private communication, 27 February 1974. Plant Breeding Institute, Cambridge.
35 Manual of Nutrition, HMSO.
36 **Thiel C.** Private communication. National Institute for Research in Dairying, Shinfield, Reading.

Integration of NCAE with The Cranfield Institute of Technology

NCAE is the last of the eight national colleges to be integrated into larger higher educational institutions as a part of current Department of Education and Science policy. It was founded as the result of a joint approach to the Department of Education and Science from the Institution of Agricultural Engineers and the agricultural engineering trade associations. Teaching, with an initial intake of 15 students, started in 1962; the College now has an undergraduate entry of 50 students per year, and accepts 80 post-experience candidates for one-year postgraduate courses.

As a CIT School, NCAE will retain its own academic identity and its present title. It will be able to call upon the expertise of the Cranfield schools to help expand its teaching and research activities and will continue to organise and develop short courses for the agricultural engineering profession and industry. In common with the other schools of CIT, NCAE will be fully represented on the various academic and legislative boards of CIT and will plan its own future development within the CIT faculty structure. A professional and industrial liaison committee will be formed, which will include many members of the retiring governing body to advise on this development.

Energy sources

by G E Bowman B Sc

DISREGARDING meteorites and space vehicles, the material resources of the earth form a closed system. We have available to us stored energy in the form of fossil and nuclear fuels, there is a net loss of energy by long wave radiation from the earth's surface and a net gain of short wave solar energy. The solar energy gain exceeds the long wave loss, the difference being accounted for by the evaporation of water, convection in the atmosphere and storage via photosynthesis. Fossil fuel is transformed solar energy and is replaceable only on a geological time scale, and if the environment is appropriate, whilst nuclear fuel is irreplaceable. Thus the only continuously available supply of energy is from the sun — even this may not be true on a cosmological time scale.

Solar energy

The sun is a nuclear reactor conveniently situated 1.5×10^{11} m (93 million miles) from the earth and has a power output of 3.9×10^{26} W (5.2×10^{23} horsepower). Taking the mean radius of the earth to be 6.4×10^{6} m (4000 miles), the solar radiation flux intercepted by the earth is 1.79×10^{17} W (2.4×10^{14} horsepower)[1]. About half of this is absorbed and re-radiated by the atmosphere; at latitude 52^{o} the annual mean receipt of energy[2] is 270 W/m^2 (0.43 horsepower/yard^2) outside the atmosphere, but only 110 W/m^2 (0.18 horsepower/yard^2) at the surface.

The energy emitted by the sun approximates to that from a black body at 6000 K, although solar radiation is emitted simultaneously by layers at varying depths and temperatures. For the present purpose the process is adequately described by Planck's law

$$E\lambda d\lambda = \frac{(hc^2/\lambda^5)\, d\lambda}{\exp(hc/k\lambda T) - 1}$$

which leads to a spectral distribution of the form shown in fig 1, in which the uppermost curve represents the solar spectral energy distribution outside the atmosphere. The five successively attenuated curves represent the spectral energy distributions after passage through a turbid and humid atmosphere[3] of relative air masses 1-5, where relative air mass is defined as the secant of the zenith angle ie proportional to the path length of sunbeams through the atmosphere. The highest attenuated curve represents the condition when the sun is directly overhead, for example midsummer noon on the tropic of Cancer, or equatorial noon at the solstices. The lowest curve, relative air mass 5, is representative of conditions at noon in British mid-winter, when the solar elevation is about 12^{o} above the horizon. Most of the absorption bands in fig 1 are due to water vapour, though absorption in the ultra-violet (at wavelengths less than 300 nm) is due to ozone — the presence of which is vital to the continuance of life. Energy within the waveband 400-750 nm is photosynthetically active and this constitutes nearly half of the available energy.

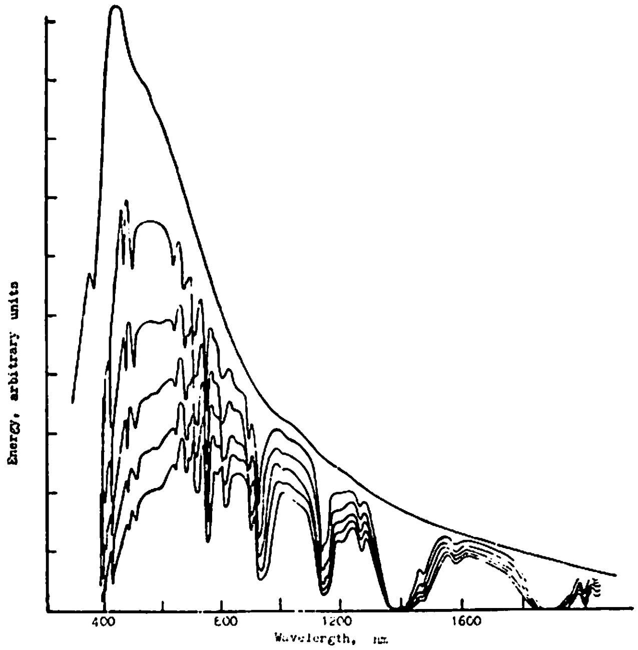


Fig 1 Spectral distribution of solar energy for various air masses (after Duggar 1936).

In temperate latitudes, because of atmospheric scattering, approximately half of the solar radiation received is diffuse. Fig 2

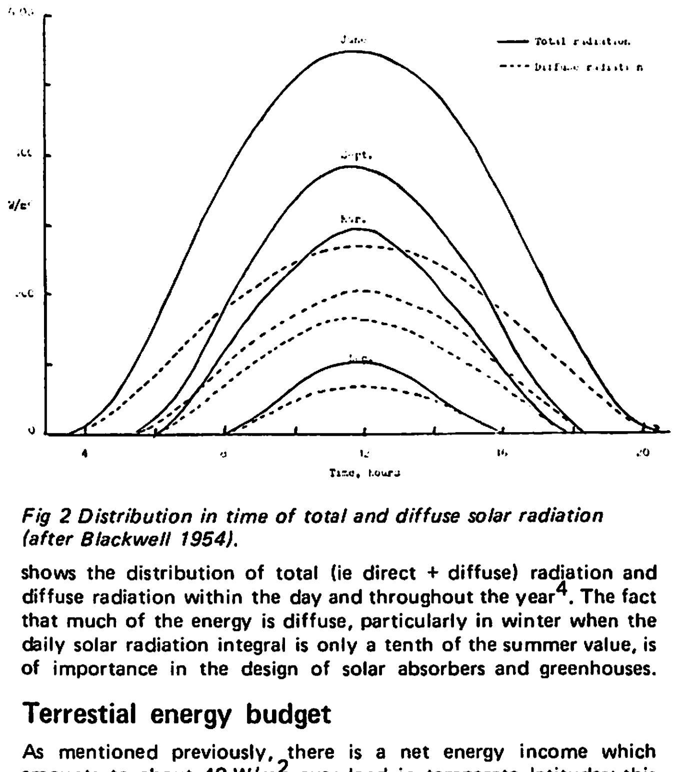


Fig 2 Distribution in time of total and diffuse solar radiation (after Blackwell 1954).

shows the distribution of total (ie direct + diffuse) radiation and diffuse radiation within the day and throughout the year[4]. The fact that much of the energy is diffuse, particularly in winter when the daily solar radiation integral is only a tenth of the summer value, is of importance in the design of solar absorbers and greenhouses.

Terrestial energy budget

As mentioned previously, there is a net energy income which amounts to about 48 W/m^2 over land in temperate latitudes; this is made up of 110 W/m^2 short wave solar radiation, of which a quarter is reflected by vegetation, 330 W/m^2 long wave low temperature radiation from the atmosphere and 370 W/m^2 long wave re-radiation from the earth's surface. Most of the energy income is dissipated in the evaporation of water. The annual difference between rainfall and runoff is 410-480 mm; taking the latent heat of vaporisation water as 2.26 MJ/kg, evaporation requires an average energy supply rate of 32-38 W/m^2. Most of the remaining energy (about 12 W/m^2) is used in maintaining atmospheric circulation, only a very small part, perhaps 0.5 W/m^2, being converted by photosynthesis into vegetable dry matter of calorific value.

Fossil and nuclear fuels

Table 1 shows the estimated world recoverable fuel reserves. It is extremely difficult to be definitive about such estimates, since much depends on what is meant by recoverable: generally the exact meaning will be decided by economic considerations. The data were taken from the general discussion following a Royal Society discussion[5].

The energy unit 10^{20} J, though unconventional, will be found convenient later when considering contemporary rates of con-

Mr Bowman is from Control Department, National Institute of Agricultural Engineering, Silsoe, Bedford.

Paper presented at the annual conference of the Institution of Agricultural Engineers held at the Bloomsbury Centre Hotel, Coram Street, Russell Square, London 13 May 1975.

Table 1 Estimated world recoverable fuel reserves

Coal, lignite	2000 x 10^{20}J
Oil	140 "
Natural gas	100 "
Tar sand	20 "
Oil shale	10 "
Uranium (thermal)	50 "
(fast breeder)	(1500) "

sumption. Alternatives for the energy value of uranium arise because only 0.7% is naturally fissionable U235. But U238, by neutron bombardment, can be converted into fissionable material, which after two rapid radioactive transformations changes into fissionable Pu 239. Such a conversion or breeding process greatly enhances the energy yield. Even greater theoretical possibilities exist in the use of lithium as fuel for a deuterium-tritium reactor; 1% of the lithium thought to be dissolved in the sea would yield the energy equivalent of a thousand times the coal and lignite reserves, 56% of which lie within the USSR[6].

Energy consumption

Increase in world population and economic growth have demanded, and so far obtained, a large increase in energy consumption, as indicated in fig 3. A notable feature is that most of the increase

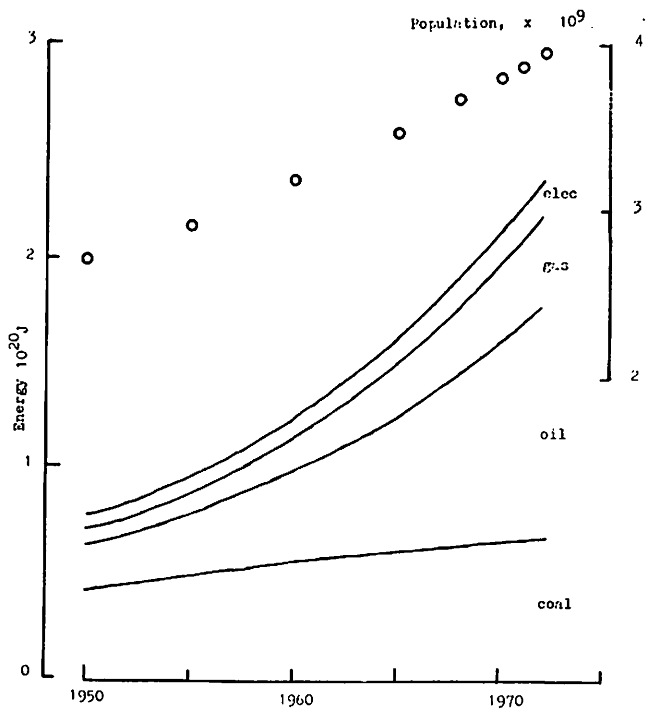


Fig 3 Changes in population and energy consumption (after Darmstadter and Schurr 1974).

within the last decade has been provided by oil, which is not the most abundant fossil fuel. Furthermore, fuel consumption is increasing at a faster rate than population, as enumerated[7] in table 2.

Table 2 Percentage annual rates of increase, world average

Period	*Population*	*Energy consumption per head*	*Total energy consumption*
1925–50	1.1	1.1	2.2
1950–55	1.7	3.6	5.3
1955–60	1.9	2.5	4.5
1960–65	1.9	3.4	5.3
1965–70	1.9	3.9	5.9
1970–72	1.9	3.2	5.2

Thus if we maintain our energy demand pattern by that set since 1950, this will lead to an annual increase rate of 5.3%, or a doubling of energy demand every 13 years.

Having gathered data on conventional energy resources and consumption patterns, an obvious step is to calculate the likely life time of the various fuels. History may well prove such a calculation to be wrong, either because a hitherto unsuspected energy source is discovered, or because the human race moderates its demand for energy. However, table 3 shows what we may expect to happen if a population, increasing annually at 1.9%, demands energy at an annual rate of increase of 5.3%. The life times quoted are based on the exclusive use of any one fuel, since it is not possible to predict the component proportions of a mixture of fuels, nor is it realistic to suppose that such proportions would remain constant.

Table 3 Estimated life in years of world fuel reserves

Fuel	*1975*	*1980*	*1985*	*1990*
Coal	698	535	409	301
Oil	45	31	19	10
Gas	31	20	11	4
Tar sand	3	–	–	–
Oil shale	–	–	–	–
Uranium (thermal)	14	6	–	–
Uranium (fast breeder)	523	399	304	230

It has often been said that coal is much too valuable a mineral to burn; if this is true, then it is almost impossible to justify the use of petroleum as mere fuel.

Alternative energy sources

Both windmills and watermills have been used for many centuries, and in both cases the power is derived from converted solar energy. Although about 2% of the solar energy received is converted into wind, only a small proportion is exploitable, partly because of site limitations and also because of the engineering problems inherent in the construction of large machines[8]; altogether exploitable wind power is estimated to be 9.5 x 10^3 MW, ie 3 x 10^{17} J annually or about just over a thousandth of the present energy demand.

Since most of the solar energy is used in maintaining the hydrological cycle, it is not surprising that water power represents the greatest natural concentration of solar power, and is estimated[6] to be some 3 x 10^6 MW. This represents an annual energy of 9 x 10^{19} J or rather more than one third of the present energy demand.

Potential tidal power, based on a day lengthening of 0.001 second per century, is about 3 x 10^6 MW. As in the case of wind, full exploitation is difficult and is estimated to be 1.3 x 10^4 MW, again about a thousandth of the present energy demand. Geothermal energy, resulting from the temperature gradient within the earth's crust, has been exploited at several geologically suitable sites, the first being at Larderello in Italy[9]. It is estimated that full exploitation of geothermal energy would yield some 6 x 10^4 MW for a period of 50 years[6]; this is only half of one per cent of the present energy demand.

One man's share

Having enumerated global resources, it is perhaps worth considering their significance on a per capita basis. One man's share of the available solar power is 18.7 MW, or 5.9 x 10^{14} J annually; this is exactly ten thousand times the present annual *per capita* of consumption of fossil fuel.

Man's daily food has an energy content of 8 MJ (2000 kilocalories); this is equivalent to an annual global requirement of 1.14 x 10^{19} J. If we assume this food to be entirely vegetable, grown at a photosynthetic efficiency of 0.5%, then the solar energy required is 2.3 x 10^{21} J. This amount of energy is received by one thousandth part of the earth's surface, the total area of which is 5.09 x 10^{10} hectares. Of this, 1.46 x 10^9 hectares are classified as agricultural[10]. One concludes that such a subsistence diet could support a population of 1.1 x 10^{11}. At present rates of agricultural production and population increase, this limit would be reached in 178 years. A conversion efficiency of 0.5% applies to a crop such as sugar beet and excludes the energy content of any fertiliser used. Conversion efficiencies depend on the nature of the crop[2], the lowest being 0.03% for rough grazing; the average for British agriculture is about 0.2%. Thus if all of the future population were to be supported by a system equivalent to present British agriculture, the limit would be reached in 129 years.

Energy and greenhouse technology

A greenhouse is a building, admitting solar radiation, within which an environment suitable for the growth of plants may be maintained. In energy terms, it is necessary for the greenhouse to admit solar radiation efficiently during the day and to retain heat during the night.

The optical properties of glass are ideal for greenhouse cladding; transparency is high in the solar spectrum but low in the long-wave infra-red region, the wavelengths characteristic of thermal radiation from surfaces at ambient temperature. Glass therefore acts as an energy trap, in that the heat radiated from the sun-warmed contents of a greenhouse cannot pass through the glass — but heat loss does occur by conduction through the glass. The most commonly used plastic film in horticulture, polyethylene, is substantially transparent to radiant heat and so exhibits a weaker "greenhouse" effect than glass. The refractive index of glass, and that of most transparent plastics, is close to 1.5 and thus some light is lost by reflection at the surfaces. Such reflection losses may be calculated from Fresnel's equations[11]; the losses depend upon the angle of incidence as shown in fig 4.

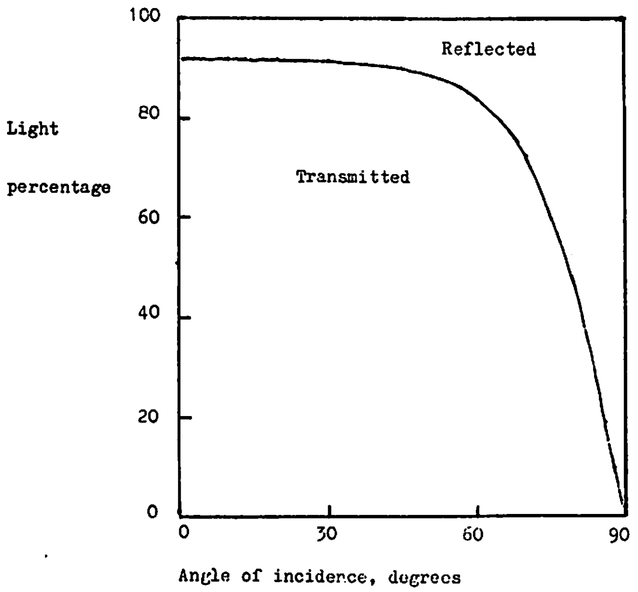


Fig 4 Reflection and transmission of light by glass.

Light transmission

In the early nineteenth century serious consideration was given to greenhouse geometry and, before mechanised computation, it was deduced that maximum light transmission is given by a hemispherical cap[12]. Apart from constructional problems, it is difficult to utilise a circular plot effectively and greenhouses first developed as long and narrow buildings with pitched roofs. About a century later, studies of the problem of orientation[13] led to the conclusion that in winter (when daylight is the limiting factor in plant growth) the best light transmission is obtained when the ridge is aligned E-W. Within the last twenty years, the timber supporting frameworks of commercial greenhouses have been replaced by metal ones, reducing the area of opaque structure, further improving the light transmission[14]. Complete elimination of the supporting structure is possible, as exemplified by the "bubble" greenhouse[15], in which a plastic film is supported by low pressure air. However, the large angle of contact between water and most film plastics gives rise to globular condensation, which in turn may lead to reflection losses of up to one third of the incident energy[15]. Because glass is readily wetted, condensation is generally filmwise and the light transmission unimpaired. In diffuse light (the major component of winter solar radiation) a typical metal frame greenhouse has a light transmission of 68%, compared with 82% for a dry bubble greenhouse[16]. It is of little use to build efficient greenhouses if the cladding is allowed to become dirty; in commercial greenhouses in England it was found that loss of light due to dirt[17] varied within the range 1-27% with an average of 10%. The nursery boiler chimney was the usual source of contamination. The soot from oil-fired boilers makes a chemical bond with glass, making simple washing with water ineffective.

Heat retention

Assuming that the nursery boiler is well maintained, heating mains are adequately lagged, all control gear is correctly installed and adjusted, then the only remaining means of reducing the energy input to a greenhouse is to reduce the thermal transmittance. Since the insulating value of a structure such as a greenhouse consists almost entirely of the sum of the inner and outer surface heat transfer coefficients, it is very dependent on wind speed[18], the heat loss at 6 m/s (15 miles/h) being double that under still conditions. Double glazing, apart from being expensive, involves unacceptable loss of light, since two more partially reflecting surfaces are introduced into the light path. Where structure and crop permit, the use of shading blinds during darkness reduces fuel consumption by 30% by virtue of the air layer trapped between the roof and the blind. An extension of the "bubble" greenhouse concept, the inflated roof house[19], makes possible fuel saving without overall loss of light, since the structure may be reduced to a few support wires between rain gutters. Measurements on an experimental single span inflated roof greenhouse[20], indicated a fuel saving of 20%, and a 3% higher light transmission compared with a glazed multispan greenhouse. In a vertical air cavity, a gap width of 20 mm is sufficient and a greater width gives only a marginal improvement in insulation[21]. The horizontal air cavity in an inflated roof varies from zero at the edges up to a metre or more in the centre of the span. The dependence of thermal resistance on gap width and temperature difference is shown in fig 5, the calculations being made in accordance with equations given in Ref[22]. At a temperature difference of 10°C, a value typical of present practice, a gap width of 100 mm provides full insulation.

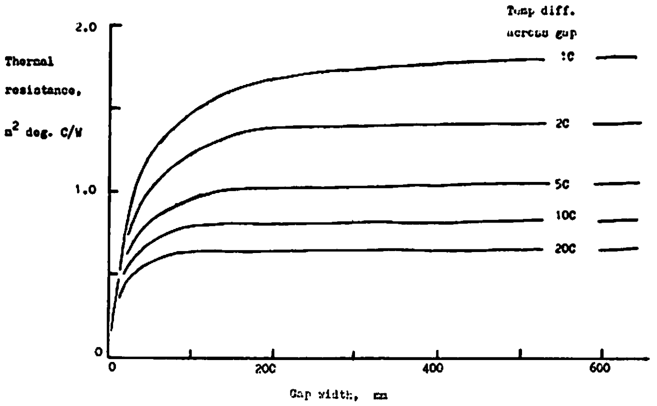


Fig 5 Thermal resistance of a horizontal air gap.

Having constructed an efficient greenhouse, a familiar energy problem remains — that of storage. Maximum energy demand is in winter, when solar radiation is minimum, and vice versa. There do not appear to be any economically acceptable ways of providing energy storage for a six months' period, nor does the saving of energy by lowering environmental temperature appear to offer economic advantage, even at present fuel costs.

Heating greenhouses by means of waste power station heat has often been considered; indeed the available heat would theoretically permit a sixty-fold increase in greenhouse acreage. Unfortunately the policy so far adopted has been to build generating stations to give the lowest cost per kWh, rather than to make the best overall use of the energy input. Thus the exhaust heat is available only at a low temperature, typically 25°C, requiring expensive heat exchangers of large surface area, and even on a daily basis the exhaust heat supply pattern does not match the greenhouse demand.

Finally, it is perhaps worth drawing attention to the great difference between energy and monetary budgets, as shown in table 4.

Table 4

	1 acre wheat	*1 acre tomatoes*
Yield	2.5 tons	80 tons
Monetary value	£125	£20 000
Calorific value	3.6×10^4 MJ	1.7×10^5 MJ
Pence/MJ	0.4	12

References

1 *Solar Radiation* (Edited by N Robinson), Elsevier, 1966.
2 Monteith J L. Solar Power and Food Production. *Physics Bulletin*, 1969, 20, 409.
3 Biological Effects of Radiation (Edited by B M Duggar), McGraw-Hill, New York, 1936.

→ *foot page 62*

Economy in the use of manufactured fertilisers

by R B Austin BSc

CONCERN over energy use in the developed countries has stimulated much interest in the energy needed to 'support' agriculture. A common feature of many studies is that, of the support energy used for the production of non-leguminous crops, about half is required to produce and transport the fertilisers. Calculation of the primary energy inputs for the UK barley crop in 1971 provides a typical example of this (table 1).

Of the mineral fertilisers used in the UK, nitrogen is the one used in the greatest amount. As at present organised, UK agriculture is heavily dependent on nitrogen. It is the nitrogen fertiliser that requires the most support energy for its production: that required for the extraction and processing of a similar weight of potassium or phosphorus fertiliser is much less. Naturally, figures vary considerably depending on the processes used and the transport costs, but values applicable to the UK are shown in table 2. However, judgements made on the basis of the energy requirements for the manufacture of fertilisers may be irrelevant for phosphorus and potassium fertilisers since, unlike nitrogen fertilisers, these are essentially non-renewable resources and the emphasis should be on conservation. Re-cycling of phosphorus and potassium, which in effect would mean recovering these elements from the sea, would be prohibitively expensive in energy and money terms and can be ruled out at present.

R B Austin is Head of Physiology Department, Plant Breeding Institute, Cambridge.

Paper presented at the annual conference of The Institution of Agricultural Engineers held at the Bloomsbury Centre Hotel, London 13 May 1975.

Table 1 Requirements of primary support energy for barley production in the UK in 1971

Requirement for:		*Energy MJ ha^{-1}*	*%*
Cultivations[1 2]		2340	19
Machinery[2]		3300	27
Fertiliser[2 3]:	nitrogen	5140	41
	phosphorus	290	2
	potassium	400	3
Herbicides[2]		200	1
Grain drying[4]		730	6
	Total	12400	

1 Nix J (1971). *Farm Management Pocket Book.* Fourth edition. Wye College, London.
2 Leach G and Slesser M. (1973). Energy equivalents of network inputs to food producing processes. Mimeographed paper. Strathclyde University.
3 Imperial Chemical Industries Limited (1974). The energy input into a bag of fertiliser.
4 Nellist M E (1973). Private communication.

Table 2 Primary energy equivalents of fertilisers

Element	*Energy equivalent, MJ kg^{-1}*	*Consumption in 1973, '000 tonnes*
Nitrogen (as N)	76	922
Phosphorus (as P)	32	207
Potassium (as K)	10	349

Sources: Leach & Slesser and ICI, as table 1

So from the viewpoint of conservation of the support energy used in fertiliser manufacture, the main concern will be with nitrogen. It is beyond the scope of this discussion to examine the energy efficiency of nitrogen fertiliser manufacture, although chemical engineers who are concerned with this question may not all be aware that biological nitrogen fixation appears to be about four times more energy-efficient than the best industrial processes. Long-term research being carried out at the ARC Unit of Nitrogen Fixation may lead to improvements which will enable the chemical engineer to fix nitrogen at a similar efficiency to that achieved by the *Rhizobium* in legume nodules. If this were possible, we could be less concerned to reduce application rates to crops, at least on the grounds of energy cost.

History and present pattern of nitrogen use in UK agriculture

Early in the nineteenth century, it was recognised that nitrogen was a constituent of plant material and that most plants acquired their nitrogen from the soil. Experiments begun by Boussingault and by Lawes and Gilbert in the 1840's, showed that crop yields could be considerably increased by the application of nitrogen fertiliser. Farmers' use of nitrogen fertiliser has increased more or less exponentially since 1913 and if this trend continued, annual consumption would be 1.5 m tonnes in 1980 and 3.0 m tonnes in 1990. At present, consumption is about 1.0 m tonnes (table 3). Whereas until about 1940, most of the nitrogen was a by-product of coal-gas manufacture, most is now produced in plants which use natural gas or naphtha as a feedstock.

Cont from page 61

4 **Blackwell M J.** Five years continuous recording of total and diffuse solar radiation at Kew Observatory. Met Res Comm Lond. Paper no 895, 1954.
5 **Fry T M.** General discussion, *Phil Trans RSoc Lond* 1974, A, 276, 606.
6 **Hubbert M K.** In: *Resources and Man,* W H. Freeman and Co., San Francisco, 1969, p 203 *et seq.*
7 **Darmstadter J** and **Schurr S H.** The world energy outlook to the mid-1980s: the effect of an alternative supply path in the United States. *Phil Trans RSoc Lond,* 1974, A, 276, 413.
8 **Stodhart A E.** Natural conversions of Solar Energy. IEE Colloquium on Solar Energy, London, May 1973.
9 **Leardini T.** Geothermal Power. *Phil Trans RSoc Lond,* 1974, A, 276, 507.
10 *Production Yearbook,* FAO, 26, 1972.
11 **Holmes J G.** The Reflexion Factor of Glass. *Trans Illum Eng Soc* (London), 1947, 12 (5) 108.
12 **Mackenzie G S.** On the form which the glass of a forcing house ought to have. *Trans Hort Soc of London,* 1812, 2, 171.
13 **Lawrence W J C.** *Science and the Glasshouse,* Oliver and Boyd, Edinburgh, 1948.
14 **Edwards R I** and **Lake J V.** Transmission of solar radiation in a large-span east-west greenhouse. *JAgric Engng Res,* 1964, 9 (3) 245.
15 **Canham A E.** Air-supported plastic structures – materials and design factors. Proc Agric Engng Symp, 1967, Silsoe, Inst Agric Engng.
16 **Morris L G.** Solar radiation in greenhouses: a brief review. *Israel J Agric Res,* 1972, 22 (2) 85.
17 **Jones M P.** A survey of glasshouses and glasshouse practice. J Agric Engng Res, 1966, 11, 113.
18 **Bowman G E.** A comparison of greenhouses covered with plastic film and with glass. Proc 16th Int Hort Cong, Brussels, 1962, 5, 551.
19 *Batiment a toiture gonflable pour usages agricoles.* Etudes de CNEEMA. No 377–378, 1973.
20 **Bowman G E.** Inflated roof greenhouses. Proc Subject Day on Greenhouse Engng, Silsoe, October 1973.
21 **Billington N S.** *The Thermal Properties of Buildings.* Cleaver Hume Press, London, 1952, p 26.
22 **Fishenden M** and **Saunders O A.** *An introduction to heat transfer,* Oxford University Press, 1950, p 101 *et seq.*

Table 3 Consumption of nitrogen as fertiliser in the UK

Year	*Consumption '000 tonnes*
1913	29
1939	60
1948	184
1958	312
1963	508
1965	559
1972	922
1980	(1500) *
1990	(3000) *

**Estimated by extrapolation of the existing trend based on expectation of continued exponential increase*

Sources: Rothamsted Experimental Station Survey of Fertiliser Manufacturers Association, and **Cooke G W** (1967). *The control of soil fertility*, Crosby Lockwood, London

The increase in nitrogen fertiliser use has come about because of increases in the proportion of the acreage receiving it, and of increases in the rates of application used. At present, over 90% of the acreage of the major arable crops is dressed with fertiliser nitrogen, and almost the same proportion of the temporary grass receives it. However, only about 60% of the permanent grass receives nitrogen, and at much lower rates than for temporary grass or arable crops. Data for the UK are difficult to obtain but the rates for wheat, based on national surveys, have almost doubled since 1957, and there have been parallel increases in yield (table 4). Rates of application of phosphorus and potassium fertilizer have changed little over this period. The estimated use of nitrogen by the major crops and grassland in 1971/72 is shown in table 5.

Table 4 Rates of application of nitrogen fertiliser and yields of wheat

Year	*N, kg ha^{-1}*	*Grain yield t ha^{-1} **
1957	49	3.25
1962	57	3.64
1966	80	3.95
1974	89	4.57

**Estimated from linear regression of yield on years 1950-1974, ie short-term fluctuations eliminated.*

Sources: Rothamsted Experimental Station Survey of Fertiliser Practice, and Annual Abstracts of Statistics, HMSO, London

Table 5 Area and nitrogen fertiliser use of major UK crops 1971/72

Crop	*Area '000 ha*	*N applied* kg ha^{-1}*	*N applied† '000 tonnes*	*% of N used*
Cereals	3805	81	308	29
Potatoes	240	169	40	4
Sugar beet	190	173	33	3
Grass leys	2360	98	231	22
Permanent grass	4905	51	250	23
Rough grazing	6600	30	198	19

*estimates based on survey
†product of area times rate

Source: Fertiliser Manufacturers Association

If nitrogen were to be applied to all grass at the rates used for that proportion of the area which is fertilised, nitrogen consumption would increase by about 410 000 tonnes/annum. If there were no other changes in nitrogen use, annual consumption by agriculture as a whole would become 1.4 m tonnes, close to the estimate of the consumption in 1980 based on extrapolation of present trends. If rates were to increase to the levels used in the Netherlands, about 220 kg ha^{-1}, nitrogen applied to grass in the UK would increase from its present value of 680 thousand tonnes to three million tonnes. Such a large increase is very unlikely because, over large areas of rough grazing, soil and climatic factors are likely to limit the profitable use of nitrogen at much lower rates than those of the Netherlands.

Despite the uncertainties entailed in extrapolation, it seems clear that unless there is a very dramatic change in agriculture which reduces the profitability of applying nitrogen fertiliser, consumption of this fertiliser will increase during the next decade but at a slower rate than would be expected from the extrapolation of past trends.

Sources of nitrogen for crops and the fate of applied fertiliser nitrogen

As a first step in looking for ways to economise in the use of nitrogen fertiliser, it is informative to look at the nitrogen balance of a crop. This has been attempted for the national wheat crop (table 6) but some of the entries are subject to considerable uncertainties. In eastern England where most of the wheat is grown, there will be some loss of nitrogen as a result of leaching of nitrate from the rooting zone. Meteorological data (MAFF Technical Bulletin No. 24: The significance of winter rainfall over farmland in England and Wales, pp 69, 1971) show that, on average in eastern England, the drainage of water through the rooting zone is about 140 mm per annum. Typical values of the nitrate concentration of drainage water are in the region of 15 parts per million (as nitrogen). Multiplication of these figures gives an estimate of the average loss of nitrogen by leaching of 21 kg ha^{-1}. Some of this will have been mineralised from the soil organic matter, but some will have come from recently applied fertiliser. Unaccounted losses which include those from denitrification and those to the soil organic matter are based on estimates made, using nitrogen-15, of the fate of applied fertiliser nitrogen. While much of the fertiliser nitrogen incorporated into soil organic matter will be available to subsequent crops, that denitrified represents a total loss. It must be emphasized that the total amount of nitrogen in the rooting zone is 2-4 t-ha^{-1}, so slight changes in the proportion mineralised will have large effects on the turnover which has been conservatively estimated for the national wheat crop as 160 kg ha^{-1}.

Table 6 Approximate nitrogen balance sheet for wheat crop, kg ha^{-1}

Available to crop		*Removed by crop and other losses*	
Applied as fertiliser	100	Removed in grain	73
		Removed in straw	31
Rainfall	20	Unaccounted losses of fertiliser nitrogen including denitrification	10
Mineralised from soil organic matter	40	Fertiliser nitrogen incorporated into soil organic matter	25
		Leaching of mineralised soil nitrogen and fertiliser nitrogen	21
Total	160	Total	160

Sources: N-15 in Soil-Plant Studies, IAEA Vienna, 1971; Fertiliser Manufacturers Association; crop removal calculated from analyses done at the Plant Breeding Institute.

Denitrification is very dependent on soil conditions, being favoured at high soil moisture contents and by high temperatures, conditions which in England do not usually coincide. Not enough is known in quantitative terms about the extent of losses by denitrification and other processes and how they are affected by cultivation methods and the timing and placement of nitrogen fertiliser. Work recently begun at Letcombe is aimed at quantifying these losses. The limited evidence suggests that 25% of the fertiliser nitrogen may be unaccounted for, some of which is lost by denitrification. If this is genreal for crops and grass in the UK, the loss amounts to some 250 000 tonnes/annum and further research is needed to assess whether the loss can be reduced significantly and economies made in the use of nitrogen fertiliser.

If nitrogen applied in the form of ammonium compounds could be kept in this form, both leaching and denitrification would be reduced. A chemical, with the proprietory name 'N-Serve' inhibits nitrification and was tested in the 1960's. Field experiments showed that it had only slightly beneficial effects on nitrogen uptake and it has not come into general use. As it seems likely that nitrogen may be lost from the soil by a variety of processes (apart from uptake by the plant), it seems unlikely that a single chemical will be found which is capable of greatly reducing or eliminating the 25% loss of fertiliser nitrogen which commonly occurs.

The potential for increasing the efficiency of nitrogen use

Cereals. Commonly, 90% of the nitrogen present in the crop at maturity, has been absorbed by the time the plants are in anthesis;

only some ten per cent is taken up during grain filling. However, if a period of drought precedes anthesis, and grain filling takes place in wet weather, up to about 25% of the nitrogen may be taken up during grain filling. At harvest, about 70% of the nitrogen in the above ground parts (straw and grain) is present in the grain and 30% in the straw. Thus most of the nitrogen present in the grain at harvest is mobilised from the leaves and stems. This is in marked contrast to the situation for grain carbon, the great majority of which, at least in wheat, is derived from photosynthesis during grain filling. At first sight, it would appear that there is considerable scope for improving the efficiency of nitrogen use because 30% of the nitrogen is 'wasted' in the straw. However, there is little variation in modern wheats in the percentage distribution of nitrogen at harvest time. At high rates of fertiliser application a greater proportion of the nitrogen is in the straw.

Because the carbon for grain filling is derived from current photosynthesis, the leaves and other photosynthesising organs need to be kept fully functional. For this, the leaves must retain their nitrogen which is largely in the form of proteins and chlorophyll. Hence there are conflicting requirements. If leaf nitrogen is lost too rapidly, grain filling and, hence, yield will suffer. If the nitrogen is lost too slowly grain yields may be high but grain protein concentration may be low. There are no sharp discontinuities in the functioning of leaves during grain filling, there being a slow decline in both photosynthetic rate and nitrogen concentration. As a result a strong negative correlation between grain yield and grain protein concentration is generally found, when comparing a range of varieties grown at a given nitrogen level.

Nevertheless, there may be scope for breeding varieties having acceptable grain protein concentrations and high yield which translocate more than 70% of their nitrogen to the grain, and work at the Plant Breeding Institute has been started to explore the possibilities. Additionally, or alternatively, it may be possible to identify and exploit genetic variants in which uptake of nitrogen continues during grain filling.

Regarding the uptake of nitrogen during the vegetative phase of growth, a considerable body of evidence suggests that uptake is mainly a function of plant weight, and that variations in nitrogen concentration are of smaller importance. Plant weight and nitrogen concentration are, however, strongly negatively correlated. To maximise uptake at a given level of nitrogen supply, it will be necessary for breeders to produce plants, the vegative parts of which have a high dry weight per m^2 of cropped surface. There may be some conflict here with the breeders' objective to produce dwarf plants, though the correlation between plant weight and height is only weak.

Thus there is some scope for breeding cereal plants which use nitrogen more efficiently. However, as the figures in table 4 suggest, any substantial increase in yield or grain protein concentration, made possible by the breeding of new varieties, will require the use of more nitrogen than is at present used.

Action to improve the efficiency of nitrogen use by breeding should give benefits in the long-term. By the better application of existing knowledge, particularly to diagnose fertiliser needs, improvements may also be obtained in the short-term. This, however, is chiefly the concern of farmers and the advisory service. For winter-sown cereals the timing of applications is very important and the amounts required need to be adjusted to compensate for leaching losses caused by winter rain. Placement near to the seed, by combine-drilling, appears to be beneficial mainly at low levels of fertility, but nitrate and urea applied in this way can impair germination.

Grass. When other factors, particularly rainfall, temperature and phosphate and potassium are not limiting, dry matter yields of grasses increase with nitrogen application up to levels of at least 400 kg ha^{-1}, when yields of 14 000 kg ha^{-1} can be obtained (maximum potential yields, however, are in the region of 30 000 kg ha^{-1}). To sustain yields at this level, other essential elements need to be applied to prevent the development of deficiencies. Average application rates of nitrogen to leys are only about 100 kg ha^{-1}. One interpretation of this difference between rates is that, in England at present, there is not sufficient demand for grass to induce farmers to raise yields to levels approaching those which can be obtained experimentally. Looked at in another way, land is not in sufficiently short supply to require production to be raised to greatly higher levels than are at present obtained. A further aspect of importance is that there are considerable logistic problems in harvesting, conserving and feeding grass to animals so that these and the transport costs are important factors in determining grass use in intensive animal production units. This is a greatly over-simplified view of the national situation, but provides some perspective for determining the objects of research on the nitrogen nutrition of grass.

At low levels of production, legumes grown in association with grass replace all or a substantial proportion of the fertiliser nitrogen that would otherwise be required. The main problem with such systems is to manage the sward so that the legume persists, and there appears to be considerable scope for the breeding of legumes (in this case clovers) with improved performance in mixed swards, and of the ***Rhizobium*** needed to effect the maximum nitrogen fixation.

At higher levels of production, the contribution to the nitrogen in the herbage from legumes, where they are present, is much smaller because high production requires high fertiliser applications, and in these circumstances clovers are 'competed out'.

In both contrasting situations there may be scope for breeding plants which use nitrogen more efficiently. In contrast to cereals, virtually the entire above-ground parts of the crop are harvested and there is thus no loss corresponding to straw loss in cereals. Other losses, including those due to leaching and denitrification were considered to be less than in cereals, but recent work shows that grasses may be similar to cereals in these respects. However, not enough is known about the losses from either cereal or grass crops, and it is not possible to assess whether losses can be reduced and savings made in fertiliser nitrogen.

When grazed, there is considerable loss of nitrogen, as protein, by ruminant animals. This loss could be reduced if grass of acceptable productivity, but lower protein (and hence nitrogen) concentration could be produced. Again, this would require the breeding of suitable varieties, but there are physiological reasons for believing that progress in this direction would be very limited.

A more attractive proposition would be to extract some of the protein from the grass, giving products suitable for feeding to both ruminant and monogastric animals, and the feasibility of this has been studied. Looked at solely from the point of view of energy conservation, however, the energy cost of extracting protein may equal or be greater than the cost of producing more protein by using more nitrogen on grass.

Nitrogen in animal wastes

It has been estimated that the nitrogen excreted by livestock in the UK amounts to about 0.8 and 1.0 m tonnes per year. About half is produced under cover and much of this is wasted. The remainder is deposited on to grassland by the grazing animals but probably less than half of it is absorbed by the grass.

The utilisation of nitrogen in wastes presents many problems because the nitrogen is present in low concentration so transport and application are costly. It may be that the energy cost of collecting, storing and dispersing the wastes is greater than the energy cost of producing the amount of fertiliser nitrogen needed to give the equivalent effect. This is of course a very partial way of looking at the overall problem of the disposal of animal wastes (for example they also contain appreciable amounts of phosphorus and potassium), but I am not aware that they have been looked at in this perspective.

Biological nitrogen fixation

Legume-Rhizobium associations contribute nitrogen to agriculture both in leys and, to a small extent, in mixtures of crops, and in rotations involving legumes and non-legumes grown in association. Reference has already been made to legume-grass pastures: legumes in arable crop rotations will now be considered. Their value in supplying nitrogen can only be assessed from quite elaborate experiments in which the response of a test crop to a range of nitrogen dressings is compared either after a legume crop or after a non-leguminous crop. The response curves are compared and from their displacement on the nitrogen axis estimates can be made of the value of the residual nitrogen to the crop. Since there are many possible combinations of legume and test crop, and the experiments have to be carried out for several years, it is not surprising that they are not undertaken lightly. Estimates of the nitrogen contributed by several legume crops and for comparison, by leys, are given in table 7.

The benefit of the nitrogen contributed by legumes or leys may be reduced because a smaller proportion of the non-leguminous crop will be grown in the rotation and the complexity of farm operations will be increased. Unless there is a demand for the leguminous herbage the farmer's enterprise may well be more profitable if he pays for fertiliser nitrogen and dispenses with the legume crop, obtaining a higher average production of say, wheat

Table 7 **Estimates of the nitrogen contributed to the succeeding crop by legumes and leys. Test crops were wheat**

Crop	*Nitrogen contributed to test crop, kg ha^{-1}*
Field beans	38
Lucerne (cut)	34
Lucerne (grazed)	66
3-year ryegrass ley, high N, cut	25
3-year ryegrass ley, high N, grazed	75
3-year ryegrass ley, low N, grazed	50
1-year ryegrass/red clover	25
Average	45

Sources: **Heard A J (1965).** *Journal of Agricultural Science* 64, 329-334; **Williams T E (1967).** Annual Report of the Grassland Research Institute for 1966, 63-71.

or barley. Thus, unless the farmer's gross margin from herbage production plus the value of the nitrogen available to the subsequent crop is equal to or greater than that from growing cereals in a rotation without a ley, the farmer's enterprise will be less profitable.

An alternative to cropping legumes in rotations is to use them as 'green manures'. In this system, the legume is undersown in a nurse crop. The nurse crop is harvested, the legume ploughed in and the next crop sown. In long-term experiments at Rothamsted and Woburn, trefoil was found, by analysis of its dry matter, to contribute about 50 kg ha^{-1} of nitrogen, the yield of the nurse crop being reduced by about 0.2 t ha^{-1}, or 4 per cent. Measured by the subsequent cereal crop the contribution was some 50-70 kg ha^{-1}. Taken at face value, nitrogen provided in this way seems to be in energy terms, 'free'. Ploughing-in and additional cultivations are required, however, and the system requires very skilled management. There may be problems in very wet or dry seasons, and on light soils, and the money cost of the legume seed has to be deducted from the cost of the nitrogen it contributes. In practice, it seems that this system is unlikely to gain wide acceptance in farming.

Long-term research aimed at introducing nitrogen fixing capacity into non-leguminous plants has excited considerable interest recently. In principle, it may be achieved in a variety of ways. The most elegant and novel would be to transfer genes from the *Rhizobium* or other nitrogen fixing micro-organisms either to the chromosomes of the host plant or to autonomous genetic units which would exist within the cells of the host plant, which might for example be wheat. It is possible that this could be achieved by transfer of DNA from *Rhizobium* to wheat, and selecting from variants which, while possessing the characteristics of wheat, also possessed *'nif'* (nitrogen fixing) genes. Like thermonuclear energy, this seems within our capabilities, but it has not yet been achieved.

An alternative would be to create an environment in the wheat root which would allow it to become infected by *Rhizobium*, or its surface to be colonised by free living nitrogen fixing organisms such as *Azotobacter*. Like the transfer of *nif* genes this may be technically possible, but it has not yet been achieved. These are exciting challenges to plant scientists and may yield considerable benefits in the future. It should be borne in mind, however, that biological nitrogen fixation requires an expenditure of energy and it may turn out that the energy cost to the plant may unacceptably reduce its dry matter production and yield.

Conclusions

1 As a proportion of the total primary energy consumption in the UK, that used for the manufacture of fertilisers is very small, being for nitrogen about 0.8%.
2 With present technology, the energy used to make nitrogen fertiliser is much more than that needed to process phosphate and potash into fertilisers.
3 There may be prospects for improving the energy efficiency of nitrogen fertiliser manufacture.
4 Production and yields from UK farms would decrease if less fertiliser, particularly nitrogen, were to be used, and no other changes were made.
5 If present trends in agriculture continue, there will be a considerable increase in the amount of nitrogen fertiliser used on UK farms.
6 There appears to be relatively little scope for increasing the efficiency with which nitrogen fertiliser is used on cereals and grasses, but all means of improving efficiency should be exploited.
7 The amount of nitrogen in animal wastes approaches that used as nitrogen fertiliser. This nitrogen is in dilute form and it is produced in places and at times that do not coincide with the demand by crops, and it is therefore inefficiently used. There may be a net energy and money cost of recycling the nitrogen in animal wastes as compared with making good the losses by using fertiliser nitrogen. However, the value of the other minerals, especially phosphorous and potassium, in the wastes and the need to conserve resources of these elements, should stimulate increased attention to the problems of the effective use of such wastes.
8 Legume crops and legumes in leys can contribute about 50 kg ha^{-1} to the succeeding crop.
9 In the long-term, there is some prospect of producing non-leguminous crops with ability to fix atmospheric nitrogen.
10 If current trends towards increasing specialisation in agriculture were reversed and mixed arable/animal farming with increased use of legumes in rotations employed, agriculture's need for fertiliser nitrogen could be reduced. However, production might decrease, and the manpower requirements of farms would increase. It can be argued that these changes would be desirable on conservationist and ecological grounds.

Efficient use of tractors

by J Matthews BSc

1 Introduction

IN relation to the total fuel energy needs of the world that used on the farm is estimated to be only within the range 1-2%. The proportion used in powering field machines obviously varies with the type of farming and in the varied farming pattern of UK for example tractors and other field machines account for 37% of petroleum fuel energy (table 1)[1] or approximately 25% of the total energy taken by the farms as petroleum fuels, electricity or coal. These figures exclude the considerable energy inputs in chemicals and the other significant contribution in the production of the machinery used in agriculture.

Table 1 Petroleum fuel consumption in various farm applications in the UK

Application	*Tonnes x 10^3*	*Megajoules x 10^9*
Tractors and field machines	760	39
Heating, drying, CO_2 enrichment	270	14
Greenhouse heating	800	41
Road vehicles	80	4
Domestic heating	165	8
Total	2 075	106

An Australian study of energy in food production[2] has emphasised the relatively large proportion, 85% of the total, which can be involved after the food leaves the farm; in transport, retailing and cooking. The significance of this in relation to arable work is that it would be wrong to grow those crops or employ those harvesting methods which require a minimum input of power or labour in the field, if the product then requires larger inputs after leaving the farm before it is ready to eat. In field work one trend is clear and worldwide, the increasing employment of machinery to reduce labour. In some areas this trend is motivated by shortage of people wanting to work on farms, in others by the need to increase the treatment given to the soil or crops in order to increase the yield. In almost all cases the economics demand greater use of machinery which, despite massive increases in fuel and equipment costs, is still cheap.

Worldwide agriculture uses some 17 m tractors and 3 m combine harvesters and although self propelled machines, mainly for harvesting, are increasing in numbers and variety, more than 80% of the internal combustion engines used in agriculture are thus in tractors. In view of the seasonal use of most self propelled machines resulting in perhaps 50-200 hours use per year, compared with 200-1000 hours typical tractor use, it may be assumed that more than 95% of the fuel is used by tractors. With the tractor performing so many different tasks its power output and hence its fuel consumption obviously varies greatly. Table 2[1] shows some

Table 2 Typical fuel consumption rates of various tractor tasks[1]

Tractor task	*Consumption, 1/ha*
Ploughing	18
Rotary cultivating	15
Chisel ploughing	9
Spring tine harvesting	6
Drilling	3
Mowing, baling	3
Forage harvesting/chopping	5
Fertiliser distribution	3

typical consumption values and clearly demonstrates the importance of cultivation and, to a lesser extent, forage harvesting as high energy consuming tasks. One worrying trend identified by many researchers and advisory staff is that, whereas the power of individual tractors is increasing continually the work output is not going up in proportion[3]. In part this may be due to lower tractive efficiencies of larger tractors and in part to operators not driving as fast as their tractor's power would allow due to discomfort, implement limitations or just habit. This lower employment of power reduces efficiency as the engine is only at its most efficient near to maximum power.

J Matthews is Head of Tractor and Cultivation Division National Institute of Agricultural Engineering Wrest Park, Silsoe, Bedford.

Paper presented at the annual conference of the Institution of Agricultural Engineers held at the Bloomsbury Centre Hotel, Coram Street, Russell Square, London, 13 May 1975.

2 Cultivation

As a high consumer of energy it is not surprising that much research and practical application should be devoted to reduced cultivations. With many crops cultivations have been reduced from traditional systems including mouldboard ploughing, two or three secondary treatments with discs or tines and then drilling, to only two passes over the land. The crop may for example be drilled directly into a stubble or grassland following a chemical herbicide treatment or, due to the cost of herbicides purely mechanical treatments may be economically more attractive. The replacement of conventional mouldboard ploughing by power take off driven machinery with the elimination of much of the tractor's wheel losses and lower implement power consumption, and the combination of implements behind the same tractor (see fig 1) may reduce the energy input and cost of cereals cultivation by almost a half[4].

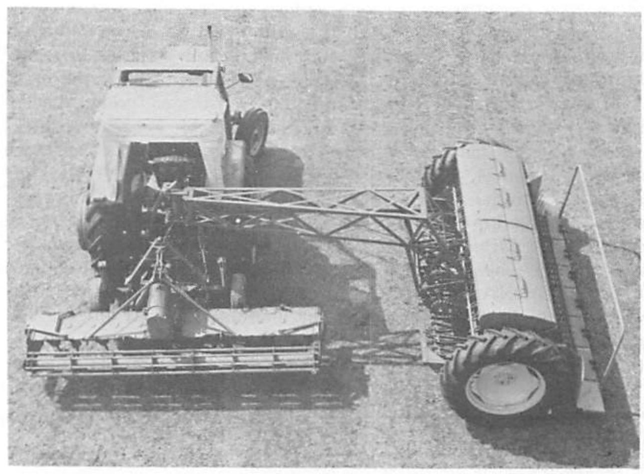


Fig 1

In primary cultivation the depth of ploughing is obviously important in determining power input and in table 3 the specific energy consumption data indicates that less energy is required to deal with the upper layer of the soil in ploughing than to move an equivalent amount of soil at a greater depth, as shown by the figures of 131 kJ/M^3 for 20 cm deep ploughing and 105 kJ/M^3 for 11 cm ploughing. There is little evidence of large differences in specific energy requirement for the implement alone between mouldboard, tined and powered primary cultivation. These data however apply at the implement connection and in the case of powered machinery the efficiency of the tractor is clearly greater due to the lower traction losses at the wheel. Further the lower energy requirement per hectare of the p.t.o. driven digger (fig 2)[5] compared with the other implements working to equivalent depth is clear on both the heavy soil and lighter soil sites although it is more marked with heavier soils.

The energy used in primary cultivation is employed partly in soil cutting, partly in lifting and inversion of the soil and partly is dissipated through friction between the tool and the soil. The friction represents a wastage of energy and on the mouldboard plough, for example, it seems probable that this accounts for 40%[6] of the input power. Many means of reducing this surface friction have been proposed including heating the tool surface, lubrication, low friction plastic coatings, air cushions, electrc-osmosis, moving tool surfaces or ultrasonic vibration[7]. None c

Table 3 Comparative energy consumptions and labour requirements of various primary cultivation implements average values 1971-74

	Energy per unit area (MJ/ha)		*Specific energy consumption kJ/M^3*		*Labour requirement (man hours/ha)*	
	Heavy soil	*Light soil*	*Heavy soil*	*Light soil*	*Heavy soil*	*Light soil*
Mouldboard plough (20)	275	160	131	77	2.47	1.58
Shallow plough (11)	114	68	105	74	0.95	0.70
Chisel plough (12)	120	98	123	105	0.99	0.80
Rotary digger (rotor 10, tines 20)	120	122	120	84	0.83	0.77

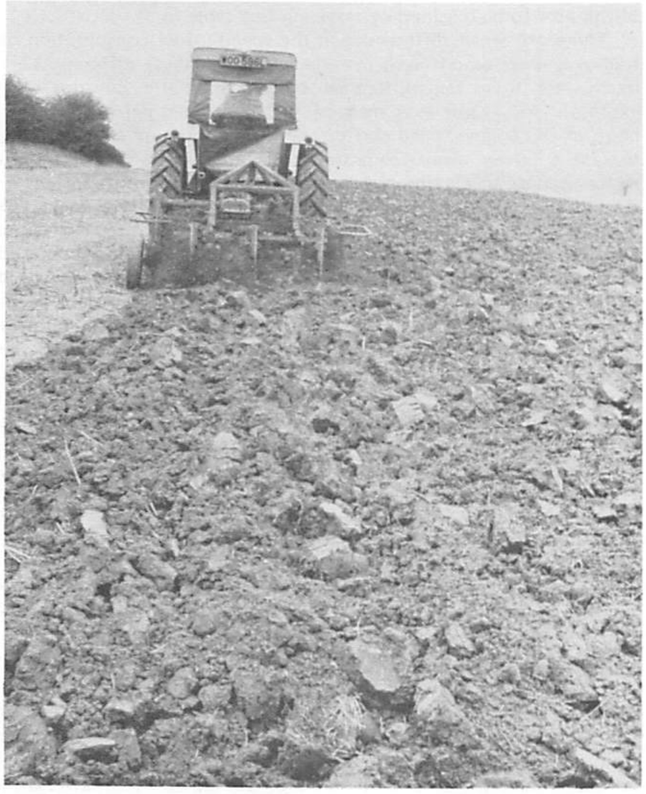


Fig 2

these approaches appears particularly practicable at present either for economic or technological reasons. A comparison of the total energy input for complete systems of cultivation and drilling is shown in table 4, together with data on labour requirements and the total cost of the work. These data from NIAE experiments show an energy saving of approximately a half and an equivalent cost saving may be attained in using the most efficient reduced cultivation compared with the traditional technique.

The comparative data above has been derived for one tractor size, approximately 70 hp. Further work is in progress at NIAE to study theoretically the effect of varying the tractor and implement size on the economy of the process. As with an earlier more limited study by Zoz[8] the cost optimum will be sought. A similar study could, however, be undertaken in relation to optimising the energy requirement. Finally reference should be made to the additional power required in cultivation due to the compacted nature of soil surfaces from previous wheel traffic. There is evidence with rotary tools at least that power increases instantaneously by up to 40%

Table 4 Comparative energy consumptions and labour requirements for cultivations for winter wheat – average values 1971-74

Cultivations	*Energy, MJ/ha*		*Labour, man hours/ha*	
	Heavy soil	*Light soil*	*Heavy soil*	*Light soil*
Plough (20 cm)	320	200	3.7	2.4
Disc harrow	320	200	3.7	2.4
Drill				
Chisel plough (2 passes, 13cm) Disc harrow (2 passes) Drill	260	220	3.5	2.4
Shallow plough (10 cm) Combined cultivator and drill	180	110	1.6	1.2
Rotary digger Combined cultivator and drill	180	130	1.6	1.2
Combined chisel plough rotary cultivator and drill	130	130	1.2	0.8
Sprayer Direct drill	30	40	0.5	0.5

while traversing a wheel track. This further emphasises the need to lighten tractors used in cultivation, a possibility with p.t.o. driven equipment and also suggests a further possible reason for reducing wheel loadings during harvesting and other tasks. It has not yet been possible however to quantify properly the effect of compaction on cultivation energy requirement or on crop yield in British arable farming.

3 Other tractor tasks

In the harvesting of forage, in contrast, fuel energy inputs are increasing but this will be dealt with in detail by Manby and Shepperson[9]. The rapid transport of large quantities of forage to store and the need to remove ever increasing yields of other crops from harvesting machines of increasing output rates means that the power level of tractors in transport is becoming increasingly important. Dwyer has estimated[10] that to keep up with existing harvesting machinery, potatoes and beet require approximately 19 kW (25 hp) of tractor power for each mile of distance between field and store, forage crops require approximately 26 kW (35 hp) per mile of distance and grain 9.5 kW (12.5 hp) per mile of distance. He suggests that future harvesting equipment with greater capacity may require these levels to double. Efficient field transport requires not only the correct capacity of trailer but also the use of trailer tyres of the correct size to minimise the rolling resistance as well as compaction. Other tractor tasks generally require relatively low levels of power but as examples of energy efficiency improvements, greater accuracy of swath matching will lead not only to improved distribution of spray or fertiliser but also to reduced power since overlaps can be reduced, whilst more flexible speed adjustment in baling for example by automatically coupling baler throughput to tractor transmission can further optimise power utilisation.

4 Environmental factors

Due to the tractor's use on the roads environmental requirements such as the control of exhaust smoke or noise are becoming increasingly important. The effect on fuel consumption of engine design measures taken to comply with environmental requirements is likely to be small however. The increasing complement of auxiliary functions connected with the tractor engine including powered brakes, steering and clutch plus ventilating and perhaps heating systems for the cab all absorb significant power and result in a lower overall power performance. These additions are, however, being increasingly demanded to provide satisfactory working conditions and some of them are also being employed in response to regulations.

5 Alternative power units and energy sources

With the withdrawal in the USA of most of the manufacturers' options of LPG tractors the compression ignition diesel engine has a virtual monopoly. Extensive research has continued for many years on gas turbine engines for earth moving machinery which, if successful, could result in their use on larger agricultural tractors, say those over 150 kW (200 hp) but elimination of damage from dust continues to present serious problems. In any event petroleum fuels would continue to be needed. Fuel cell tractors have been built experimentally but as with other types of vehicle await a much lighter and smaller cell. Fairly extensive development work has been undertaken intermittently over a number of years on 'producer gas' tractors with coal, wood, straw and even camel dung as the primary fuel source. Probably the greatest advance has been made in Sweden where wood burning gas tractors have been developed to the point where, in a critical petroleum shortage, conversion units for existing diesel engines could be immediately produced in quantity. The disadvantages are accepted, however, of a 20% power loss, the inability to use a turbo charger due to turbine blade damage by unburned hydrocarbon particles in the gas and the need for some diesel fuel for starting[11]. For agricultural use, straw may seem to be the most natural fuel, but it has not in the past proved practicable to compress it sufficiently to raise the combustion temperature to the point where a satisfactory gas is produced. Further work is in progress but the problems of transport, compression and feeding of straw fuel to burners on field machines still appear to make it an unlikely fuel for these vehicles. In the long run, if petroleum fuels must be replaced hydrogen fuel engines or fuel cells charged from a nuclear powered national electricity supply appear most likely. As engines for agricultural machines represent only about 2% of the total manufactured it seems unlikely that a special kind of engine will be produced for agriculture. This appears to rule out the possibility of engines designed to run on organic fuel which may only be readily available on farms.

The most significant change in the tractor engine over the next two or three decades is likely to be the adoption of the stratified charge phenomenon. In such engines, the combustion chamber is shaped such that a coordinated arrangement of air swirl and high pressure fuel injection leads to a more controlled ignition with the avoidance of pre-ignition and of knock, together with the ability to run on low cetane fuels. Many claims have been made for the excellent fuel economy of such engines as well as their improved emissions and noise performance[12]. In one test fuel economy was 58% better than in the standard carburetted engine. Richardson[13] has forecast that by 1985 practically all new diesel engines will be of the stratified charge type.

One final option which needs to be mentioned is the use of draught animals. Although there are those who consider the draught horse or ox to have many features unmatched by the combustion engine, labour costs with animals are probably unacceptably high and the animals also require about 10% of the acreage for their own keep.

6 Energy conservation with present equipment

It is worth considering the factors which lead to a waste of fuel in the use of tractors; similar considerations will apply to other field machines. There are four main influences on energy economy, maintenance of tractor and implements, choice of tyres and ballast, setting of the implement and skill in driving. Observations in several countries have shown that a 10-15% reduction in fuel consumption may be achieved by cleaning or replacement of injectors or air cleaners which have been in use for say 12 months. NIAE farm trials of tractors carried out in the 1950s and 1960s show power losses of up to 10% over a year with the majority of this able to be regained by servicing (see table 5)[14].

Table 5 Available power measurements during NIAE field trials of tractors

Tractor model	*Power after 12 months work, percentage of initial power*	*Power after cleaning of injectors and air cleaners, as percentage or initial power*
A	95.0	103.2
B	95.1	101.7
C	92.4	95.3
D	96.2	97.2
E	89.0	96.7
F	97.9	96.7

There are small differences in the specific fuel consumption of tractor engines of different manufacturers but these differences are much less than the difference between specific consumption, expressed for example as mass of fuel consumed per horse power hour, at the engine speed and torque giving optimum economy and that at a power away from the optimum (fig 3). This optimum region is near to maximum torque and it is therefore important in driving the tractor to select a gear which allows the engine to operate near to its maximum torque with engine speed being reduced as necessary. Take for example in fig 3 the tractor operated in a lower gear with the engine at 90% of rated speed and delivering 50% of the maximum horse power. Specific fuel consumption in this case will be 0.40 lb per horse power hour. If by changing up a gear engine speed can be reduced to 60-65% of rated speed the specific fuel consumption improves to 0.37 lb per horse power hour, a saving approaching 10%.

Another option which may often be open to the farmer is to use lower power capacity tractor or a higher power tractor for a task which is well within the capability of both. Table 6 compares typical results with pairs of tractors from the same manufacturer and indicates that in using the higher power tractor a typical penalty of 20% in fuel economy may have to be met. This is partly due to the lower specific fuel efficiency of the engine at a lower proportion of maximum power and partly due to the greater losses in propelling the heavier tractor. It should be pointed out that this comparison is made on a test track surface with relatively low traction losses and that in a field with higher rolling resistance the difference in relative efficiencies will increase somewhat.

The optimisation of tractive efficiency by a correct choice of tyres and ballast is as important; perhaps more so under cultivation conditions; than engine efficiencies. In practice the choice of tyres cannot be solely made on the basis of gaining optimum efficiency for the particular task in hand since it is unreasonable to expect tyres to be changed between roadwork, heavy draught field work and other field work. Because of the high proportion of energy devoted to cultivation it is probably most important, however, to use the best tyres for this task and in the Appendix the example is examined of a 45 kW (to hp) tractor and a three furrow mouldboard plough. Two tyre sizes are considered with appropriate inflation pressures, the difference in maximum tractive efficiencies being seen to be 5%. A clear interaction between the implement draught, speed of work and the tyres is seen by the fact that greater tractor efficiency than is possible with either tyre pulling the three furrow plough may be achieved by reducing the plough to two furrows, providing that the tractor and implement may be at a speed sufficiently high to make use of the available engine power. Discomfort and functioning of the plough may often of course prevent such an option.

The comparative tractive efficiencies of two wheel drive and two different designs of four wheel drive tractor, measured in recent NIAE studies is shown in table 7[15]. Throughout this study in which ploughing was carried out on 12 different surfaces and secondary cultivation on one ploughed surface the four wheel drive tractor with unequal sized wheels gave on average 7% higher tractive efficiency than the two wheel drive tractor whilst the four wheel drive tractor with equal sized wheels was 14% higher in efficiency than two wheel drive. These differences assume each tractor may be operated at a speed appropriate to the maximum tractive output. If speed is limited the difference may of course be greater and when making a direct comparison with the same

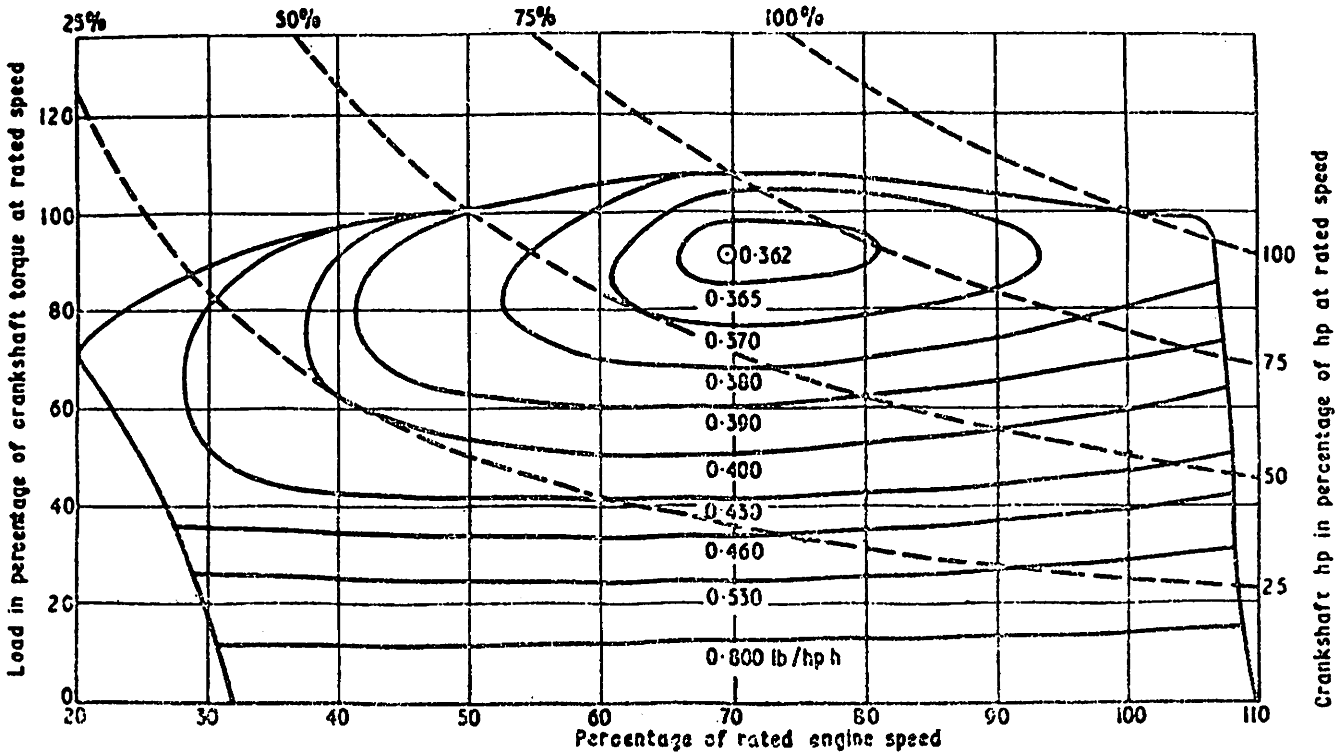


Fig 3 Graph from engine test showing fuel economy over full range of load and speed

Table 6 Comparison of the efficiencies of smaller and larger tractors employed for a similar low effort task. (Task assumed to require 11.5 kW (15 hp) drawbar power at 6.5 km/h (4 miles/h), engine operating at std pto speed)

Tractor	*Max engine power kW (hp)*	*Engine speed for 540 rev/min pto*	*Gear for 4 miles/h*	*Engine power needed for 11.5 kW (15 hp) drawbar power*	*Specific fuel consumption at engine operating conditions kg/kWh*	*Fuel consumed per hour kg*
Manufacturer A, smaller	35.6 (47.4)	1685	5	16.6 (22)	0.233	3.86
Manufacturer A, larger	56.0 (74.1)	1684	5	19.0 (25.2)	0.247	4.69
Manufacturer B, smaller	37.8 (50.0)	1811	6	18.0 (23.9)	0.261	4.70
Manufacturer B, larger	66.3 (87.7)	1902	5	19.5 (25.8)	0.306	5.97

number of furrows the average pull at 20% slip on the four wheel drive tractor with unequal sized wheels was 17% higher than the two wheel drive tractor and the average pull of the four wheel drive tractor with equal sized wheels was 38% higher than the two wheel drive machine. These figures include the losses in the respective transmissions so that they represent overall efficiencies. It must be made clear that other factors notably very poor conditions in which only a four wheel drive tractor can work or improved stability of this model on hillsides will also govern the choice of type.

Table 7 Comparison of tractive performance of two and four-wheel drive tractors

Tractor type (all 65 kW engine power)	*drawbar power kW*	*drawbar power % of engine power*	*Pull at max power, kN*	*Speed at max power, km/h*
Two-wheel drive	37.3	57	20.9	6.7
Four-wheel drive, smaller front wheels	39.8	61	21.8	6.5
Four-wheel drive, equal size wheels	42.6	66	23.2	6.9

Finally on implements worn shares and tines or worn knives and cutting elements can increase the energy needed to carry out the work as, of course, can poor lubrication and maintenance. Again cultivation equipment is likely to be the most significant. In the case of the mouldboard plough in particular the adjustment of angles and positions of component parts can influence draught forces by several per cent.

7 Conclusions

The greatest proportion of petroleum fuel used in agriculture is for the operation of field machines. Almost half of this is used in cultivation showing the importance of reductions in tillage treatments and combination of implements behind the same tractor to increase efficiency. Implements and even trailers which rely on draught from the tractor can imply a 40% waste due to tractive inefficiency. This is why engineers are attempting to replace draught tools by pto driven types and are considering other means of farm transport. This probably also accounts for the greater proportion of four wheel drive tractors being introduced and can often justify the fitting of larger tyres. No revolutionary changes in field machinery or its power sources seem likely in the foreseeable

→ *foot page 76*

Straw production, collection and utilisation: some energy considerations

by DLO Smith BSc, I Rutherford NDA NDAgrE and R W Radley BSc PhD

1 Introduction

THE national increase in the area under cereals over the last two decades, particularly during the period 1957–1967, along with more intensive crop management have together given rise to the current situation in which more than a third of the straw now produced in Britain is apparently surplus to the needs of the farming industry. In the absence of sizeable industrial outlets, farmers have therefore been confronted with a growing disposal problem and of the alternative solutions, burning has proved to be overwhelmingly the most attractive. Whilst this practice is undoubtedly distasteful to most farmers and to the public alike, it is cheap and moreover is widely held by many agriculturists to confer some benefits to the farm business.

But, recently a movement toward 'utilisation' as opposed to 'disposal' has developed as has been the case with all farm 'wastes'. The factors which have contributed towards the change in attitude arise basically from our awareness of the need for mankind to live to a greater degree on current (photosynthesis) rather than stored (fossil fuel) solar energy. The fuel crisis, escalating costs of cattle feed and fertilisers are compelling farmers and researchers to examine the fundamental energy implications of modern farming systems. Straw, then, is beginning to be examined as a crop in its own right, in much the same way as the grain component of cereals. Its potential uses derive in the main from its energy and/or its fibre content.

This paper seeks to throw more light on the national waste of energy associated with straw burning and some of the energy costs which utilisation would necessarily incur and examines briefly a number of the potential uses of straw now being investigated. Some of the gaps in our knowledge are highlighted.

2 Availability of straw

The concern expressed about straw burning prompted the National Farmers' Union to set up a working party to study straw disposal and their report was published in 1973.

The main conclusion was that there was no economic alternative to burning at that time, but that the opportunities for utilisation should be explored. The report contained useful data on the geographical distribution of the straw and estimated the proportion burnt in each area of the country. Assuming a yield of 2.89 tonnes/ha, it was concluded that about 3.5 million tonnes of straw were burnt in 1972.

A number of questions concerning the availability of straw for on- or off-farm usage remain unanswered. First, events in the wet summer of 1974 suggest that there are marked seasonal variations in the amount of straw burnt. Second, in view of the fact that some industrial straw utilisation processes require only one type of straw, there is clearly a need to differentiate in the 'straw burning map' of Britain between the various straw types; this is not attempted in the NFU Report. Third, straw allocation – factory location models being developed at the National College of Agricultural Engineering require that a more detailed, within county, straw distribution map be constructed. Finally, the extent to which straw yield/ha is influenced by such factors as species, variety, season, height of cut, management etc need to be assessed. Any industrial processor must be concerned about the long term reliability of straw supply and accordingly should be furnished with the answers to these questions.

D L O Smith is the Wolfson Foundation Research Officer, Agricultural Production Technology Division, National College of Agricultural Engineering, Silsoe, Bedford MK45 4DT. I Rutherford is from Crop Production Engineer (Agriculture), MAFF, ADAS Liaison Unit, Wrest Park, Silsoe, Bedford MK45 4HS. R W Radley is Head, Agricultural Production Technology Division, National College of Agricultural Engineering, Silsoe, Bedford MK45 4DT.

Paper presented at the annual conference of the Institution of Agricultural Engineers held at the Bloomsbury Centre Hotel, Coram Street, Russell Square, London. 13 May 1975.

2.1 Straw yield

Although there would appear to be few published data concerning straw yield (the National Institute of Agricultural Botany no longer records this information in their regional variety trials), those which are available suggest that the average yield might be considerably higher than 2.89 tonnes/ha.

Data extracted from NIAE Combine Test Reports where the straw is weighed accurately are shown in tables 1 and 2. In table 1, barley and wheat straw and grain yields are presented for the six years 1961–1963, 1966, 1967 and 1969; each yield figure represents the mean for all varieties featured in the tests.

Table 1 Mean straw and grain yields of cereal crops featured in NIAE combine harvester tests

Year	*Crop*	*No of Tests*	*Yield (tonne/ha) Grain*	*Straw*	*Grain:Straw ratio*
1961	Barley	18	3.26	2.41	1 : 0.74
	Wheat	8	6.53	7.61	1 : 1.17
1962	Barley	15	4.34	3.74	1 : 0.86
	Wheat	15	5.32	6.55	1 : 1.23
1963	Barley	20	4.42	3.11	1 : 0.70
	Wheat	16	5.30	4.17	1 : 0.79
1966	Barley	4	5.15	4.14	1 : 0.80
	Wheat	4	4.64	4.85	1 : 1.26
1967	Barley	15	4.57	3.99	1 : 0.87
	Wheat	15	5.07	6.25	1 : 1.23
1969	Barley	4	5.10	4.14	1 : 0.81
	Wheat	3	5.60	5.85	1 : 1.04
Total	Barley	76	4.24	3.34	1 : 0.79
	Wheat	61	5.22	5.90	1 : 1.13

In table 2 year-to-year results are meaned for each of the varieties occurring in the tests.

The information presented here must be interpreted with caution because the purpose of the work was such that no attempt needed to be made to keep crop management factors constant. Thus, there were changes in varieties over the years, different fields were used etc. However, the data serve the useful purpose of indicating the order of magnitude of seasonal differences in straw yield. The varietal data are perhaps less meaningful because in most instances very few tests were conducted. But, the varietal differences in grain: straw ratios are of interest.

Other observations which further suggest that the NFU straw yield estimate is too low include work done by ADAS[2] in Oxfordshire in 1974 and by Austin[3] at the Cambridge Plant Breeding Station. With respect to the former, 13 wheat crops were examined and the mean straw yield was 3.77 tonnes/ha. Austin's data which are presented in table 3 were obtained in growth analysis experiments with winter wheat in 1973 and 1974. They demonstrate that very high yields of non-grain, above-ground dry matter are produced in a cereal crop.

The yield of oat straw has not been investigated in depth in this paper because little oat straw is burnt. Taking an average value for

Table 2 The effect of variety on straw and grain yields (extracted from NIAE combine test reports, 1961 – 69)

Crop	Variety	Year*	No of Tests	Yield (tonne/ha) Grain	Straw	Grain: Straw ratio
Wheat	Cappelle	a, b, c, d, e, f	24	5.47	5.84	1 : 1.07
	Hybrid 46	a, b, c	10	4.84	6.02	1 : 1.24
	Jufy	b, c	6	5.47	4.84	1 : 0.89
	Atson	b	3	4.44	7.35	1 : 1.66
	Opal	d, e	8	4.41	5.92	1 : 1.34
	Kloka	e, f	8	4.54	5.75	1 : 1.27
	Sprite	e	2	5.27	7.66	1 : 1.95
Barley	Vada	a, b	7	4.59	3.29	1 : 0.71
	Rika	a, b, c	6	3.71	2.89	1 : 0.77
	Proctor	a, b, c, d	32	3.76	3.01	1 : 0.80
	Pioneer	a, b, c	6	4.82	3.64	1 : 0.76
	Pallas	a, b, c	4	5.47	3.71	1 : 0.69
	Dea	c	2	3.77	2.26	1 : 0.60
	Maris Otter	e	4	4.72	3.97	1 : 0.84
	Impala	e	4	4.72	4.22	1 : 0.89
	Deba Abed	e, f	4	5.47	4.22	1 : 0.77
	Zephyr	e	2	3.39	3.64	1 : 1.07
	Swallow	e	2	4.14	4.14	1 : 1.00
	Senta	f	2	5.27	4.52	1 : 0.86
	Sultan	f	1	3.77	2.26	1 : 0.60

* 1961 = a, 1962 = b, 1963 = c, 1966 = d, 1967 = e, 1969 = f

Table 3 Effect of (a) genotype and (b) genotype x nitrogen level on total dry matter yield of above-ground plant parts less grain in winter wheat at Cambridge, in 1973 and 1974 respectively (tonne/ha)

1973	*Breeding selections*			*Varieties*	
TJB300/241	*TL365a*	*TL/363/30*	*Maris Templar*	*Maris Widgeon*	*Cappelle Desprez*
9.21	7.73	7.83	9.86	9.39	8.36

1974	*Breeding Selections*				
TJB300/241			TL365a/34		
27kgN/ha	70kgN/ha	170kgN/ha	27kgN/ha	70kgN/ha	170kgN/ha
10.27	11.04	9.86	8.71	8.18	8.86

after Austin[3]

all oat crops appearing in NIAE combine test reports, however, reveals a figure of 5.52 tonnes/ha.

2.2 The effect of height of cut on harvested straw yield

Because of the relative values of grain and straw, farmers necessarily give the grain harvest the priority and this may mean leaving a long stubble to maximise combine throughput. Even where farmers are intending to bale rather than burn straw this is often the case.

The effects of cutting height on straw yields were studied on a commercial farm near Silsoe and at the High Mowthorpe Experimental Husbandry Farm in the summer of 1974. Square metre samples of two varieties of wheat were examined *viz* Bouquet (winter) and Maris Huntsman (spring). The data are shown in fig 1 and in table 4. Over the range of cutting heights presented in table 4 the harvested yield of straw varies by between 25% and 35%. The penalty costs associated with slower combine speeds, which are inevitable at low cutting heights, would of course have to be set against the value of the increased yield of straw. But were the grain: straw price differential to narrow as would probably happen if an industrial market for straw came into being, then lower cutting heights would probably follow with marked effects on harvested yield.

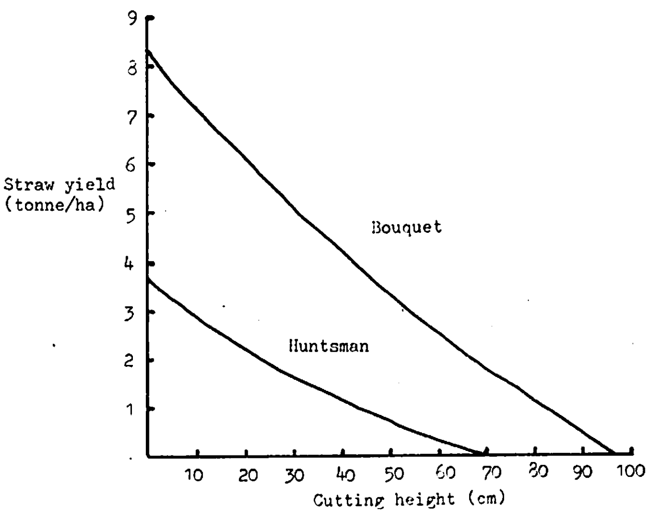


Fig 1 The effect of cutting height on straw yield of two wheat varieties.

3 Energy considerations

3.1 General

The energy crisis has provided the stimulus for a number of energy output: input studies of agricultural production activities[4,5]. Leach[4] has calculated, for the UK farm situation, E ratios (energy out/energy in) for wheat, oats, barley and maincrop potatoes; these are estimated to be 2.2, 2.0, 1.8 and 1.1 respectively for produce at the farm gate, i.e. the energy costs associated with transportation, processing and packaging are not included. Where these energy

Table 4 The effect of three cutting heights on straw yields

Cutting height	Bouquet Straw yield (tonne/ha)	Yield as % of total	Maris Huntsman Straw yield (tonnes/ha)	Yield as % of total
Ground level	8.34	100	3.55	100
10 cm	7.25	86.9	2.84	80.0
20 cm	6.18	74.1	2.20	61.0
30 cm	5.14	61.7	1.60	45.0

costs are taken into account, then the E ratios appear even less favourable and in one case (sugar) fall well below unity (0.49).

In the United States, Pimental *et al*[5] have examined for maize the change in E that has taken place over the period 1945–70. Whilst maize yields have more than doubled during this period, the production methods employed have been such that the E ratio has declined from 3.70 to 2.82 due largely to higher N fertiliser usage and mechanisation.

Whilst it is undoubtedly true that modern agricultural production technology is indulgent in its consumption of energy the fact remains that in the UK more than 50% of the nation's food needs is home-produced using only 3% of the annual fossil fuel bill[6]. Thus, even profound modifications to current farming methods can only have a marginal influence on our total fossil fuel consumption. Nonetheless, within the limits imposed by the UK's high population, which renders it imperative that high yields per ha be maintained and indeed advanced, we should strive to improve the efficiency of energy utilisation in agriculture and reduce, where practical, waste. It is in this context that straw utilisation should be considered.

3.2 Straw as an energy source

The gross energy value for straw has been estimated by various authors[7,8,9]. The precise value depends on species and variety but it is generally between 17.5 and 18.5 MJ/kg which is about the same as that for wood but only half of that for coal.

The gross energy value is the calorific value of oven dry straw and represents the total energy content. However, straw normally contains a certain amount of free water which will effectively reduce the calorific value due to the energy requirement of the latent heat of vaporisation. This 'net energy' value is shown in table 5 for various straw yield levels assuming a moisture content of 16% (on the wet basis), a gross energy value for straw of 18.4 MJ/kg and taking the latent heat of vaporisation of water as 2.26 MJ/kg.

Table 5 The 'net energy' output of straw crops of specified yield levels (where the moisture content = 16%)

Straw yield tonnes/ha	*'Net energy' output MJ/ha*
2.50	3.8×10^4
3.75	5.7×10^4
5.00	7.5×10^4
6.25	9.4×10^4
7.5	11.3×10^4

On the basis of the above assumptions, 3.5 million tonnes of straw is equivalent to a total net energy value of 53×10^9 MJ. If the mean yield of straw is rather higher than the 2.89 tonnes/ha assumed in the NFU report, say 4.4 tonnes/ha, then the amount of straw burnt annually would approximate to 5.3 million tonnes or 80×10^9 MJ.

3.3 Energy costs of on-farm collection and handling of straw

The primary energy costs of baling and carting straw using a conventional baler and the Flat 8 system of handling bales are summarised in table 6 and set out in rather more detail in Appendix 1. A number of the assumptions made have been drawn from Wainwright's[10] comparative study of systems of handling and storing straw. In the table, various straw yield levels are specified. It is clear that the energy costs of this part of the straw harvest are very low indeed, about 1.5% of the 'net energy' contained in the straw (cf. table 5).

Table 6 Energy costs of baling and carting straw

Straw yield tonnes/ha	*Primary energy cost MJ/ha*
2.50	693
3.75	1039
5.00	1385
6.25	1731
7.5	2077

Of the primary energy costs approximately 90% might be described as "fixed" costs (these relate in the main to the manufacture of the baler and the handling equipment) and 10% "variable costs" (fuel for the baling and carting operations).

No attempt is made here to (energy) cost other systems of packaging and handling straw or to speculate upon the additional energy inputs which might be required to produce more dense bales. Further, the energy costs of storage have not been calculated but they would be very low indeed.

3.4 Energy costs of straw transportation by lorry

One of the major problems associated with off-farm usage of straw relates to high transportation costs which in turn is largely a consequence of bale density. In table 7 the dimensions of conventional, Howard 'Bigbale' and New Holland (also Vermeer and Hesston) round bales are shown. Examination of the data presented in table 8 indicates that if maximum advantage is to be taken of the full payload capabilities of lorries then the density of conventional and round bales should be increased by between 70% – 180% depending on the lorry, and for the Howard 'Bigbale' much greater density increases would be required. For rail transport, again depending upon the type of wagon used an increase in bale density of between 70% – 400% would be necessary if their full payload is to be exploited. Work in this area is being done at the NIAE and at Cranfield Institute of Technology.

Table 7 Approximate dimensions of conventional, Howard 'Bigbale' and New Holland round bales

Straw bale type	*Weight (kg)*	*Dimensions (m)*	*Density (kg/m^3)*
Conventional	18	0.46 x 0.36 x 0.91	119
Howard 'Bigbale'	320	1.52 x 1.52 x 2.44	57
Round	450	1.83 x 1.52	113

Table 8 Lorry capacities and load densities

Lorry bed length (m)	*Type*	*Capacity (tonne)*	*Volume* (m^3)*	*Minimum bale density for full payload (kg/m^3)*
4.88	4 wheel rigid	8	38	211
6.55	"	10	51	196
7.32	"	16	57	281
8.23	6 wheel rigid	18	64	281
9.14	Articulated	21	71	296
10.36	"	21	81	259
12.19	"	21	95	221

*Assumes load width of 2.44 m and height above lorry bed of 3.20 m.

The primary energy costs of transporting straw by two lorry types (one with a straw payload of 9 tonnes and one with a payload of 5 tonnes) on a per tonne km basis have been calculated (see Appendix 2). Surprisingly, there would appear to be little difference between the two lorry types but this might reflect the inadequacy of the method employed to calculate "fixed" energy costs. For both, a figure of 2.8 – 2.9 MJ/tonne km was obtained. Compared to the energy contained in a hectare of straw the energy transportation cost then is also very small.

3.5 Other energy costs

No attempt is made in this paper to estimate the energy costs associated with factory processing or with the transportation of the processed product to consumers. Indeed, until more is known about these aspects such work is not possible.

4 The uses of straw

4.1 Straw as a fuel

Apart from some Scandinavian farms where the homestead is heated by straw-burning furnaces there is little evidence of straw being used directly as a fuel. Wilton[11] at Nottingham University is investigating the possibility of using straw to dry grain. Straw must compete as a fuel with wood, coal or oil. The price structure of the forage market in 1974 was distorted by several factors, such as high cereal prices and very poor weather during the hay-making season and cereal harvest. Even in a 'normal' season, however, it is unlikely that straw can compete with traditional fuels for sale off the farm. The value of the product is unlikely to justify the cost of cubing although machines are available which compress straw and sawdust into artificial 'logs'[12]. The Irish Peat Authority[13] presses peat into briquettes for use as a domestic and industrial fuel.

With coal at £25/tonne, straw based logs or briquettes must sell at not mote than £12.50/tonne for equivalent calorific value. Established methods of coal handling are now so sophisticated that the user is likely to require considerable financial incentive to change from coal. It is difficult to envisage straw collection and handling systems to deliver straw to the user in a dense, free-flowing briquette or cube below £15/tonne. The conclusion must be that straw cannot compete for use as a fuel off the farm.

4.2 Straw for animal feed

Swan and Clarke[14] and Stigsen[15] discuss the use of processed straw in rations for ruminants and describe in some detail the means by which the digestibility of straw (barley) can be raised (approximately doubled) through sodium hydroxide treatment. The use of sodium hydroxide in this connection has been known for many years but the method has recently been developed into a mechanised short-time technique. The process is at an early stage of commercial exploitation in Britain by BOCM Silcock Ltd, which, if successful, will create a substantial additional outlet for barley straw.

4.3 Straw as an industrial resource

4.3.1 Building materials

Straw has been used to manufacture boards for roof insulation and partitions. This outlet appears to have declined with the advent of alternative materials which are both easier to handle and erect on site. A dramatic increase in demand for these products would make very little impact on the total quantity of straw which is at present burnt.

4.3.2 Paper-making

The paper-maker is interested in straw because it contains about 40% fibre. There are many paper-making factories throughout the world using cereal straw, sugar cane begasse and other annually renewed fibres, including some in Holland, France and Spain. Straw was used in England during and immediately after, the War to produce pulp for paper-making. As soon as wood pulp supplies from abroad were restored, however, straw was abandoned as a raw material, mainly as a result of the supply problems due to seasonality of production, and difficulties with effluent pollution.

Renewed interest in straw for paper-making in the UK has come about as a consequence of the uncertainty attached to the long-term wood supply situation. An extensive report on the feasibility of using straw for this purpose has recently been published[16]. Whilst work is being undertaken at the Paper Industries Research Association with the aim of developing a satisfactory pulping method, there is no prospect of a large market being created for straw for paper pulp before 1980.

4.3.3 Straw as a source of cellulose

In addition to exploiting the structural strength of the fibre in the straw it is also possible to utilise the cellulose as a chemical compound. Straw contains about 50% cellulose (see Appendix 3). This represents a source of energy which is renewed annually via the process of photosynthesis.

There are three principal methods of treating cellulosic wastes worthy of consideration in the context of cereal straw.

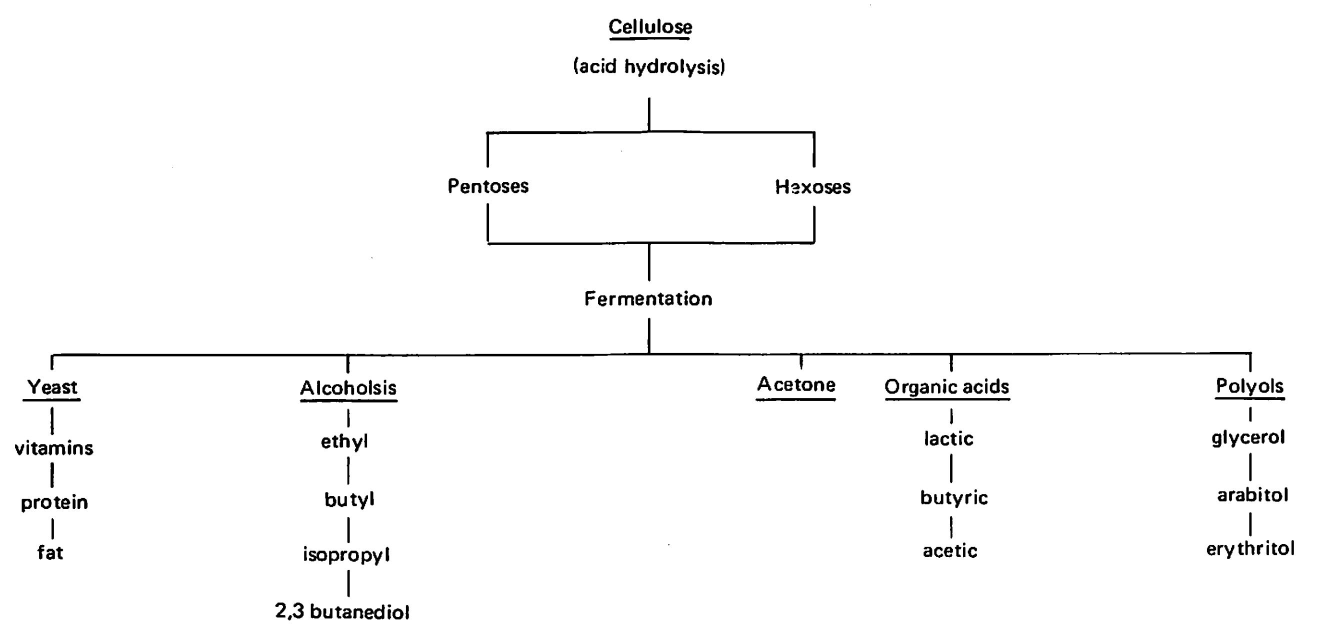
a) Pyrolysis
Straw may be pyrolysed by heating in a closed retort to temperatures within the range 500-1 000°C. A combustible gas, a liquid containing organic compounds including tars and oils and ash are produced (see Appendix 4). Work at the Warren Spring Laboratory on domestic wastes[17], suggests that the amount of useful combustible gases depends largely on the temperature of the retort. The economics of the process are not yet clear and may depend on further processing of the liquid fraction to produce chemicals of commercial importance. A pilot plant is reported to be operating on domestic refuse, which contains large quantities of cellulose rich paper, at Kolding in Denmark.

b) Hydrolysis
The advent of the internal combustion engine inspired considerable research into producing fuel from cellulose and starch[18]. As abundant oil supplies were discovered, this work was abandoned only to be revived first during the 1914–1918 War and again during the 1939–1945 War. Large quantities of ethanol were produced in the USA, England and Germany[19], from cellulosic materials such as wood waste. The process of hydrolysis is accomplished by treating cellulose with sulphuric acid to produce sugars. These sugars are then fermented to produce ethanol. Porteous[20] has listed (see fig 2) the fermentation products of cellulose hydrolysis and urges that hydrolysis should be considered as a new method of domestic waste utilisation.

Hansford[21] proposes an hydrolysis system for straw which includes using the dried pulp for use as a building board and as a fuel to run the plant. It has been reported[22] that a factory is already operating at Leningrad using wood waste to produce ethanol, furfural and yeast. An increasing amount of evidence suggests that the hydrolysis of straw merits further study.

c) Biological recycling
Apart from the fermentation process of sugars, it has been suggested that biological transformation can be exploited for the production of single cell protein and other useful products[22]. Another possibility[23] is to use microbial action to improve

Fig 2 Fermentation products of cellulose hydrolysis



biodegradability and digestibility of straws. The protein production capacity of microbes is many times more efficient than a beef animal and if this can be achieved using waste products such as straw, then the system deserves closer examination.

5 Towards an integrated straw utilisation policy

In recent years much necessary effort has been expended in investigating both on- and off-farm uses for that straw produced in the UK which is apparently surplus to the traditional needs of the agricultural industry. Whilst a number of these show promise, more development work is undoubtedly needed before commercial exploitation can be seriously contemplated.

Discussions on the possible uses for straw in recent years have tended to consider each suggestion in isolation — building materials, paper pulp, ethanol, furfural, and so on. On this basis the economic viability of some of the proposals appears doubtful. It is possible, however, that a wider view should be taken of the straw problem and a series of integrated operations performed in one industrial complex. It is envisaged that a whole range of products could be manufactured. The best quality straw could be used for paper pulp; if one of the newer acid pulping processes is adopted, hydrolysis of second grade material could perhaps be economic. Fermentation of sugars to ethanol could yield by-products of yeast and protein-enriched cattle food. Production of other valuable chemicals such as ethylene and furfural may also be possible. The final inert residue could be briquetted as a fuel to generate power to run the plant.

Irrespective of the uses to which straw might be put, there are a number of other aspects of the total problem apart from the processing technologies *per se*, requiring further attention.

Assuming industrial outlets, the key questions to which answers must be found concern the price that can be afforded by processors for straw of specified quality delivered to factories and the response of farmers (also contractors, straw merchants, hauliers etc) to the price offered in terms of supply of straw forthcoming. These questions raise such issues as:

(i) Annual variation in cereal acreages and straw yields. With respect to the latter much more information is urgently required on a systematic basis.

(ii) The costs and benefits of straw burning. These need to be quantified, particularly the benefits attributed to burning straw *in situ*.

(iii) The logistics and costs associated with year-round supply of straw from farms to processing factories. The flow includes a number of inter-related activities *viz* packaging, handling, storage and transportation; both the existing and the new systems being developed need to be appraised thoroughly.

(iv) The direct and indirect effects of weather in the July — September period and the problem of weather uncertainty.

(v) The managerial implications of introducing another farming activity at the time of the grain harvest. At what straw price would farmers consider the effort worthwhile? In this connection net farm income and taxation considerations are of importance.

Thus, better utilisation of this national resource is undoubtedly a complex matter requiring an integrated multi-disciplinary approach. Straw is a potentially useful commodity produced in large quantities annually. The data presented in this paper suggest that, from a purely energy standpoint, it does not constitute prudent national house-keeping to continue to burn the material. The energy costs of baling, carting, and transporting straw would appear to be small in relation to the energy value of the material.

Appendix 1

The primary energy costs of baling and carting straw

The energy cost of performing a particular operation includes not only the energy content of the fuel used but also the energy required to process and transport the fuel and a proportion of the energy required to manufacture and deliver the operating machinery. Thus it can be seen that the total or primary energy costs consist of direct and indirect energy inputs.

The value of the direct energy inputs is easily established by calorimetry and data on the calorific values of fuels is readily available[24].

The value of the indirect energy inputs is less easily established. Factors have been derived[6] by which the calorific values of fuels must be multiplied to allow for the energy cost of their production. This factor is 1.12 for petroleum fuels.

To calculate the energy cost of manufacturing a particular piece of machinery is very difficult. However, an estimate can be made by introducing the concept of capital having an energy equivalent. Thus the capital cost of a piece of machinery reflects the energy cost of its manufacture.

The energy equivalent of capital for the manufacturing industry in 1973 was calculated in the JCO report[6] as follows:

$$\text{Energy equivalent of capital for manufacturing industry} = \frac{\text{Total energy usage of manufacturing industries}}{\text{Gross domestic product for manufacturing industries}}$$

$$= \frac{3740 \times 10^{15}\text{J}}{£2.1 \times 10^{10}} = 178 \text{ MJ/£}$$

Therefore as an approximation it has been assumed that every £ of capital expenditure incurs at energy cost of 178 MJ.

Fuel energy cost/tonne of straw baled

1) Assumptions:

Calorific value of diesel oil	45.5 MJ/kg
Density of diesel oil	0.84 kg/1
Fuel consumption during baling	0.6 1/tonne
Primary energy factor for diesel oil =	1.12

Energy cost of fuel/tonne of straw baled:

$= 0.6 \times 0.84 \times 45.5 \times 1.12 = 26$ MJ/tonne

Machinery energy costs/tonne of straw baled

2) Assumptions: Baling (baler)

Capital cost of baler	£1700
Annual throughput of baler	400 tonne
Depreciation life of baler	7 years
Energy equivalent of capital	178 MJ/£

Baler capital energy cost/tonne of straw baled:

$$\frac{1700 \times 178}{400 \times 7} = 109 \text{ MJ/tonne}$$

3) Assumptions: Baling (tractor 1)

Capital cost of Tractor 1	£3000
Annual use for baling	100 tractor hr.
Rate of work	4 tonne/tractor hr.
Depreciation life	10 000 tractor hr.
Energy equivalent of capital	178 MJ/£

Tractor 1 capital energy cost/tonne of straw baled:

$$= \frac{3000 \times 100 \times 178}{10\,000 \times 4 \times 100} = 13 \text{ MJ/tonne}$$

Fuel energy cost/tonne of straw handled

4) Assumptions:

Calorific value of diesel oil	45.5 MJ/kg
Density of diesel oil	0.84 kg/1
Fuel consumption during handling	45 ml/tonne
Primary energy factor for diesel oil	1.12

Energy cost of fuel/tonne of straw handled:

$45 \times 10^{-3} \times 0.84 \times 45.5 \times 1.12 = 2$ MJ/tonne

Machinery energy costs/tonne of straw handled

5) Assumptions: Handling (Flat 8 system)

Capital cost of system	£1620
Annual throughput	400 tonne
Depreciation life	6 years
Energy equivalent of capital	178 MJ/£

Flat 8 system capital energy cost/tonne of straw handled:

$$= \frac{1620 \times 178}{400 \times 6} = 120 \text{ MJ/tonne}$$

6) Assumptions: Handling (tractor 2)

Capital cost of tractor 2	£3000
Annual use for handling	50 tractor hr.
Rate of work	8 tonne/tractor hr.
Depreciation life	10 000 tractor hr.
Energy equivalent of capital	178 MJ/£

Tractor 2 capital energy cost/tonne of straw handled:

$$= \frac{3000 \times 50 \times 178}{10\,000 \times 8 \times 50} = 7 \text{ MJ/tonne}$$

Total Primary Energy Costs of Baling and Handling Straw

Baling	Fuel	26 MJ/tonne
	Baler	109 MJ/tonne
	Tractor 1	13 MJ/tonne
Handling	Fuel	2 MJ/tonne
	Flat 8 System	120 MJ/tonne
	Tractor 2	7 MJ/tonne
	Total	277 MJ/tonne

Appendix 2

Energy costs of transporting straw by road

Fuel energy costs/tonne km

1 Assumptions:

	Lorry A	Lorry B
Diesel oil consumption	0.40 1/km	0.23 1/km
Payload with straw	9 tonne	5 tonne

Calorific value of diesel oil	45.5 MJ/kg
Density of diesel oil	0.84 kg/l
Primary energy factor for diesel oil	1.12

Primary fuel energy cost/tonne km for Lorry A:

$$\frac{0.40 \times 0.84 \times 45.5 \times 1.12}{9} = 1.90 \text{ MJ/tonne km}$$

Primary fuel energy cost/tonne km for Lorry B:

$$\frac{0.23 \times 0.84 \times 45.5 \times 1.12}{5} = 1.97 \text{ MJ/tonne km}$$

Machinery energy cost/tonne km

2 Assumptions:

	Lorry A	Lorry B
Capital cost of lorry + tyres for life	£18 000	£9 000
km life	390 000 km	340 000 km
Payload with straw	9 tonne	5 tonne
Energy equivalent of capital	178 MJ/£	

Capital energy cost/tonne km for Lorry A:

$$\frac{18\,000 \times 178}{390\,000 \times 9} = 0.91 \text{ MJ/tonne km}$$

Capital energy cost/tonne km for Lorry B:

$$\frac{9\,000 \times 178}{340\,000 \times 5} = 0.94 \text{ MJ/tonne km}$$

Total Primary Energy Costs of Transporting Straw

	Lorry A	*Lorry B*
Fuel	1.90 MJ/tonne km	1.97 MJ/tonne km
Machinery	0.91 MJ/tonne km	0.94 MJ/tonne km
	2.81 MJ/tonne km	2.91 MJ/tonne km

Appendix 3

Composition of wheat straw

	% W/W
Dry matter	90.1
Cellulose	50.1
Pentosans	11.5
Lignins	13.7
Ash	8.1
Crude protein	3.6
Ether extract	1.7
Crude fibre	41.5
Calcium	0.17
Sodium	0.15
Potassium	1.11
Phosphorus	0.08
Magnesium	0.12
Iron	0.015
Manganese	0.004

Source: Freed [12]

Appendix 4

Thermal decomposition of straw by pyrolysis

Mass Balance

	Products (% W/W)	
Pyrolysis Temperature	500°C	800°C
Gas	16.0	31.9
Liquid *	44.3	42.9
Char	39.4	25.6

*This is liquid produced not moisture (i.e. water is formed in the pyrolysis process)

Analysis of Products

	Gas (% V/V)	
Pyrolysis Temperature	500°C	800°C
Hydrogen	3.87	24.89
Carbon dioxide	44.72	23.25
Carbon monoxide	38.71	31.48
Methane	6.31	16.01
Ethane	1.94	1.32
Ethylene	2.71	1.92
Propane	0.41	0.25
Propylene	1.26	0.87

	Liquid (% W/W)	
Pyrolysis Temperature	500°C	800°C
Aqueous	88.9	69.0
Oil	11.0	31.0

→ page 76

Pyrolysis Temperature	(Char (% W/W) 500°C	800°C
Ash	13.0	14.5
Hydrogen	4.3	2.4
Carbon	73.4	72.5
Oxygen (by difference)	9.3	10.6

Source: Daborn [25]

References

1 NFU Working Party on Straw Disposal (1973). Report on the Use and Disposal of Straw Cyclo: 1186/95/73 TM66.

2 **Wood R S** (1974). Straw Production and Disposal in Oxfordshire. Report on Straw Utilisation Conference, ADAS, Oxford.

3 **Austin R B** (1975). Private communication.

4 **Leach G** (1973). *The Man-Food Equation.* Academic Press, New York and London.

5 **Pimentel D** *et al* (1973). Food Production and the Energy Crisis. *Science,* 98, 443.

6 Joint Consultative Organisation for Research and Development in Agriculture and Food (1974). The Report of the Energy Working Party. Report No 1.

7 **McDonald P** *et al* (1966). *Animal Nutrition.* Oliver and Boyd, Edinburgh and London.

8 **Morrison F B** (1959). *Feeds and Feeding.* The Morrison Publishing Co, Clinton, Iowa.

9 **Robb J** (1975). Private communication.

10 **Wainwright R** (1974). On the Determination of an Optimal System for the On-farm Handling and Storage of Straw. Special Study Report, NCAE, Silsoe, Bedford.

11 **Wilton B** (1975). Scope for Straw. *Span,* 18, 1.

12 **Freed V** (1974). Straw Utilisation. Oregon State University Research on Field Burning. Circular of Information 647. Oregon State University, Corvallis.

13 **Martin J** (1974). Private communication.

14 **Swan H** and **Clarke V J** (1974). *The Use of Processed Straw* in Rations for Ruminants. Nutrition Conference for Feed Manufacturers: 8 Butterworths, London.

15 **Stigsen P** (1974). Nutrition Conference for Feed Manufacturers: 8 Butterworths, London.

16 **Truman A B** (1974). A Survey of Straw Pulping in Great Britain. The Research Association for the Paper and Board, Printing and Packaging Industries, Leatherhead, Surrey.

17 **Douglas E** *et al* (1974). The Pyrolysis of Waste and Product Assessment. Warren Spring Laboratory, Stevenage, Herts.

18 **Pleeth S J W** (1949). Alcohol, a Fuel for Internal Combustion Engines. Chapman and Hall, London.

19 FIRT (1945). The Production of Wood Sugars, Alcohol and Yeast in Germany. Report 499, HMSO.

20 **Porteus A** (1975). The Recovery of Fermentation Products from Cellulose Wastes via Acid Hydrolysis. Paper presented to Octagon Group Meeting, University of Manchester, March 1975.

21 **Hansford R** (1974). Other Possibilities of Processing Straw. Report on Straw Utilisation Conference. ADAS, Oxfordshire.

22 **Hughes D** (1974). Biological Aspects of Recycling. Royal Society of Arts, 113 5223.

23 **Anderson A W** (1974). Utilisation of Straws — Microbiology, Oregon State University Research on Field Burning, Circular of Information 647. Oregon State University, Corvallis.

24 **Spiers H M** (1962). Technical Data on Fuel. The British National Committee World Power Conference, London.

25 **Daborn G R** (1973). The Pyrolysis of Straw. Warren Spring Laboratory, Internal Report No IR 161 (MH).

continued from page 69

future, but by research and by more informed operation of machinery energy and operating costs can be reduced significantly.

Appendix

An example of the effect of tyre choice on tractor efficiency

Suppose a 45 kW (60 hp) tractor is fitted with 12.4/11-36 tyres and a three furrow mounted plough. Suppose the weight on the rear axle of the tractor with the plough in work is 1 180 kg (2 600 lb) and that it is intended to plough land with a resistance of 3.5 kN (787 lb) per furrow in poor traction conditions. The total pull is 10.5 kN (2 360 lb) or 5.25 kN (1 180 lb) per driving wheel. From the Handbook of Agricultural Tyre Performance[16] for a 12.4/11-36 tyre, it can be determined that the slip would be over 20% and the pull would be well above the value of 4.2 kN (940 lb) required for the maximum tractive efficiency.

The following three ways of increasing tractive efficiency are, however, possible:—

1. Increase the weight per driving wheel to 1 600 kg (3 530 lb) by adding ballast. This will necessitate increasing the inflation pressure from 0.8 bar (12 lbf/in^2) to 1.5 bar (22 lbf/in^2). The tractor will then be able to pull the plough comfortably and the maximum tractive efficiency will be 61%.
2. Reduce the plough to 2 furrows. The pull per driving wheel will then be reduced to 3.5 kN (787 lb) which will be well within the pull available with a load of 1 180 kg (2 600 lb) per driving wheel. The inflation pressure can be kept down to 0.8 bar (12 lbf/in^2) and the tractive efficiency will be 66%. Therefore, provided the tractor can be operated at a sufficiently high speed to make use of the full engine power available, the rate of work will be 8% higher than with option 1 above.
3. Fit 16.4/14-30 tyres and ballast to 1 600 kg (3 530 lb) load per driving wheel. From the handbook it can be determined that a pull of 5.25 kN (1 180 lb) is well within the capability of a 16.9/14-30 tyre even in poor traction conditions and the inflation pressure need only be 0.8 bar (12 lbf/in^2). The maximum tractive efficiency will be 64% so that provided the full engine power is used, the rate of work will be 5% higher than with option 1 above. This is not quite as good as with option 2 but may be easier to attain because it does not necessitate an increase in speed to make use of the full engine power.

References

1 **Stansfield J R** *et al* Fuel in British Agriculture. Nat Inst Agric Engng. Rep no 13, 1974.

2 **Gifford R M** and **Millington R J.** Energetics of food production with special emphasis on the Australian situation. Paper to National Symposium on 'Energy and How We Live'. Adelaide, Australia, 1973.

3 MAFF. The use of large horsepower wheeled tractors. NAAS Technical Report no 17, 1968.

4 **Patterson D E, Chamen W C T, Richardson C D.** Perennial experiments with tillage systems to improve the economy of cultivations for cereals: 3rd year — 1973/74 experiments. Dep Note. DN/Cu/501/1260. NIAE, 1975.

5 **Chamen W C T, Cope R E.** Studies of the design of a rotary digging machine: Part 2. 1973-74 Investigations. Dep Note DN/TC/502/1260 NIAE, Silsoe (Unpubl.).

6 **Sohne W.** Influence of shape and arrangement of tools on driving moments of rotary hoes. *Grundlagen der Landtechnik* 1957, 9; 69-87.

7 **Harral B B.** An analysis of cultivation techniques. Dep Note DN/Cu/543/1260. NIAE, Silsoe, 1975 (Unpubl.).

8 **Zoz F M.** Factors affecting the width and speed for least cost tillage. *The Agricultural Engineer,* 29 (3), 1974.

9 **Manby T C D, Shepperson G.** Increasing the efficiency of grass conservation.

10 **Dwyer M J.** Farm transport requirements and their effect on tractor design. Dep Note DN/TC/426/1400. NIAE, 1973.

11 **Moberg H A.** Private communication, 1974.

12 **Tierney W T, Mitchell E, Alperstein M.** The Texaco controlled combustion system. A stratified charge engine concept review and current status. Paper C1/75 to the Conference on Power Plants and Future Fuels. Institution of Mech Engs 1975.

13 **Richardson R W.** Automotive engines for the 1980s. Paper No. C12/75 to the Conference on Power Plants and Future Fuels. Institution of Mech Engs 1975.

14 **Manby T C D.** The measurement of tractor performance. IMechE Proc Auto Div 1961-62, Number 4.

15 **Dwyer M J, Pearson G.** A field comparison of the tractive performance of two and four-wheel drive tractors. Dep Note DN/T/574/1405, NIAE, Silsoe 1975 (Unpubl.).

16 **Dwyer M J, Comely D R, Evernden D W.** Handbook of agricultural tyre performance. Report no 14, NIAE, 1974.

Increasing the efficiency of grass conservation

by T C D Manby BSc MSc CEng MIMechE and G Shepperson BSc

1 Introduction

AT a time when the deficit in the national balance of payments is about £4 000 m/year, our food import bill is also about £4 000 m*, and the worldwide demand and cost of high energy foods have markedly increased, it is vital to reappraise the potential of grass. This is the natural feed crop for production in the UK but often much of the conserved product has been of such poor quality that it was incapable of providing maintenance to milking cows. The sharp rise in the price of energy and imported feed stuffs, the disastrous weather for haymaking in 1974 which led to drastically reduced production may both encourage many farmers to think again about their conservation policy. Hopefully they will decide to make a high quality product.

Interesting work remains to be done to determine the strategy and tactics which they should be advised to adopt regarding machinery and management improvement. It is fortunate that as the potential power from nature's resources becomes recognisably more precious, so more help can be provided by technologists to harness the power of the computer to help optimise the strategy to meet particular farm and even – if need be – to individual animal requirements. The engineer benefits also from this new tool in his research and in development of improved equipment. Whether farmers will respond to the advice which will become increasingly available in terms of probability of success for one form of conservation compared with another will depend, as always, on the incentives and leadership provided.

On 25 February 1975 the Minister of Agriculture, Fisheries and Food advised that "the important contribution already being made by ADAS could be taken still further to a national, co-ordinated campaign to publicise the benefits of grass. He believed it should be directed particularly at smaller farms because they contain much of our grassland and at the continuing need to put over to farmers the techniques of good silage making and new developments in haymaking, particularly barn hay drying. The value of regular forage analysis, of the use of nitrogen and of improved field drainage were emphasised. On small and medium sized farms, use of machinery syndicates and private contractors was advocated. In the immediate future the emphasis will be on improving conservation techniques, especially silage making, by adopting known and proven technology which gives better results than the generality of farming practice." Such a campaign is of considerable importance to manufacturers because it should increase the demand for larger machines which can be used more efficiently than small ones. The White Paper[1] of 18 April emphasised this need for expansion with a view to reducing food imports by £500 m by 1980. If 1 m acres of grassland is to be released to produce an extra 1.5 m tons of cereals there must be a substantial increase in output from the remaining grassland.

A basic study for this conference is firstly to determine whether the high costs of imported sources of energy, and its recognition as a precious resource, should pre-empt its use in particular ways to produce and conserve crop of higher value, secondly to examine the areas where results of research and development already show how best to increase efficiency and should be adopted and thirdly to highlight the areas where more research and development would be most beneficial. This paper must be confined to basic questions concerned with harvesting and conservation and provides outlines for study in greater depth at next year's annual conference, which will be devoted entirely to the engineering problems for forage and conservation.

2 Strategy

When compared with traditional practice on the majority of farms in the UK the scope for energy production from grass is enormous. The general principle that grass has a reduced nutritive value as maturity increases[2] is appreciated by a comparatively large number of farmers. It is probable, however, that only those who have specialised in the production of dried grass fully appreciate the massive available from frequent cutting and from top level management of production. It is suggested that the main strategy must be to provide equipment, techniques and leadership to make it much easier to achieve this potential from silage and hay.

An example of what might be obtained has been indicated in work by Lonsdale at the Grassland Research Institute[3] The yield and digestibility of primary and re-growth cuts of S23 perennial ryegrass were examined for three harvesting sequences which provide respectively for six cuts, four cuts and three cuts per annum. Tables 1A and 1B.

Table 1A Effect of date of harvest and number of cuts on yield and efficiency of use of S23 ryegrass

Harvest date	*D value (in vitro)*	*Harvested yield dm t/ha.*	*Efficiency of use LWG/100 kg of dry matter intake*	*LWG per ha kg/year**
Sequence 1				
14 May	70	4.1	14.6	599
4 June	70	0.6	14.0	84
4 July	67	1.3	9.6	125
4 Aug	67	1.0	9.2	92
4 Sept	67	1.0	8.7	87
4 Oct	69	0.6	10.5	63
		8.6		1050
Sequence 2				
4 June	64	7.3	6.1	445
30 July	64	3.7	5.7	211
10 Sept	68	1.8	10.1	181
22 Oct	68	0.6	9.3	56
		13.4		893
Sequence 3				
15 June	61	9.0	1.9	171
17 August	61	3.4	1.7	54
22 October	65	2.2	6.0	132
		14.6		357

* Based on feeding 3-6 month old Friesian steers

The results of the estimates of the yield, adjusted for losses during harvest, are given in terms of both energy and efficiency of use when fed to young beef cattle. When considered as sole feeds the comparisons, at first sight, are particularly interesting to engineers. The meat produced from sequence 2, for example, is 2.5 times greater than from sequence 3, in which the yield was higher but the feeding value lower. Energy stored as animal tissues is respectively only 3% and 1.1% of the output of energy from chopped herbage. The intake and conversion has been markedly affected by the digestibility, but intake can also be improved by grinding with interesting differential effects between high and low quality herbage. The improvement in performance for lower quality feed is

T C D Manby is Head of Machine Division and G Shepperson is Head of Forage Conservation Department of the National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford.

Paper presented at the annual conference of the Institution of Agricultural Engineers held at the Bloomsbury Centre Hotel, Coram Street, Russell Square, London, on 13 May 1975.

*For comparison. Visible deficit on fuels for 1974 was £3 500 m.

Table 1B Effect of milling and pelleting on energy stored as animal tissues

Sequence	Output of energy per year MJ/ha x 10^5	Energy stored as animal tissues			
		Chopped grass		Milled and pelleted+	
		MJ/ha x 10^3	% of energy output	MJ/ha x 10^3	% of energy output
1	1.55	8.40	5.4	9.89	6.4
2	2.41	7.14	3.0	11.20	4.6
3	2.63	2.86	1.1	8.54	3.2
For comparison					
Barley, Grain 3300 kg/ha	5.89×10^4 (+ 660 kg protein supplement containing 11.9×10^3 MJ)			6.8×10^3 MJ	

+ Modulus of fineness = 2.0

shown by the figures for energy stored when feeding milled and pelleted products with a modulus of fineness of 2.0 (table 1B). Hence the respective efficiency figures for the three sequences which produced food of high, medium and low grade are increased by 19%, 53% and 190% to give overall figures for efficiency of utilisation of energy of 6.4%, 4.6% and 3.2%.

The constraints on making hay in May and in October are that the necessary vapour pressure deficits to dry grass in the field to a safe baling moisture content will seldom occur. Therefore in the sequences discussed the final cuts must be dried or ensiled.

Greater use of contractors for the silage making would avoid increasing capital investment. Manufacturers of equipment will need to consider whether it works efficiently with rather shorter length grass. When concentrate supplements are fed to provide 30–40% of the ruminant's daily intake the form in which the herbage is conserved eg hay or silage, is less important and the most reliable and economical method should be used. If further justification is required for increasing the complexity of harvesting by conserving in two forms, it may be argued that there are many farmers who wish to feed hay to young stock and to out-wintering cattle and require it in a form involving minimum labour and maximum ease of handling.

Although the purpose of this paper is to consider the energy criteria of forage production, energy use and its cost are only a part of the complex economic equation; farmers must be mainly motivated by profitability, rather than by ideology. The increasing cost of labour on the farm and in the factories making the farmer's equipment may influence their decisions more than the direct cost of energy. An increase of input energy is probably justified if it is accompanied by an increase in throughput for the same labour content. Nevertheless because of its increased cost it is interesting to examine the energy content of various methods of conservation. Often the rate of increase in cost of equipment will roughly follow the trends in its potential to use energy.

Furthermore, to achieve the government's aim to improve output it must be recognised that there are six million acres of temporary grass leys and other forage crops and from most of this area the proposed 1 m acres will be diverted to cereals. There are 4.86 m ha (12 m acres) of permanent grass and a further 6.48 m ha (16 m acres) of rough grazing[4]. As much permanent grass is associated with medium and small farms, two important points emerge. Firstly there may be difficulties of providing capital from within the industry for high energy consuming machinery and processes. Secondly a large proportion of this grassland may involve sloping ground or difficult access situations and so machine stability, particularly when handling and transporting materials, can be a significant factor if systematic improvements in output are to be achieved and maintained.

2.1 Determining advice on systems for different farm types and locations

Having established experimentally, as the first strategic necessity, that multiple cuts of grass for either silage or hay are vital to obtain maximum annual production, how can improved advice be formulated to ensure that the choice of a particular conservation system gives the greatest likelihood of success? The aim must be to quantify, in probability terms, the scope for silage, field hay or barn dried hay. If, for example, a farmer is keen to make as many hay crops as possible, what priority should he then be advised to adopt regarding investment of capital? Should he first buy a combined mowing and conditioning machine, replace his baler with one making large bales, or install barn drying equipment, or all three? First and foremost ADAS should be equipped to advise on the best varieties to grow to obtain the chosen starting date for the most appropriate sequence of cutting and grazing to suit the farmer's requirements and regional climatic conditions. These many aspects have never been fully quantified for the advisers' use: it was with this need in mind that we first suggested that the computer was a tool of prime increasing value because modelling techniques can be used to simulate wide ranging conditions[5].

This process is most useful for conservation studies; historical meteorological data can be rapidly analysed, it is easier to recognise the gaps in knowledge on machine performance and in the crop drying process in the field. Mitchell and Shepperson were limited in their studies of these problems nearly 20 years ago by the lack of this facility[6], but new studies in depth can progress. Although empirical relationships have been developed there is little fundamental understanding either of the way in which incoming solar energy and air movement within swathed grass removes moisture from leaves and stems or of the removal of this water from the swath.

Penman made the first field drying studies involving wind speed data[7]. Spatz in Germany followed with the concept of vapour pressure deficit[8]. Brown and Charlick[9] used the latter approach to assess the value of mowing and conditioning machines in two areas of the UK. Sims[10] has taken the concept of vpd and the historical weather data over ten years and worked out the probability of being able to make hay in periods from three to fifteen days; the results have been expressed as a frequency curve (fig 1). Staff at NIAE and GRI are jointly interested in developing sufficient expertise in system modelling to enable them to use such weather data, with an understanding of the effect of machines on crops and the basic crop drying function. Regrettably there is a long way to go before quantified evidence can be assembled to provide advisers with a much more soundly based aid to judgement. Work by Corrie[5], fig 2, illustrates the quantification which can already be provided by modelling to determine the value of first cut hay made and used on a 8 ha (200 acres) all grass dairy farm at cutting dates from mid-May onwards.

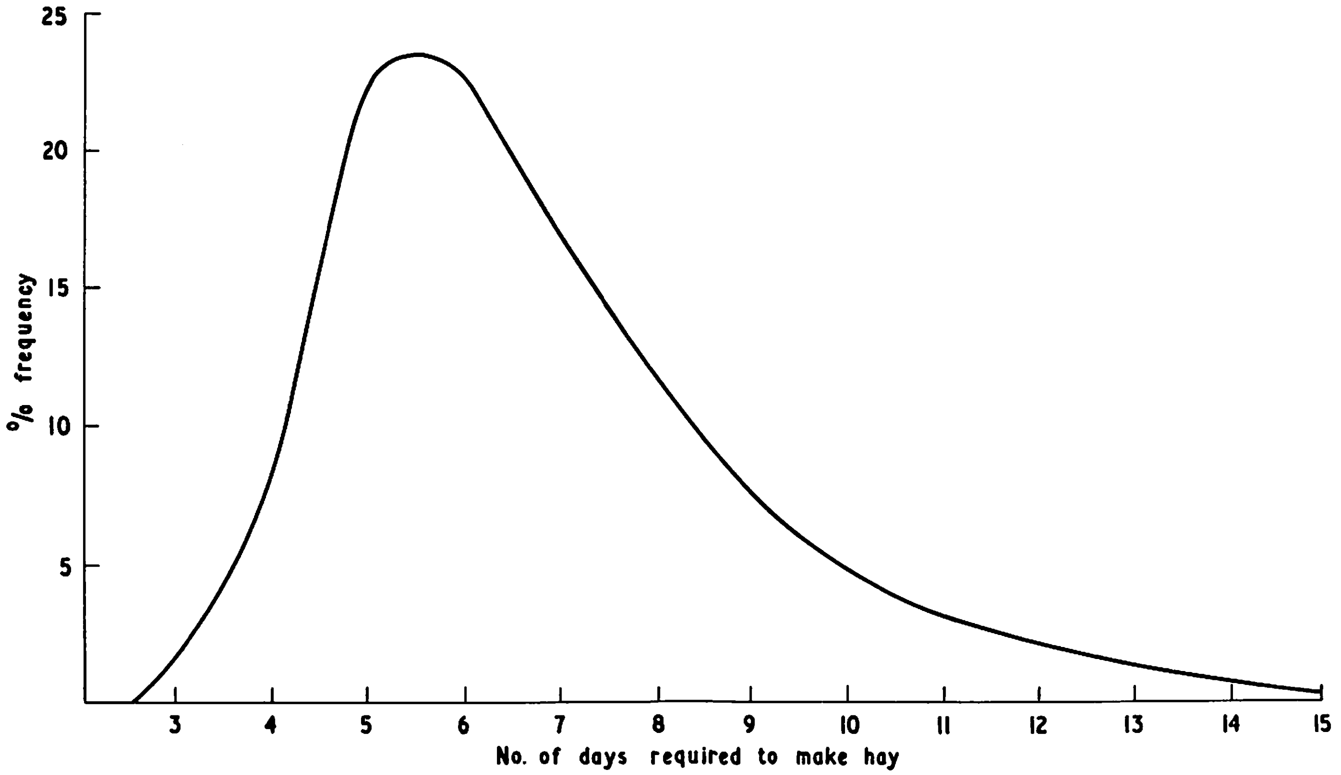
3 Tactics: Research and development being undertaken to improve the efficiency of conservation methods

The commercial grass drying organisations use the multiple cutting approach which can provide maximum use of the grass crop: the high cost in terms of energy demand in relation to the other methods of conservation is highlighted in table 2 which shows the energy content of four established processes for conserving grass[11]. Capital costs of drying are also high so first we will examine the ways of improving the efficiency of the methods demanding lower energy inputs.

3.1 Developments in mowing and conditioning machinery

These machines are likely to require more power than basic single purpose mowing machines but because they increase the speed of drying while minimising crop losses are likely to improve the efficiency of energy use in relation to the crop value. This arises mainly because their use maximises the energy to be recovered from solar radiation and drying power of the air. They are valuable in making hay or wilted silage. Table 3 summarises work at NIAE reported by Klinner[12]. In the last five years the aim has been to examine and develop a beater conditioning process for use at the time of mowing which in particular (1) evens out the drying rate by dealing more severely with stem than leaf, (2) can provide adjustment for severity of treatment, (3) forms treated herbage into self-supporting, low density swaths which resist settling and in which a large proportion of stems are inverted to provide exposure to the drying elements. Flail mowing gives the fastest drying rate and the greatest risk of dry matter loss, especially if incorrectly used or if the weather is poor. An interesting relationship between power applied during conditioning and dry matter losses can be seen from the results of many experiments (fig 3).

Fig. I. % Frequency of Number of Days Required to Make Hay in Period May 25th– July 3rd Shawbury 1961 - 1970



The latest illustration of what can be done to improve efficiency is the development of a 7 ft-cut two drum mowing and beater conditioning machine which is semi-mounted within a suspension arrangement to provide evenly cut stubbles at higher travelling speeds than are usually obtained. The resulting high rate of work also increases the probably drying time available in the field before the onset of bad weather.

3.2 Distribution of additives to hay

The drying rate obtained with many mowing and conditioning arrangements have highlighted the disproportionately long period still required for drying from about 35% mc to a safe baling value of less than 25%. If baled much above this value and not barn dried, hay may heat and grow moulds, thus using energy from the valuable soluble carbohydrates, as fuel. The high temperature reduces protein digestibility and the moulds can cause respiratory diseases in man and mycotic abortion in cattle. The distribution of chemicals to hay as baled may reduce the probability of this type of deterioration and also help to avoid protracted exposure to weather risks; potential benefits would be enormous if practical solutions to the problems of application could be found. The most

Table 2 Primary energy inputs for grassland systems (MJ/ha)

Operation	*Grazing*	*Silage (per cut of 25 tonne/ha*	*Field cured hay (per cut of 5 tonne/ha*	*Barn dried hay (per cut of 4 tonne/ha*	*Dried (per cut of 2.5 tonne/ha*
Chain harrow	45	45	45	45	45
Fertilising	36	36	36	36	36
Mowing		186	186	186	186
Tedding		54	54	54	54
Windrowing			54	54	
Baling			186	186	
Bale handling and storage			150	150	
Forage harvesting		771			
Transport		297			600
Ensiling		219			
Field operations sub-total	(81)	(1608)	(711)	(711)	(921)
Drying				7200	39160
Totals	81	1608	711	7911	40081
Input/tonne DM					
MJ/t	20	320	178	1330	17800
Oil equivalent l/t (1l = 41.1 MJ)	0.5	7.8	4.3	56.7	433
Fertiliser — per annum					
(permanent grass)	4020	4020	4020	4020	4020
(temporary grass)	8440	8440	4880	8440	8440

Fig. 2. Relationship Between Farm Gross Margin and Hay Cutting Date

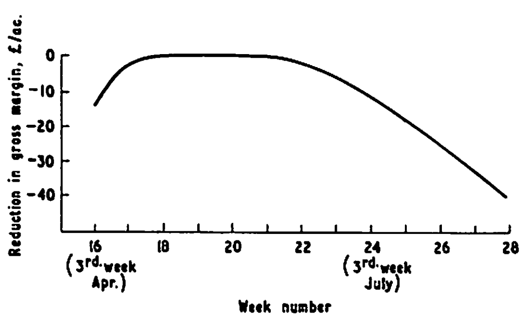
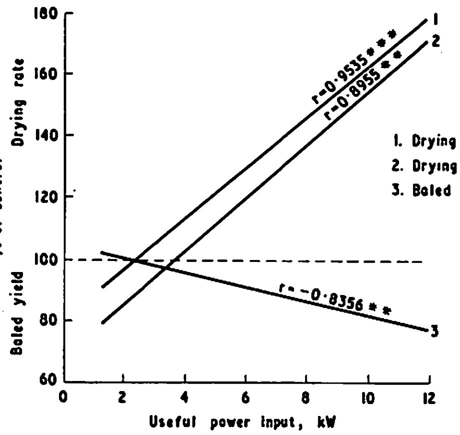


Fig. 3. Effect of Power Input on Drying Rate and Dry Matter Yield



widely used preservative at present is propionic acid. The significance of this from the point of view of energy input depends on whether the acid is produced specifically for hay conservation, or whether it is a by-product from other processes; if the former it requires 1½ litre oil (63.5 MJ) as a feedstock for each litre produced.

Applicators for preservatives are already being marked for use when baling, but there are problems of effective distribution throughout the crop. These are difficult to solve and complicated because the acid is corrosive, unpleasant to handle and volatile. If 2% by weight can be uniformly distributed, it seems likely that it will inhibit moulding on hay of up to 35% mc. Total cost per ton of hay was estimated at about £5 for 1973 and about £8 in 1974 so this increase in margin between cost and product value may reduce to some extent the need for accurate control of the application rate in relation to swath density. We are reasonably optimistic about future prospects since field experiments at NIAE using a forward acting tedder to thin out crop during spraying have shown that heating and mould development can be prevented in some grass crops[13], but more experience is required to determine the scope for practical solutions. In 1975, a less volatile propionic acid derivative (ammonium propionate) which is less unpleasant to use will be tried out. Important questions are whether the nausea felt by some workers inhaling propionic acid fumes will also be experienced with the new material, and the comparative costs at effective application rates. For maximum benefit modifications to machines must be relatively simple, safe and easy to use, and the method should not impose additional field tasks on the haymaking process. One aim of the NIAE experimental work will be to spray during a final windrowing prior to the baling operation; if windrows can be made more even then the case for devising a control to match acid rate to swath density will be further reduced. Newcastle University in co-operation with ADAS are experimenting with an alternative approach for small balers and are injecting acid from positions on the ram face. Cost of acid per tonne of hay will be reduced if a rapid method of determining the moisture content of the crop in the swath can be developed.

Table 3 NIAE Swath Drying Experiments Average results of plot experiments

Machine system	No of experiments	Drying rate improvement over control, % to 60% mc wb	Drying rate improvement over control, % to 35% mc wb	Baled dm yield, % of control
Recip mower with tandem crimper	4	52	63	110
Flail mower	8	103	79	103*
Exp recip mower conditioner	8	61	43	110*
Exp mounted drum-mower-conditioner	4	58	63	115*

* based on one experiment less than indicated in column 2.

The problems of using preservative sprays on hay harvested by large balers have received little attention even compared with conventional balers. The best recommendation to advisers at present is to await the outcome of further experiments; development of inappropriate treatments can increase risks of crop deterioration.

3.3 Barn hay drying

Few farmers in the UK have installed equipment for this, although it is a proven method of conserving hay of high quality. Experiments at Drayton EHF about 12 years ago[14] indicated that a lower cost per kg live weight gain could be achieved from barn dried hay than from silage when feeding a small amount of cereal; feeding more cereal, up to say 2.7-3.2 kg (6-7 lb) daily would increase total unit cost of feed, but the cost of hay and silage would be equal. Reasons for lack of interest in drying have been that hay was often regarded as a cheap feed to provide maintenance, capital cost/tonne has been fairly high and much hand work has been involved in loading and unloading driers; a fourth reason, valid for larger farms, is that large capacity drying barns are needed if all hay is to be harvested at the appropriate stage of growth. Experiments have been carried out by NIAE and Drayton EHF staff[15] to develop techniques for drying the large rectangular bales which can be transported at twice the rate of conventional bales. Drying in tunnels with four, five or eleven bales per section is possible; larger versions will be attempted in 1975. A diesel engine powered fan unit was used and extra heat input was not provided. Some of the provisional results are summarised in table 4. The maximum batch weight used to date was initially 17.0 t with a final weight of 14.7 t. Attempts to tunnel dry material wetter than about 35% have been less successful because of uneven distribution of air caused by irregular bale density and shrinkage. Passages opened between bales. At lower moisture contents the bales packed together but the uneven distribution of air, resulting from variation in density and moisture content, led to reduced efficiency in drying. Improvements in field treatments to obtain more even drying in the swath and development of ways of obtaining more even density in the bales would undoubtedly improve the efficiency of energy use. The likely input of oil for drying will be 45-90 l/t equivalent to 1750 to 3500 MJ/t dried hay and so a much improved feeding value must be expected since total energy input may be about 13 times higher than for field made hay (table 2).

Undoubtedly high quality hay will be made by combining the handling advantages of large bales with the added insurance of barn hay drying. It has yet to be shown, however, how far the large bale can compete in terms of quality of product with hay dried either loose, chopped or in conventional bales, since from observations made, immature leafy crop is more difficult to package and handle in this form. Specific problems are total weight and shape of the bale and the tendency for grass to fall away during handling; it is envisaged that it may also be difficult to obtain even air distribution during drying.

3.4 Silage

To reduce risks from inclement weather an obvious choice of method is to make silage. In spite of improved techniques and equipment and many years promotion by ADAS, less than 25% of the dry matter is so conserved although there has been increased interest recently in the south west of England and parts of Scotland. When cow herd sizes exceed about 100 head, there is sufficient incentive to mechanise silage feeding, which in turn helps remove human resistance because of odour. The constraints, apart

Table 4 Drying large rectangular bales in 11-bale arches (3 sections)

Expt No	Ventilation time h	Vol/bale m^3/s	Duct pressure in WG	Moisture content % Mean	Max	Min	m^3 air kg H_2O removed	Specific fuel consumption l/tonne
A	0	23	55.9	31.8	33.2	30.2	–	–
	144	11	22.9	21.7	25.4	17.6	2 394	34.9
	359	23	55.9	12.0	14.4	9.9	2 530	71.6
B	0	22	45.7	25.8	21.8	21.8	–	–
	33	22	45.7	21.0	25.0	18.8	1 737	13.4
	117	22	45.7	14.2	18.7	11.8	2 296	42.5

from this are the need for equipment to produce a reliable product, with moderate levels of management and operator skill, and the power available on the smaller farm. An important requirement is that material is harvested and ensiled at a rate in excess of about 40 tons/day and preferably much faster, so that good fermentation can be assured. Forage harvesters which can produce more than this per hour are available; an extreme example is that of a user of a 160 kW self-propelled machine who quotes sustained harvesting rates of 60 t/h (and even 90 t/h for short periods). If a machine of this type, costing £18 000 works at such rates there is then the major problem of providing transport and ensiling facilities. An expansion in contractor services or machine sharing arrangements would help meet some of the problems in obtaining increased silage production. This has already been well proven in Holland.[16]

For the machine designer the main ways to help reduce costs and increase reliability can easily be stated in general terms. They are to

(1) improve the efficiency with which power is used; much power is required, for example, to chop grass and convey it to trailers

(2) decrease vulnerability and simplify maintenance to keep chopping components working to specified performance limits.

Berentson[17] recently published results from excellent but limited studies with laboratory apparatus to define the parameters determining the energy requirements of cylinder type grass choppers. Further experiments and design studies to produce improved machinery seem to be needed. For example he recommended that reduction of wrapping plate length would be most effective in reducing the energy used because friction between a throwing knife cylinder and its wrapping plate amounted to one third to one half of the total energy requirements. He made recommendations regarding knife edge sharpness having found that energy for chopping increased by 30% when the edge radius increased from 50 μm to 240 μm and material is then torn and not cut.

Energy requirements for forage harvesting have been calculated also by Diebold[18] in an attempt to show where power is utilised in the process, and a distinction has been made between machines which chop and throw, and those which are fitted with a separate blower to move the chopped crop into the trailer. Harvesting crop containing 50% mc is likely to require from 9 to 15 MJ/t, but apart from mc%, this figure depends very much on the rate of work, the mechanical condition of the machine and chop length, especially if a recutter screen is used.

However successfully the machine has been developed the ability of the maintenance engineer to adjust it and of the operator to keep it in correct adjustment will always have an important bearing on field performance. Diebold quotes a very much higher figure than Berentsen for the effect of blunt knives, stating that they increase the energy at the cutter-head, where most of the power is used, by 80 to 100%, and exceptionally by 300%; knife clearance at the shear bar is also more critical when knives are not sharp. The work has established figures for the difference between crops and show for example that twice as much energy may be needed to harvest red clover than lucerne. The value of harvesting crop at the optimum stage of growth, in terms of feeding value, is re-inforced by the finding that energy requirement per tonne increases with physical maturity of the crop.

Information of this kind will come as no surprise to farmers, especially those who have harvested S23 ryegrass; they must maintain output in one of two ways and a partial practical solution to this problem has been to change knives regularly on a fly-wheel harvester, and to make full use of in-built sharpeners on other machines. An all too obvious method is to use a larger tractor or engine in difficult going, whether this is brought about by crop or machine state and so utilise energy inefficiently. A much better answer will be to produce machinery which can be simply and accurately adjusted and on which knives and shear plates can be easily maintained in good working order.

To help machinery designers optimise energy requirements still further we suggest studies are needed to define more precisely the length of chop, or the distribution of chop length, which gives the best animal feeding performance. At present the designer is asked for shorter and more precise chopping because longer chop length material caused trouble when being conveyed and often needed more effort to consolidate. A reduction, however, in the theoretical chop length from 8.4 to 4.3 mm has increased the energy requirement of the cutter-head by up to 30%[18]. Regarding the most appropriate type of machine ie flail, double or precision chop machines, attention is drawn to the paper by Witney and Beveridge in The *AGRICULTURAL ENGINEER* which carried analysis of performance estimates for a range of cutting areas[19]. A most important conclusion in this paper, however, is that high mechanisation costs for silage systems, may be more easily justified by reduction in energy loss after harvest than by reductions in energy loss during harvest. We agree; based on data in table 1 the loss of 1% dm per ton ensiled is equivalent to a loss of 180 MJ and hence a 10% loss from a 5t/ha dm crop costs 9000 MJ compared with the total energy input of 1608 MJ required to grow, harvest and ensile this amount of crop. (table 2). Nevertheless, a new look at concepts for cutting and chopping grass should probably be taken at the minimum there is scope for design studies on how best to:—

(a) produce the most practical arrangements for reducing knife vulnerability to damage and keeping them sharp.

(b) arrange for material to be fed and held between the knife/shear plate so that it is cut with maximum efficiency.

(c) move the material from knife to trailer.

Farmers on hilly land with low powered tractors have special problems, particularly if there are only two workers available. To obtain the best output it may be preferable for one of these to load the clamp continuously so that the driver in the field is free to operate a conventional harvester with trailer attached. Such a triple unit may become unstable, however, and is often difficult to handle. Therefore an increasing number of the farmers in the south west and west are purchasing continental pick-up wagons for collecting and transporting silage, because of the superior stability of the double unit. Originally designed for haymaking, some makes have had an increased number of knives added following the pick-up, but as yet there have been few measurements of their performance. An example of the limited data obtained with machines which had up to 11 knives only[10], giving a nominal slice length of 127 mm (5 in), has indicated that over 30% of the crop could be expected to fall in a 76-152 mm (3-6 in) group, and nearly 40% in a 152-229 mm (6-9 in) group, but much of the remainder would be longer than 229 mm (9 in). It is therefore reasonable to expect that when up to 23 knives are used, the standard of chopping might be at least equivalent to that expected from a double chop harvester. Even if cutting is improved by further development, the power requirement may still be lower than for a conventional harvester because conveying is mechanical rather than with air and impact. The limited data also indicates that with fields near a clamp about 10 h will be handled, allowing about 4 ha of wilted grass (34% dm) to be cleared in a 6 h working day; in six days enough silage to keep 60 cows could be harvested allowing 2 t dry matter per head for a 200 day winter feeding period.

When more labour is available to shuttle feed trailers to a conventional harvester which can work continuously then obviously the cutting and conveying equipment will be used for a greater proportion of time and capital more usefully employed.

3.5 Dried grass

The amount of dried grass and lucerne likely to be produced in 1975 is less than 200 000 t, which is only a small percentage of total forage conserved in the UK. It merits special mention because it requires an input of about eight times as much energy per tonne as barn dried hay and over 100 times as much as field made hay to process it. Because of this, however, its production is largely independent of the weather and the process makes it possible to achieve the level of energy output from grassland obtained in experimental work; up to 10 t/ha would normally be expected and as much as 15 t/ha has been obtained by some drier operators.

The problem therefore is not so much one of how to use the potential energy of grassland as how to modify the process to improve efficiency and so reduce both cost of production and the energy subsidy. About 53 000 tonnes of fuel will be used annually (2300 x 10^6MJ) and so mean input per tonne of dried grass is about 11.5 x 10^3MJ for oil consumed in drying out of a total drying and processing requirement of about 16 x 10^3MJ/t. Metabolisable energy produced is about 10.92 x 10^3MJ/t.

The effect of crop moisture content on the drying load, and hence the amount of oil required to produce a tonne of dried product is the most critical factor. Data in table 5 indicate the savings that may be achieved by reducing moisture content after allowance has been made for a higher specific fuel consumption at the lower moisture contents.

Table 5 Effect of crop moisture content on fuel consumption

Fresh crop, mc %	*Water evaporated to produce I t dried grass at 10% mc*		*Oil consump-tion* l/t dried grass*	*Energy input MJ x 10^3/t dg*
	kg	*MJ/kg evaporated*		
85	5000	3.108	367	15.1
82	4000	3.192	310	12.8
80	3500	3.275	279	11.5
75	2600	3.360	212	8.7
70	2000	3.444	168	6.8

* 1 litre oil equivalent to 41.1 MJ

The benefits to be obtained by field wilting are apparent, and many operators are finding that mowing and tedding or turning the crop alone can save 20% fuel input: this may well be increased to 40% if a field conditioner is used in very high moisture content crops. Although field wilting is likely to show to advantage over the season as a whole, once the additional management problems have been mastered, it is often ineffective when most required, during May and September or October. The alternative is to squeeze water from the wet forage immediately before drying and recently this process has been applied experimentally and on a limited commercial scale Work by NIAE[22] during 1974 showed that the direct energy cost of processing in this way, with a screw press, was likely to be about 6 kWh/t (21.6 MJ/t) fresh crop which is a similar figure to that obtained with other types of equipment. An example of the relative cost of removing water by mechanical extraction and by conventional drying is shown by the following data. Fresh crop was reduced from 80.5% to 71.3% mc reducing the drying load from 3.61 to 2.14 t/tonne of dried crop, and reducing fuel used by about 130 l/t. Allowing for the removal of 23% of the dry matter in the juice a total of 432 kg of water was therefore removed from a ton of fresh crop for the cost of 21.6 MJ, ie 0.05 MJ/kg of water. This figure is less than 1/60th of the cost of removing the same amount of water with heated air (table 5).

However, direct savings of energy in this way could only be made by the removal of a considerable amount of high quality protein in the dry matter contained in the juice, amounting in this particular case to 34% of the original protein. A very high energy input may be required to enable the extracted protein to be utilised, unless it is fed in the liquid form to pigs.

4 Discussion and conclusions

4.1 As a result of the disastrous economic and weather situations which affected farm food supplies in 1974, we hope farmers will be more interested in conserving higher quality fodder

4.2 Measured in terms of animal production maximum output is likely to be obtained from frequent cutting of high quality herbage; one example considered shows two and a half times more meat may be produced from a four cut sequence than from three cuts. Low quality forage has little productive capacity and although grinding and pelletting can improve its utilisation this requires expensive equipment and the input of up to 130 MJ/t[23]. Work at Boxworth[24] EHF with dairy cows has shown good quality mineralised chopped dried grass can provide maintenance plus 23 l (5 gal) of milk for the first four months of lactation and there seems little doubt that better results will always be obtained by cutting a high quality crop than by processing a low quality feed.

4.3 Research on the field drying process and modelling techniques by computer, involving analysis of historic weather data, are showing promise of providing better advice regarding the strategy which farmers should adopt having regard to their regional and farm conditions. ADAS must be equipped to advise on the most suitable crop varieties to meet recommended cropping sequences and weather probabilities. These studies should also highlight where the value of further development and research to provide equipment will be the greatest.

4.4 Comparison of the fuel energy inputs required per tonne of dry matter for four methods of conservation (excluding fertiliser) were calculated as follows:

Method	*MJ/t*	*litre/t*
field hay	178	4.3
silage	320	7.8
barn dried hay	2330	56.7
dried grass	17800	433

Energy input as fertiliser may vary from 1000 MJ/t for field made hay to 4000 MJ/t of dry matter for dried grass production (table 2).

4.5 The best method of improving the efficiency of haymaking and wilting for silage is to condition at the time of mowing with machines of improved design. A relationship between power input, losses and drying rate is given from NIAE research to help establish design criteria.

4.6 NIAE experiments to try to overcome the very difficult problems of distributing propionic acid to hay so that it can be moved to the store at up to 35% mc, and so reduce the risk of heating and moulding following inclement weather, have provided encouragement to continue research and development. Deterioration of some crops in store has been avoided by using a modified forward acting tedder to thin crop during spraying.

Laboratory trials at Rothamsted Experimental Station suggest that ammonium propionate may have advantages over propionic acid but this has still to be proved in the field.

4.7 If hay is no longer regarded as a cheap but inferior food, requiring concentrate supplementation, barn drying may become more widely practiced. This could be especially appropriate on small and medium sized farms where the rate of throughput can be more easily matched to seasonal production. Handling problems have been reduced by improved mechanisation, including the use of the Howard Big Baler and experiments to improve the efficiency of drying in tunnels of increased size continue to provide more data. Energy requirements are likely to be 13 times higher than for normal field drying and nearly 3 times higher than for field drying plus the use of a preservative, if energy input of the latter is charged in full; high temperature drying of direct cut herbage is likely to use eight times as much energy as barn hay drying, but this figure may be reduced to five or less where wilting or mechanical de-watering is practiced successfully.

4.8 If herd size is over about 100 head, it is usually considered that handling and feeding silage can be sufficiently well mechanised to make its use acceptable to farmers and equipment manufacturers should note work at NIAE[25] and elsewhere on silo design, automatic weighing and feeding of silage[26]. Because it can be conserved with less dependence on spells of fine weather its production ought to have greater appeal than is the case at present. From the point of view of providing energy to animals its value per hectare is less than from an equivalent quality crop which has been or artifically dried because these products, or cereals, will usually have to be added to silage to meet the animals' optimum requirements. For young stock or out-lying animals, however, hay is often preferred. Therefore on some farms, otherwise prepared to change to a silage system, the maximum energy is likely to be raised by, say, a four-sequence harvesting system in which hay is made from one or two of the late spring or summer cuts. The scope for this approach will be substantially widened if hay additives are developed successfully for future use. Use of contractors or of large machines which are group owned, to deal quickly with the silage cuts may prove to be the most economical way to increase total energy output.

4.9 The adoption of silage making would be further assisted by reconsidering the design of forage harvesters to ensure greater ability to achieve and maintain specified performance levels, preferably with reduced power requirements. Research to date has been very scanty.

4.10 To minimise the energy requirements for silage production, and so help the machine designer, more information is required about the effect of chop length on in-silo losses and on animal response. There is little point in saving 10% of the 320 MJ/t dry matter required to grow and harvest the crop, if this leads to poor fermentation and increases in-silo losses. For a 10% loss of dry matter there is a loss in energy of 1800 MJ from each tonne placed into store.

4.11 To improve utilisation from some of the permanent pastures attention to convenience and safety in handling equipment on sloping land is likely to be of increased importance. For silage production the continental loader waggons may have an appeal if only one driver and a small/medium sized tractor is available for field work — but not enough is known about quality of the silage made. If two or more drivers are available then separate chopper-loaders seem likely to give better utilisation of capital.

4.12 Dried grass production can be more economic, particularly in terms of throughput and fuel usage if wilting either in the field or by mechanical expression of juice is practiced. Protein will also be extruded and must be used either by feeding it in the form of juice for pigs or by drying it. The latter process would have a comparatively high energy input, but might eventually produce a high protein feed which can be fed directly to man, so eliminating the inefficiencies of ruminant conversion. Ruminants will of course continue to utilise forage feeds, albeit inefficiently, which cannot be effectively used by mono-gastric animals.

4.13 Even if the best conservation practices are followed the efficiency with which the total energy produced from grass will be used by beef animals seems unlikely to exceed about 5%. Protein is already being prepared as meat analogs for human consumption, from soya bean.

In the long term we have to consider the comparative energy requirements for the production of microbial protein by bacteria, yeast or fungi from substrates such as methanol, methane, n-Alkanes and carbohydrates for example maize grain[27].

References

1 **Anon.** Food from our own resources. White Paper Cmnd 6020 HMSO April 1975.

2 **Raymond W F.** The nutritive value of forage crops *Adv in Agronomy* 1969 Vol 21. 2-108.

3 **Lonsdale C R.** Grassland Research Institute. Private Communication 1975.

4 **Anon.** Grass and grass products. NEDO Rept. London November 1974, pp 65.

5 **Corrie J C.** Development of models for the evaluation of hay making systems. Nat Inst Agric Engng, DN/SY/563/1957. May 1975.

6 **Mitchell F S** and **Shepperson G** 1955. The effect of mechanical treatment on the drying rate of hay in the swath, *J Instn Brit Agric Engrs.* Vol 11, 3-18.

7 **Penman H L.** Natural evaporation from open water, bare soil and grass. Proc Roy Soc. London 1948 193A 120-146.

8 **Spatz G; van Eimern J; Lawrynowicz R; Der Trocknungsverlauf von Heu im Freiland.** (The drying process of hay in the field) Hayr landw Jahrb. 1970. 29, 446-464 (Eng transl No 315. NIAE Silsoe, England).

9 **Brown F R, Charlick R H.** An interpretation of the effect of conditioning in relation to meteorological data in two regions. Subject day, Paper 4, NIAE Silsoe. Sept 1972.

10 **Sims F P.** Private communication. Bristol 1975.

11 Engineering Working Party Report. Engng and buildings board *JCO for Res & Dev in agri and food.* December 1974.

12 **Klinner W E.** Design and Performance Characteristics of an Experimental Crop Conditioning System for Difficult Climates. *J Agric Engng Res,* 1975 20 (2).

13 **Charlick R H.** The application of propionic acid in the conservation of hay. Nat Inst Agric Engng. DN/M/572/1365.

14 **Culpin S.** The utilisation of barn dried hay. Paper to EDA Rural Elect. Conf. Sutton Bonington 1963.

15 **Arnold R E** and **Comely D R.** Drying large rectangular hay bales in bulk. Nat Inst Agric Engng. DN/FC/421/1380. May 1975.

16 **Manby T C D** and **Shepperson G.** Report of visit to Holland 1974. Nat Inst Agri Engng DN/FC/503/1300 June 1974.

17 **Berentsen O J.** Energy requirements for grass chopping Research Rept. No 22. 1973. Norwegian Inst Agric Engng pp 65.

18 **Diebold D.** Energy and forage harvesting. American Forage and Grassland Conference, Omaha, Nebraska, 13 February 1975.

19 **Witney B D** and **Beveridge J L.** Some economic aspects of ensilage mechanisation for beef production. The *Agricultural Engineer,* 1975 30(1), 12.

20 **Armitage A J** and **Boyce B M.** ADAS, MAFF. Private communication.

21 **Davys M N G.** An introduction to de-watering 1973. *Grass J.* Assocn Brit Green Crop Driers No 7. 62-78.

22 **Chestney A A W** and **Shepperson G.** Experiments with a twin-screw press to express juice from lucerne 1974. Nat Inst Agri Engng. DN/FC/511/1385. March 1975.

23 **Marchant W T B** and **Shepperson G.** The high density packaging of dried forage crops. Proc 1st Internatl Green Crop Drying Congress 1973. Oxford. 282-296.

24 **Strickland M J.** Maintenance and five gallons from dried Grass. *J Brit Assocn Green Crop Driers.* Spring 1974. No. 8 3-6.

25 **Turner M J B** and **Filby D E.** The use of conveyors for feeding cattle. Proc NIAE Subject Day. Livestock feeding and weighing. Oct 1973.

26 **Messer H J M; Lindsay R T; Chaplin R G;** The flexible wall silo at Rosemaund EHF. 1973-74. DN/FB/424/3030. April 1975.

27 New Protein, ICI Educational Publication, The Kynoch Press.

Edited summaries of discussion

A D Trapp (Edinburgh School of Agriculture) questioned the discrepency between some of Dr White's E ratios and those of the Joint Consultative Organisation.

D J White said the arable figures were similar but that his animal values were more reliable since they were based on additional information than the JCO figures.

R Q Cannell (Letcombe Laboratory) asked Dr White whether there was any significance in the higher E ratio for oats as compared with the figures of barley and wheat. D J White replied that there was no significance.

R F Craven (farmer) suggested that the extrapolation made in Mr Austin's paper to arrive at a nitrogen consumption in 1990 of 3 million tonnes was wide of the mark, when present trends are showing a decrease in the rate of increasing nitrogen usage. A more realistic figure would probably be half that value.

R B Austin emphasised the weaknesses in trying to estimate future usage in this way and agreed his figure may be high, although it could be possible if more nitrogen was used on grass.

J Kinross (farmer) observed that no mention had been made in the papers of the energy cost of lubrication. He suggested that the use of oil based lubricants should be replaced where possible and wondered to what extent such an approach would result in a saving of energy.

J Matthews considered that only a relatively small amount of energy could be saved but at higher financial cost. Reduction of soil-metal friction might make a more significant contribution to energy economy.

I B Warboys (Dept of Agriculture, Wye) thought that some reference should have been made to chopped hay since this material could have particular benefits for use with additives and represented an alternative to hay or silage.

G Shepperson agreed with this suggestion and said that for some time he had been trying to persuade farmers to handle hay in chopped form but without much success.

J Wood (consultant) commented generally on conservation methods, suggesting that the use of additives in hay was the wrong approach and expressing surprise that the authors of the forage paper had not distinguished between the different silage making methods. He suggested tower systems were the most efficient of all methods including high temperature grass drying. Although progress had been made on the grass wilting front for silage, research effort would be more rewarding if it was concentrated into finding ways of reducing the energy loss during fermentation rather than during the field harvesting period.

T C D Manby hoped that the practice of wilting would spread, but emphasised that farmers would continue to make hay for many years yet and additives were one way of helping them to produce a higher quality product.

J Shapiro (Wind Energy Supply Co Ltd) challenged the criticisms that had been levelled against windpower and comprehensively reviewed the merits and potential uses for this source of energy.
P H Bailey (Scottish Institute of Agricultural Engineering) questioned the rather high figure of 5760 MJ/ha for grain drying in Dr White's paper and suggested that electrically powered fans and oil fired boilers provided the most efficient system for drying in the short term. In the long term it would be necessary to investigate the use of solar energy but there was the problem that although this could be efficient for small temperature rises it was not appropriate for powering the fan.

D J White outlined the basis for his figure, but no consensus opinion was reached.

B D Witney (Dept of Ag Eng Edinburgh School of Agriculture) wondered whether possibilities existed for the use of chopped straw and asked if any work was being undertaken in this respect. He suggested that there might be a need for a machine with an output of 2-5 tonnes/h to provide chopped straw for feeding.

J R O'Callaghan stated that this aspect of straw utilisation had not yet been investigated.

J H Wilder stated that forage harvesters were used in New Zealand for chopping straw for feed.

G W Cooke (Agricultural Research Council) made a number of comments on the use of nitrogen fertilisers. He pointed out that nitrogen provides economic yields which must be at least maintained in view of high production overheads. The future use of nitrogen largely depends on future grassland policies, particularly the combined use of grass and legumes. Despite the criticisms of nitrogen as a contributor to land damage, poor crop quality and high energy demands, ADAS advice on the application of nitrogen fertiliser is comprehensive and if followed by farmers would give improved yields with minimum adverse effects. Attention was drawn to the large leaching losses which have occured this year and which in eastern, central and southern England may be of the order of 60 kg/ha. Dr Cooke also drew attention to the fact that three million tonnes of nitrogen was in circulation each year but only approximately half this amount was harvested.

T A Oxley (University of Aston in Birmingham) questioned Mr Rutherford as to why no mention had been made of biological methods of straw degredation. He indicated that this technique had been proven and simply wanted applying in the farm context.
A W B Davies (College of Agriculture, Bishop Burton) asked the speakers whether work was being done on the application of land drainage as an aid to improving land utilisation with associated energy benefits. He also wondered if the pre-germination of seed was being considered as a means of increasing productivity.

E Bowman stated that work undertaken at Manchester University included germination of seeds in growing rooms under artificial light with considerably lower heat losses than would be incurred in greenhouses.

J K R Gasser (Agricultural Research Council) reported that the Field Drainage Experimental Unit of the MAFF were investigating the benefit of drainage in agriculture as a whole and that the National Vegetable Research Station had already developed a fluid drill for sowing pre-germinated seed.

T Sherwen (consultant) recalled that a method of direct feeding straw to animals was used during the Second World War and pointed out that one problem associated with the use of small scale windpower was the very large rotor span required to produce modest power outputs.

I Rutherford suggested that the direct feeding method, most probably involved a form of caustic soda treatment, which necessitated the use of large quantities of water with consequent effluent problems.

G W Cooke (ARC) reported on the results of experiments on the incorporation of straw into soil. The results from early experiments when crop yields were generally low showed little yield gain from ploughed-in straw but recent results with higher yielding varieties and cultural methods were showing useful responses.

I Rutherford in reply said that some of the Experimental Husbandry Farms were investigating the effects of ploughed in straw on yield at the present time.

R H F Jeffes (farmer) pointed out that the practice of leaving straw in the field for cattle to eat was a method which has been tried in some areas.

W E Klinner (NIAE) asked whether chopping straw as an alternative to baling was being seriously considered. He saw the harvesting of straw rapidly and economically in chopped form by forage harvester as an intermediate processing stage giving an easily handled material capable of further processing. Packaging in baled form which requires further handling before the next stage in its use is an inefficient approach.

B Wilton (School of Agriculture, Sutton Bonington) referred to the high energy cost associated with grass conservation by conventional artificial drying methods. An alternative approach might be to grow cereals and grass in combination using straw to dry the harvested cereals followed by surplus straw being used to dry grass. He mentioned that it requires approximately one tonne of straw to produce one tonne of dried grass.

I Rutherford considered that farm chopped straw might be collected from the farm for subsequent processing by an industrial user.

J Wood commented that whole crop cereal silage stored direct in sealed containers could be a possibility in future.

G Shepperson said that if this concept did develop care should be taken to feed grass at the same time as the silage otherwise severe constipation would result.

J K R Gasser suggested that waste did not exist in a natural cycle. Sunshine is available to plants as an energy source through photosynthesis but it is well known that plants are notoriously inefficient. Is it possible for biologists to increase the photosynthetic efficiency of plants?

R B Evans (Opico) thought that a contribution to reduced energy demands could be achieved through improved separation efficiency of combine harvesters to prevent weed seeds being returned to the soil. It is recognised that straw burning is one method but this consumes energy which would be better conserved. Constant use of chemical weed control prevents growth of humus building plants and subsequent reduction of moisture retaining capacity of the soil. There is a need for improvements in mechanical weed control.

Written contributions

J S Shapiro (Wind Energy Supply Co Ltd) I would like to make a number of points concerning the use of wind as a source of energy.

A fresh effort is justified by new fuel prices, new attitudes and new technical developments to extend the range of wind power plant well beyond current commercial practice.

The facts about wind have not changed, but we know more about them. The wind is statistically regular (much more regular than the sun). The UK and other countries with extensive coastlines are in a particularly favourable position for the use of wind energy.

Much progress has been made in helicopter rotors in the last 30 years. Helicopter rotors, which at first evolved into machines of increasing complexity have, in the last five years, become simpler. Because windmill rotors need not be light in weight, they can have strength and safety at a fraction of the helicopter rotor cost.

The care for the ecological factors of pollution and depletion of resources has become a prominent consideration. In the UK, balance of payments and invulnerability to outside interference must play a large part in the provision of energy.

In all these respects, the utilisation of wind power fulfils the most stringent requirements.

Wind power, like any fluctuating source of energy, can be used in several ways. (a) Fluctuating use ie milling took place when the wind was blowing. (b) The "gain" principles. Energy is injected into an existing system to save fuel. (c) A Stand-by source of power comes into play when the wind is not blowing. (d) Energy storage. Heat storage is available economically wherever low grade heat (below 100°C) is the main end use of energy.

Wind power can be used on different scales. (a) Major systems which may be conceived on a national scale. (b) Miniature systems which are often regarded as "alternative technology". (c) an intermediate range where wind power plants can be provided quickly on an immediately commercially viable basis principally in rural areas and mainly for the supply of low-grade heat to horticultural and domestic premises.

P H Bailey (SIAE) It is often assumed that a well-run in-store drier must be energy-saving compared with a higher temperature drier because the 'natural' drying potential of the air is used. However, the primary energy equivalent of the electricity used for fanning the air tends to work out higher than the total of electricity and oil in medium temperature driers. The following table is based on NIAE test reports 122, 138, 173, 360, 363, 414, 486 and 570, representing a variety of drier types, for drying 21% to 15%. Two of the three in-store driers were all-electric, the other was driven by an engine waste-heat unit, but equivalents for all-oil or all-electric heating are given for each type on the basis of an overall efficiency of 65% for the waste-heat unit, and assuming that primary energy equivalent of gas oil is 1.1 times the net calorific

Type of drier	Running energy consumption					Estimated energy for manufacture and spares of drier and store		Overall total approx	
	Electricity		Oil		Total running	Electric	Oil	Electric	Oil
In-store									
Radial bin	1200	or	(460)		–	100	160	1300	620
Floor-vent bin	1300	or	(500)		–	100	160	1400	660
Vent. floor	(1040)	or	400		–	60	120	1100	520
Mean in-store*	1180	or	450		–	–	–	–	–
Continuous oil-fired									
Multiduct	80	+	330		410	140		550	
Crossflow (thick bed)	60	+	470		530	120		650	
" (thin bed)	50	+	570		620	120		740	
Counter flow	260	+	380		640	140		780	
Multi fan	340	+	470		810	160		970	

*The variations in running energy costs between the three in-store driers are probably due to the characteristics of the specific plants tested and not necessarily typical of the different types of plant.

value at the farm. Units are MJ of primary energy per tonne of dried grain throughout; multiply by 4 for MJ/ha per annum at current average yield.

For the medium term, it is clear that the best use of fuel is made with the more thermally effective of the electrically-fanned, oil-fired driers: research and design effort should be to keep down fan power while discharging well-saturated air.

For the longer term, none of these solutions will be effective when the oil has all gone. Nuclear fusion is an uncertain hope. Solar energy, though diffuse and capricious, is at least arriving continuously, and the efficiency of capture for low temperature applications is much higher than in solar cells or biological processes that can produce high-grade energy. However, to make a solar grain drier, the biggest problem is the requirement for a large quantity of fanned air, which leads to the least thermally economic part of the foregoing table. There is a challenge in seeking a way out from this paradox.

Dr Kenneth Blaxter has said "Just as the pioneers of the 17th century set the scene and conducted the trials which were the basis of our first agricultural revolution of the 18th century, and just as the early protagonists of mechanised farming set the scene for our second agricultural revolution of the mid-20th century, so now we must plan to bring in the third revolution to hold what we have gained and to increase production to levels beyond our present vision". As agricultural engineers we have the enormous challenge to use all our ingenuity to develop subtle solutions which will enable jobs to be done with far less energy imported to the farm. We will have to think for ourselves as well as help the biologists to mechanise their new thinking. The problems will be far greater than those which we have been accustomed to solving simply by the application of more and more energy.

Branch programmes 1975/76

East Anglian Branch

Hon Secretary J B Mott MIAgrE
Norfolk School of Agriculture, Easton, Norwich NOR 54X.

September 26 — What farmers are bothered about, by C J V Baskerville (ADAS Mechanisation Advisor), The Scole Inn, Scole, 20 15 h. This talk follows a Committee meeting.

November 13 — Conference on The machine squeeze – mechanisation under high cost pressure, Norfolk College of Agriculture & Horticulture 10 30 – 16 30 h. Speakers: P Bolam (Barclays Bank), R A Bond (British Sugar Corporation), D Paterson (NIAE), D Stowe (John Deere), K Grundey (ADAS).

1976

February 28 — Dinner dance, Brome Motel, Eye, 19 30 for 20 00 h.

March 26 — Annual general meeting, Scole Inn, Scole, 19 30 h. Followed by Further problems of mechanisation.

East Midlands Branch

Hon Secretary E F Beadle TEng (CEI) MIAgrE
Lincolnshire College of Agriculture, Riseholme, Lincoln.

October 8 — Afternoon visit to be arranged.

October 28 — Rotary cultivator developments, Notts College of Agriculture, 19 30 h. (Provisional)

November 19 — Day conference on Materials handling, Kesteven Agricultural College.

1976

January 17 — Tractor and trailer braking, by J E Gannon (Girling), Lindsey College of Agriculture, 19 30 h.

February 18 — Extraction of juices from forage crops, by J Connell (NIRD), Leics. Agricultural College, 19 30 h.

March 11 — Oil seed rape production, by a representative of Quenby-Price Ltd, Sutton Bonnington, 19 30 h.

Northern Branch

Hon Secretary Dr P R Philips PhD BSc(Hons)
South West Farm, Swalwell, Newcastle-upon-Tyne.

October 7 — Use of tractors in forestry work, by Athole Whagman MBE, Northumberland College of Agriculture, Kirkley Hall, Ponteland, 19 30 h.

November 4 — The first UK potash mine, by R A Nicholson, Northumberland College of Agriculture, 19 30 h.

December 9 — Details to be announced, Northumberland College of Agriculture, 19 30 h.

1976

January 13 — Details to be announced, Northumberland College of Agriculture, 19 30 h.

February 3 — Details to be announced, Northumberland College of Agriculture, 19 30 h.

March 2 — Details to be announced, Northumberland College of Agriculture, 19 30 h.

March 23 — Annual general meeting, Northumberland College of Agriculture 19 30 h.

North Western Branch

Hon Secretary R B Kitching NDAgrE Tech(CEI) AIAgrE
4 Northall, Much Hoole, Preston PR4 4QN.

September 23 — Maize harvesting, by technical staff of New Holland Ltd, The Lancashire College of Agriculture, Myerscough Hall, Bilsborough, nr Preston, 19 30 h.

October 16 — Lighting for plant growth, panel meeting. Venue to be announced.

November 18	Hydrostatics on the farm, by D White and H Bean (International Harvester Co), The Lancashire College of Agriculture, 19 30 h.
1976	
January 15	A critical look at the average farmer's mechanical handling problems, by E Marshall (Holme Leigh Farm, Glazebury), The library, Leigh 19 30 h.
February 17	Grass drying, by G P H Caldwell (Norlands Farm, Widnes), The Lancashire College of Agriculture, 19 30 h.
March 18	Annual general meeting and annual dinner, The Royal Oak Hotel, Market Street, Chorley.
May 18	Evening visit to Mr Caldwell's grass drying plant at Norlands Farm, Norlands Lane, Widnes, 19 00 h.

Scottish Branch

Hon Secretary	J A Pascal MIAgrE Donmaree, Springhill Road, Peebles.
September 25	Visit to NEL, East Kilbride, 10 30 h at main entrance to NEL.
October 23	Bio-climatic approach to ventilation of cattle housing, by Dr J M Bruce, West of Scotland Agricultural College, Auchincruive, Ayr, 19 30 h.
November 25	Panel discussion on After sales service, The Royal Hotel, Cupar, 19 30 h. Panel: J B Cameron (dealer and farmer),. D Ebrey (manufacturer), G Baird (ATB), J A McLaren (farmer), M Cullen (dealer).
1976	
January 14	Environmental control in potato and vegetable stores, by B Montandon, Maitlandfield Hotel, Haddington, 19 30 h.
January 15	Environmental control in potato and vegetable stores, by B Montandon, Craig Hall, Ellon, 19 30 h.
February 18	Annual conference — Tractors — have you a choice? Chairmen: M Mackie and R Melville. Application of power to the land, by a speaker to be arranged; Tractor replacement policy, by A Blyth; Tractor transmissions and traction, by A Reece; Selection of mechanisation systems, by R Graham. Dunblane Hotel Hydro, 10 00 h. Annual general meeting, 17 00 h, followed by a buffet supper, 19 00 h.

South Eastern Branch

Hon Secretary	N Oldacre MIAgrE Writtle Agricultural College, Writtle, Chelmsford, Essex.
October 8	Use of high powered tractors, by a representative from Massey Ferguson, D Blenkiron (Fiat), and D Pearson (Ford).
November 12	Trench versus trenchless, by a representative from Howard Machinery Co, and J Bransdon (Bruff).
December 12	Forage harvesters — drainage for maize, by J Millington (New Holland).
1976	
January 14	Farm machinery investment, by a representative from John Deere.
February 9	Feed mixer trailers, by J Avis (Farmhand).
March 10	Forum on agricultural aviation. Speakers: P Long (Fieldspray), R Ansden (Fisons) and S Bell (ADAS).
June	Proposed irrigation and water harvester day, Writtle Agricultural College. Date to be announced.

South East Midlands Branch

Hon Secretary	J R Dawson CEng MIMechE MIAgrE 26 Larkway, Brickhill, Bedford.
October 13	Tillage and soil type, by B Wilkinson (ADAS), NCAE, Silsoe, 19 30 h.
November 17	Chemical aids for crop conservation, by Dr A D Drysdale (BP Chemicals Ltd), NCAE, 19 30 h.
1976	
January 19	Talk on the problems of servicing harvesting machinery, by a speaker from Ransomes Sims & Jefferies Ltd, NCAE, 19 30 h.
February 18	Mechanical livestock production in practise, by G Newman (IRAD), joint meeting with East of England Agricultural Society, Shuttleworth College, 19 30 h.
March 8	Annual general meeting, 19 00 h. Followed by A cereal breeder's viewpoint of machinery requirements in the future, by J Bingham (PBI), NCAE.

South Western Branch

Hon Secretary	W Blackmore CIAgrE Hillview, 12 Spurway Road, Canal Hill, Tiverton, Devon.
October 9	Pollution of the environment, Exeter, Devon.
November 13	Pollution by conservation waste, Liskeard, Cornwall.
1976	
January 8	Pollution by animal waste, Seale Hayne College, Devon.
February 12	Pollution —industrial injury, Taunton, Somerset.
March 11	Insidious pollution, Bicton College, Devon.

Southern Branch

Hon Secretary	A D B Gardiner TEng (CEI) MIAgrE Rycotewood College, Thame, Oxon.
September 19	Evening visit to farmer/innovator. Host: J Kinross BSc(Agric) AIAgrE, Manor Farm, Eton Wick, nr Windsor. Barbeque in gardens, 18 30 – 21 00 h.
October 17	Environmental control and conservation of energy in glasshouses, by Dr D Rudd-Jones MA PhD FIBiol (The Glasshouse Crops Research Institute, Rustington), Plumpton Agricultural College, Plumpton, nr Lewes, 19 30 – 21 30 h.
November 28	Pesticides and methods of application, by staff of research establishment of CIBA-GIEGY/Weed Research, Hampshire Agricultural College, Sparsholt, nr Winchester, 19 30 – 21 30 h.
1976	
January 16	Corrosion and protective coatings, by a representative from ICI, Berkshire College of Agriculture, 19 30 – 21 30 h.
February 20	Seals in hydraulics, by J A Stephens (Bestobell Ltd), Rycotewood College, Thame, 19 30 – 21 30 h.
March 19	Grain conservation and the EEC, by a representative from Brice Baker & Co Ltd, Reading University, 19 30 – 21 30 h.
April 23	Annual general meeting and members' papers, Surrey College of Agriculture.

West Midlands Branch

Hon Secretary	C L Powdrill NDA NDAgrE T Eng(CEI) MIAgrE Warwickshire College of Agriculture, Moreton Hall, Moreton Morrell, Warwick.
September 29	Simplified tractor design, by J Matthews (NIAE, Silsoe), Warwickshire Farmers' Club, Leamington Spa, 19 30 h.
October 27	Forum — Is bigger better? Speakers: R den Engelse (East Anglian Real Property Co), I Rutherford (ADAS, Silsoe) and D M Walker (John Deere Ltd), Warwickshire Farmers' Club, 19 30 h.
November 24	How much farming knowledge for the agricultural engineer? Speakers: J R Kerr (Cherwell Tractors Ltd), A J Bailey (Massey-Ferguson Ltd), and B A F Hervey-Bathurst (estate owner and farmer), Warwickshire Farmers' Club, 19 30 h.
1976	
January 26	Current methods of field measurement and testing, by a member of the staff of the Control and Instrumentation Division, NIAE,

	Silsoe, M-F Training Centre, Stareton, Kenilworth, 19 30 h.
February 23	Controlling heavy implements in work, by G R A Miller (Ford Motor Co Ltd), M-F Training Centre, 19 30 h.
March 29	Annual general meeting, followed by New films from the industry, M-F Training Centre, 18 30 h.
April 9	Annual dinner/dance, Manor House Hotel, Leamington Spa, 19 30 h.

Western Branch

Hon Secretary	H Catling NDAgrE MIAgrE Engineering Dept, Royal Agricultural College, Cirencester, Glos.
October 22	Controlled environment of livestock buildings, by H W Prosser (The Electricity Council), Mendip Motel, Frome, Somerset, 19 30 h.
November 19	The diesel engine and its development with particular reference to the conservation of energy, by W Tipler (Perkins Engines), The Cedar Hotel & Restaurant, 19 30 h.
1976	
February 18	Annual general meeting, followed by The four-wheel drive tractor — its development and place in British agriculture, by D R F Tapp (County Commercial Cars Ltd), The Cedar Hotel & Restaurant, 18 30 h.
March 17	Planned maintenance and its influence on farm safety, by I M Abbot (Royal Society for the Prevention of Accidents), The Cedar Hotel & Restaurant, 19 30 h.
April 7	Visit to Esso Research Centre, Abingdon, Oxon. (Details to be confirmed).

Wrekin Branch

Hon Secretary	W D Basford NDAgrE 14 The Paddock, Codsall, Wolverhampton WV8 2BN
October 6	Automated welding techniques, by a speaker from British Oxygen Co Ltd, Staffs College of Agriculture, Rodbaston, Penkridge, Stafford, 19 30 h.
November 3	Materials handling in agriculture — 1975, by D A Bull (Materials handling engineer Crops ADAS), Harper Adams Agricultural College, Edgmond, nr Newport, Salop, 19 30 h.
November 17	Visit to Electric Traction Maintenance Depot, British Rail, Crewe (by courtesy of F W Young, Divisional Manager, British Rail, London Midland Region), 19 00 h.
December 8	Wind — an existing energy source? by G W W Pontin (The Wind Energy Supply Co Ltd), Shrewsbury Technical College, London Road, Shrewsbury, 19 30 h.
1976	
January 12	Engineering in modern poultry production, by Dr R G Wells (Head of poultry department, HAAC), Harper Adams Agricultural College, 19 30 h.
February 9	The work of the Ordnance Survey Dept, by E H J Edwards (Assistant regional controller, West Midland Region, Ordnance Survey), Staffs College of Agriculture, 19 30 h.
March 8	Annual general meeting, Harper Adams Agricultural College, 19 00 h. Followed by short papers evening by Branch members, 20 00 h.
March 19	The Health & Safety at Work Act, by R J Hardy (Regional Safety Inspector, MAFF, Wolverhampton); Automatic tractor hitches, by M E Bloxham (Hardy Spicer Walterschied Ltd, Birmingham); Agricultural tyre developments — where have we got to? by H M Cutler (The Goodyear Tyre & Rubber Co Ltd, Wolverhampton), Annual dinner, Tiffany's, Shrewsbury.

Yorkshire Branch

Hon Secretary	J R Ashley-Smith MSc(Agr Eng) 57 Acre Lane, Meltham, Huddersfield HD7 3DH.
September 11	From teat to tank, (speaker to be confirmed), Holmfield House, Wakefield, 19 30 h.
October 2	Evening visit to Wheatley Hall Road, Doncaster plant of International Harvester.
October 23	Bearings for modern agriculture (speaker to be confirmed), Holmfield House, Wakefield, 19 30 h.
November 20	Evening visit to Allinson's flour mills, Castleford.
1976	
January 22	Forage harvesting machinery, by Brian Spofforth (Product manager, Manns), Holmfield House, Wakefield, 19 30 h.
February 19	Mechanisation of the potato crop, by Robin Jarvis (Director, Terrington Experimental Husbandry Farm), Talbot Hotel, Malton, 19 30 h.
March 11	Annual General Meeting, followed by paper presented by John Fox (President IAgrE), Holmfield House, Wakefield, 19 30 h.
March 30	Oils for farm equipment, by Richard Smith (Product specialist, Lubrizol International), Holmfield House, Wakefield, 19 30 h. Joint meeting with NE Centre, Automobile Division, IMechE.

Reprint Service

CHANGES have recently been introduced in the reprint service offered to members of the Institution. The Editorial Panel has now made arrangements with University Microfilms Limited, St. John's Road, Tylers Green, High Wycombe, Bucks., for *The AGRICULTURAL ENGINEER* to be placed on microfilm from which enlarged copies of articles or papers can be obtained. Those members wishing to obtain copies of articles should now address their requests direct to University Microfilms Limited who will make a charge for this service at the rate of $3 each for articles and 8c. per page for complete issues. Charges will of course be made in sterling, the equivalent being obtained by conversion at the rate current at the time of placing order.

At the present time only Volume 28 is available under this service but it is planned to place earlier volumes of the Journal on microfilm in the future.

A few back numbers of the Journal are still in stock at Institution Headquarters and will be made available to members upon application. Once Institution Journal and paper supplies have been used up it will no longer be possible to offer members up to six items a year free of charge and post-free through University Microfilms Limited.

Members of Council 1975/76

President	J V Fox
President-Elect	T C D Manby
Immediate Past President	J A C Gibb
Past President	T Sherwen
Vice President	L P Evans
Vice President	B A May
Vice President	J C Turner
Honorary Treasurer	O J H Statham
Honorary Editor	B A May
Fellow	G L Reynolds
Fellow	J L Carpenter
Fellow	J C Weeks
Member	G P Shipway
Member	J H Neville
Member	U G Curson
Companion	U G Spratt
Companion	A J Gane
Associate	C V Brutey
Associate	R Stokes
Associate	C L Cawood
Associate	J Kinross
Graduate	S W Robertson
Special Representative for Scotland	B D Witney

Branch Representatives

East Anglian	M G Clough	Fellow
East Midlands	R Barber	Fellow
Northern	R Cowen	Member
North Western	G R Hobbs	Member
Scottish	J G Shiach	Fellow
Southern	D G Webb	Member
South Eastern	E Barker	Member
South East Midlands	Not yet elected by Branch	
South Western	C R Clarke	Member
Western	K A L Roberts	Member
West Midlands	J Shipman	Member
Wrekin	J Sarsfield	Member
Yorkshire	J Maughan	Fellow

Members of Executive Committee 1975/76

President	J V Fox
President-Elect	T C D Manby
Immediate Past President	J A C Gibb
Past President	T Sherwen
Vice President	J C Turner
Hon Treasurer	O J H Statham
Deputy Hon Treasurer	U G Spratt
Hon Editor	B A May
Chairman, Membership Panel	L P Evans
Deputy Chairman, Membership Panel	J C Turner
Fellow	J C Weeks
Member	
Companion	U G Spratt
Associate	R Stokes

Co-opted

Representative – ERB Technician Engineer Board	J Kilgour
Editorial Panel	J H Neville

Members of Membership Panel and Education Group 1975/76

Membership

Chairman	L P Evans	
Vice-Chairman	J C Turner	(also Education Group)
Fellow	M G Clough	(also deputy representative – ERB Technician Engineer Board)
Fellow	B D Witney	
Member	E Barker	
Member	G P Shipway	
Companion	A J Gane	
Associate (Technician)	C V Brutey	(also representative – ERB Technician Board)
Associate (General)	J Kinross	

Co-opted

Chairman, Education Group	J A C Gibb	
Representative – ERB Technician Engineer Board	J Kilgour	(also Education Group)
Member	U G Curson	
Deputy Representative – ERB Technician Board	R J Fryett	

Education Group All co-options

Chairman	J A C Gibb	(also Membership Panel)
	B D Witney	
	G C Mouat	
	D L Bebb	
	R Barber	
	J C Turner	(also Membership Panel)
	J Kilgour	(also Membership Panel)
	I Gedye	

Members of Editorial Panel for 1975/76

Chairman and Hon Editor	B A May
Vice Chairman	G Spoor
Members	J C Hawkins
	F M Inns
	J H Neville

Other appointments for 1975/76

Education Honorary Adviser	J C Turner
Careers Honorary Adviser	J C Turner
Appointments Honorary Adviser	D H Sutton
Representative – PICC Council	B A May
Representative – PICC Executive	B A May
Representative – RoSPA (National Agricultural Safety Committee)	E Sudron
Representative – National Farm Safety Year	C V Brutey
Dunlop Scholarship Selection Panel Chairman	J A C Gibb
Representative – Fifth International Aviation Congress	D H Rowe
Douglas Bomford Trust – Chairman of Trustees	T Sherwen

British CIGR Association

Section Representatives (Correspondents) 1975/76

Section 1 Soil and Water Engineering	V B J Withers
Section 2 Farm Buildings and Associated Engineering Problems	S Baxter
Section 3 Power and Machinery	J H Neville
Section 4 Application of Electricity to Agriculture	P Wakeford
Section 5 Scientific Organisation of Agricultural Work	R R Meneer

ADMISSIONS

The undermentioned have been admitted to the Institution, in the grades stated:—

Member

Anazodo U G N	Nigeria		19 4 75 ED
Fellowes-Freeman P A	Gloucester	7	29 4 75 DM/RD
Jarvis R A	Herts	5	22 4 75
McKinlay W W	Swaziland		29 11 74 AD
Odigboh E U	Nigeria		29 4 75 ED/RD
O'Dogherty M J	Herts	5	29 4 75 RD
Peacocke N F	Rhodesia		29 4 75 RD/DM
Sloan W E	New Zealand		17 12 74 AD
Tofts J N	Norfolk	1	28 4 75 FM
Yong V Y F	Sabah		19 2 74 FE/DM

Companion

Bracey C J	Herts	5	13 5 75 TS/DM
Fowlie G J	Sussex	13	13 5 75 TS
Stenning B C	Beds	5	13 5 75 ED
Taylor V R	Berks	13	13 5 75 BD

Technician Associate

Akintola A O	Nigeria		28 9 73
Bhatti I A	Nigeria		21 10 74 FM
Campbell C S	Notts	2	12 6 75 ED
Daubney N J S	Yorks	10	22 4 75 PR

General Associate

Clapperton J W	Zambia		22 4 75 TS/DM
Crowder T	Canada		22 1 75
Hampson R G	Cumbria	3	29 4 75 AD
Horner R J	Essex	12	22 4 75 TS
McKenzie A J H	Beds	5	10 6 75 FE
Marks R P	Gloucester	7	22 1 75 ED/FM
Mostyn E J	Devon	6	22 4 75 AD/BD
Owonibi S A	Nigeria		29 4 75 DM
Pereira J L M	Brazil		10 2 75 RD
Stutchbury H B	Abu Dhabi		29 4 75
Watermeyer J M	Rhodesia		22 4 75 AD

Graduate

Denton A J	Salop	9	10 2 75 DM
Gray S R K	Dunbarton	4	10 6 75
Ladega A O	Nigeria		22 4 75 AD
Weekes E D	Guyana		25 3 75 FE
Wyles P W	Notts	2	22 1 75 ED

Student

Abudu S	Ghana		17 7 73
Austin P	Hants	13	21 5 75 FM
Brighton M I	Lincs	2	4 11 74 TS/DM
Carville J V	Eire		25 1 73
Holroyd P	Beds	5	5 6 74
James W D	Beds	5	22 4 75

RE-INSTATEMENT

The undermentioned has been re-instated:—

Associate

Miller R W	Suffolk	1	1 1 72

TRANSFERS

The undermentioned members have been transferred to the grades stated:—

Member

Barton J M	Leics	2	22 4 75 ED
Nwankwo J O	Nigeria		29 4 75 AD/FM
Robinson J R	Beds	5	25 3 75 CS/FE
Stamp J T	Devon	6	12 6 75 DM
Swallow M L	Sierra Leone		23 1 74
Wall B P	Turkey		28 4 75 TS
Willey R J	Berks	13	18 12 74

Technician Associate

Cherry R P	Greece		25 3 75 TS
Hannah J R	Avon	7	22 4 75 AD/FE
Jobling J E	Yorks	10	22 4 75 FE
Voss R M	Warwicks	8	29 4 75 ED

Graduate

Scott D G	Aberdeen	4	21 5 75 AD

Retired Rate

Owen R D	Surrey	13	1 1 75
Smith D G	South Africa		1 1 75
Wilson C G	Lincs	2	1 1 75

RESIGNATIONS

The undermentioned have resigned from membership of the Institution:—

Baird D H A	Norfolk	1	31 12 74
Baxter P W	Essex	12	23 6 75
Bellhouse R L	Worcs	8	30 6 75
Codd H E	Lincs	2	24 6 75
Cuthbertson J A	Lanark	4	27 6 75
Forknall J P	Beds	5	30 6 75
Hallam K E	Staffs	9	16 6 75
Hollick M	Australia		30 6 75
Jackson G	Essex	12	31 12 74
Jenkins A	Devon	6	25 6 75
Potter S L	Warwicks	8	30 6 75
White F A	Norfolk	1	26 6 75

DEATH

We regret to announce the death of the undermentioned member:—

Etuk B E	Nigeria	5 5 75

Occupations

AD — Advisory Services; BD — Buildings; CS — Consultancy; FE — Field Engineering; PR — Technical Journalism; TS — Technical Sales, Distribution and Service; DM — Design and Manufacture; ED — Education; EL — Electrification; FM — Farming; RD — Research and Development.

Branches

1 East Anglia; 2 East Midlands; 3 Northern; 4 Scotland; 5 South East Midlands; 6 South Western; 7 Western; 8 West Midlands; 9 Wrekin; 10 Yorkshire; 11 North Western; 12 South Eastern; 13 Southern.

Transfers and unpaid fees

THE Membership Panel has approved the transfer of a number of members who have not yet paid their transfer fees or subscriptions as notified by the Secretariat. It is regretted that registration in the new grade cannot be completed until all outstanding monies have been paid in full to the Institution.

LETTER

A protest about accuracy

AS a speaker at a branch meeting I must protest about the accuracy of a report of a meeting held by the West Midlands Branch in 1974 (pp 22-23).

Only one method of obtaining energy (in the form of heat) from straw is being investigated at Nottingham University — by burning straw in a furnace linked to a crop drier. The other methods mentioned in the report, namely fermentation to produce alcohol, and methane and methanol production, were referred to but are not being studied here.

B WILTON
Lecturer in farm mechanisation,
Department of Agriculture and Horticulture, School of Agriculture,
The University of Nottingham,
Sutton Bonington, Loughborough LE12 5RD.