Agriculture's uncertain claim on world energy resources

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Agriculture has been regarded as the human activity that converts solar energy into food by means of plants and animals. With increasing fuel costs it is increasingly realised that considerable amounts of fossil energy are used in the process, perhaps to such an extent that agriculture should be redefined as the human activity that converts fossil fuel into food by means of solar energy, plants and animals.

Added energy

Fossil energy is used not only to drive tractors but also for the manufacture of tractors, fertilisers, pesticides and all other inputs that are used during the production process. In analogy with the term 'added value tax', the term 'added energy' may be used.

The added energy of a product is the total amount of energy that is used for production and transport to the manufacturing place of all inputs, with the exception of labour, that are used for its manufacture. Human labour is excluded from the computation because the purpose of production is the satisfaction of human needs and desires, and not the manufacture and maintenance of human labour. It should be included only where men are exploited, as in slave systems, and it is disturbing that sometimes the so called 'social' costs of foreign labour are indeed considered.

The added energy of a tractor may be obtained by analysing in detail the production process from raw material to final product. A tractor is only written off over a period of 15 years, and a tractor factory will produce many tractors during its existence, so that the contribution of the tractor factory and of its construction to the added energy of the farm product may be negligible. Repeated calculations are needed to compute added energy, because many industries need their own output as input. For instance, on a farm which employs horses for power, it is the added energy of the horse's food, and not its calorific value, or the power of the horse, which has to be taken into consideration.

Arbitrary decisions about the division of energy costs are needed if one process results in more than one product. Thus, for instance, part of the added energy during the production of milk has to be allotted to the butter and part to the skimmed milk. This is an arbitrary decision. But what is the added energy of electricity made from fossil fuel compared with electricity made in hydro-electric stations or in nuclear power plants?

Added energy may also be estimated by means of input-output economics, as introduced by LEONTIEF (7), which not only takes account of the energy used directly by each economic activity, but also that which enters into the activity through the use of other products. The computation is again a cumulative process, which is streamlined by the use of matrix algebra. A first analysis of Japanese data (4) showed that the added energy of agricultural products at the farm gate is about three times larger than the energy used directly in the form of fuel, a figure that agrees with the results of PIMENTEL (9), who used the technical approach.

Both methods approach the same result from different sides and both require an exploding effort to achieve accuracy. For the proper use of input-output analyses, it is necessary to distinguish a large number of homogeneous activities, and the technical method requires the analysis of long production chains. Both methods may be combined by using the result of the input-output analyses as the input of the technical analyses, so that production chains may be short-circuited after the analyses of only a few of the final links.

The determination of added energy of the main products may become a valuable tool for anticipating the impact of rising prices and scarcity situations. Such an analysis has to be a common effort of economists and engineers with various backgrounds, and as long as this interdisciplinary attempt is not made, all quoted figures can only be rough guesses. For instance, the added energy value of 1 kg fertiliser-N is estimated at 27 MJ by the Tennessee Valley Authority (cited by HEICHEL [6]) and at 78 MJ by PIMENTEL *et al* (9). SCHUFFELEN (this issue and personal communication) estimates a value of 100 MJ for N in the form of NH_4NO_3. It may be that the TVA does not include energy obtained from water power, but no comment can be made on this because the origin of this figure, and of many others, is obscure. However, 36 MJ for N in the form of ammonia has been reported to the Dutch Committee on Energy Research.

Dutch and Australian agriculture

Farming in the Netherlands is about the most intensive in the world, and its energy relations are considered here in further detail to provide a frame of reference for further discussion. The added energy of the Dutch agricultural products amounted to about 10% of the direct energy used by the country in the middle of the 1960s. However, about half of this energy was used in horticulture to produce flowers and vegetables. The added energy of the products of crop and animal husbandry amounted to roughly 70×10^9 MJ/year, using the added energy of PIMENTEL (9) for nitrogen (4).

The yearly return on this investment was about 200×10^9 MJ in the form of grass and fodder, about 50×10^9 MJ in the form of arable crops, and about the same amount in the form of straw, leaves and other near-waste products. In addition, there was a net import of 70×10^9 MJ of grain, concentrates and so on. Only 40×10^9 MJ/year were consumed as such and all other primary products were used for the production of about 37×10^9 MJ/year of meat, milk and eggs, of which one third (about 12×10^9 MJ/year) was exported.

The ratio of exported energy in the form of animal products to imported energy in the form of plant products was 12/70 or 0·17. Since the average energy efficiency of the animal production process was certainly not higher, it appears that the 13 million Dutchmen who exploited a little over two million hectares of arable land and pasture were self sufficient so far as food was concerned—and that was on a diet containing much more than sufficient animal products, and at the expense of only a few percent of the total fossil fuel use of about 1500×10^9 MJ/year.

The yield of crops harvested by machine in food-exporting Australia was, according to GIFFORD (5), equal to 400×10^9 MJ/year at the end of the 1960s. Sheep consumed 2000×10^9 MJ/year, which led to an animal production (half meat, half wool) of about 40×10^9 MJ/year, the low conversion efficiency reflecting the extensive system of farming in Australia.

This production of human food in the form of plant and animal products was much larger than in the Netherlands. Nevertheless, the added energy was only slightly higher at 90×10^9 MJ/year. The population was also about the same, which suggests that the use of energy in agriculture depends not so much on output and the system of production, as on the number of people engaged in agriculture and their standard of living. This suggestion is confirmed by the observation of Schuffelen (in this issue) that the fraction of fossil fuel used for N-production in the Netherlands is the same as for the whole world.

Energy farming

As is discussed elsewhere in this issue, organic material may be converted into methane by anaerobic bacterial digestion with an efficiency of 80%. The annual consumption of energy in the Netherlands is about five times the energy content of the plant material that is produced, so that a surface of at least seven times the Netherlands, and with the same plant production, would be needed to replace fossil fuel. As the output of energy is about six times the input, this is in principle a sound method of energy production—the more so because the output of energy may be increased about two-fold by developing energy cultivation methods with high potential yields.

Computations of potential production, on a world scale, taking lack of soil quality and of water into account (3), show that enough food in the form of plant and animal products may be grown for a world population which is at least ten times larger than at present. Hence, the area of soil would be available to provide for the present energy needs of the world population by means of energy farming.

However, energy farming is still farming and requires land, human expertise, water and fertilisers that are also required for food production. An increase in food production of 3% per year is necessary to keep up with the growth of the world population, and to improve to some extent the very poor diet of the greater part of mankind. On the other hand, food production during the past few decades has increased by a smaller percentage, and attempts to accelerate production consistently have not been very successful up to now.

It makes no sense to solve one problem at the expense of another, and even greater one, so energy farming cannot be accepted as a justified substitute for the fossil fuel needs of industrialised societies. Even Australia does not expect too much from this source (1), but the situation might, perhaps, be different if there was less coal or if there were animals that could collect energy from their low yielding ranchland instead of producing meat and wool.

Claims on energy

Farming for energy must be energetically sound, but there is no reason why farming for other products should cost less energy than is produced. After all, milk is drinkable, but diesel oil is not; and although dividing the energy content of roses by their added energy value may give a beautiful, dimensionless efficiency ratio, it is meaningless.

It is not efficiencies, but added energy values in relation to current prices which act as a guide to the circumstances where shortages will hurt most. If energy becomes really expensive, greenhouse horticulture, fishing and bio-industry (see, respectively, Sheard's, Laing's, and Spedding and Walsingham's articles in this issue) may suffer to such an extent that they will practically vanish. After all, the need for animal protein of the world population may be more than covered by animal husbandry on soils that are practically unsuitable for arable crops, and meat analogues of plant origin may well gain acceptance during the present decade. Other energy-demanding processes, like the manufacture of single cell proteins out of fossil fuel, may not even get a proper start, except for the production of additives that augment the quality of animal or human food.

What, then, are the remaining claims on fuel resources in the future? By the year 2000 the world population will have doubled and, optimistically, it may be reasoned that the use of plant products, either directly or through the consumption of animal products, will be about three times the human calorific needs. The days are gone when more food can be produced by simply extending the cultivated area, and it therefore seems safe to reason that this food must mainly be produced through an input of energy comparable with the level that currently exists in the Netherlands. The energy needs per unit of food of the Australian system may be several times smaller, but the world is also several times too small to adopt it widely.

The amount of plant food required for man and animals by AD 2000 will then be 7×10^9 people$\times10^4$ MJ/caput/year or 7×10^{13} MJ/year. Taking into account that the plant material produced will partly be used for human and partly for animal consumption, and that extensive farming will not vanish completely, no more than about 1×10^{13}MJ/year of added energy will be needed to produce this amount. Even more optimistically, it may be assumed that both dietary standards and added energy needs for food production will, by the year 2000, be the same as in the Netherlands now, with energy needs amounting to $7\times10^9/13\times10^6\times70\times10^9=4\times10^{13}$ MJ/year. These figures are six to 25 times larger than the present fossil fuel consumption in the Netherlands: an impressive, but not impossibly large amount.

Purposes of energy use

The two main purposes of energy use in agriculture are to increase output per hectare and per man. It has been shown (4) that the output in terms of plant products of farms on good clay soils in the Netherlands increased from roughly 3×10^4 MJ/ha around 1800 to about 9×10^4 MJ/ha at present. The increase was relatively larger on poor, sandy soils, which were extensively grazed around AD 1800 and now yield at least half as much as the best soils in the country. The input of labour on good clay soils decreased in the same period from 0·20 to 0·06 man/ha, so that the output per man increased threefold. However, just as added energy values are needed to characterise energy used, added labour values are needed to characterise labour use. Little outside labour was added to the products in 1800, but at present added labour values are roughly twice as large as the labour actually employed on the farm.

Whatever the outcome of a more detailed study, it is obvious that part of the energy input is yield-increasing and another part labour-saving. The input through fertilisers is of the first category, and through threshing machines, the second. But what about the use of pesticides? After all, it is possible to remove insects by hand and this is actually done in some circumstances. And what about the machinery that is used for ploughing, taking into account that zero tillage methods (2) are feasible with proper weed control, and that whatever is done by means of plough and bulldozer may often be done by means of shovel and wheelbarrow?

On the basis of a rough analysis, it is concluded that about two-thirds of the added energy may be classified as labour-saving and only one-third as yield-increasing. The equality of the added energy in Australia and the Netherlands confirms that labour saving inputs are the largest in modern agriculture.

Labour saving in agriculture in the western world is rapidly approaching the extreme situation where only a few percent of the population is working on the land. It is not likely that in the rest of the world the same development will take place before AD 2000, and it may be possible for an equilibrium to be found where a larger fraction of the population retains its rural base. Developments in China provide an example, where yields of grain increased from 108 to 250 million tonnes during the last 25 years without drastic replacement of labour. The purchase of 400 million dollars worth of fertiliser factories during the last two years illustrates, however, that energy is still badly needed to provide yield increasing inputs (8).

For this reason, the claim of agriculture on future energy resources can be decreased by upwards of half the amount estimated in the previous section, although it would be difficult to reverse the situation to that extent in the western world.

Diversification of energy sources

Whatever the exact claim that agriculture has on energy, it is not necessarily a claim on conventional sources such as coal, oil and gas, or on nuclear energy, because the possibilities of exploiting unconventional forms of energy are especially large in farming.

Organic waste. In the first place, the amount of straw, manure, leaf material and other near-waste material that is produced in agriculture is in the same order as the amount of edible products, and it has been noted above that this organic material may be converted into fuel with considerable efficiency. The direct use of energy on the farm is smaller than the amount of fuel that can be produced in this way, so that farms could be operated as closed systems in this respect. Cornforth, in this issue, covers this subject in considerable detail, with only some difference of opinion with regard to the socio-economic feasibility of energy farming. However, whether organic waste will continue to remain a waste, or whether more and more will be used as raw material in industry or animal feed, is questioned by Spedding and Walsingham in this issue.

Wind. Farming is done on large surfaces and the energy of the wind that passes by may be tapped. Traditionally, this was done for pumping water and grinding grain. Since both water and grain can be temporarily stored until the wind is blowing, the problem of synchronising demand and supply was not very large. This still holds good, and as decentralised storage systems, with capacities that are not negligible with respect to farm needs, can also be developed, the rehabilitation of the windmill is quite possible.

Sun. Solar energy is especially suited to driving irrigation pumps, because the supply of solar energy and the demand for water are fully synchronised. Thought has been given to this for many years, but no simple solutions have been found, and the rather difficult use of photo-voltaic cells is still far too expensive.

Perhaps for good reasons, no attention has been paid to more decentralised manufacture of nitrogen fertilisers on the basis of organic waste, electrical energy out of wind, and heat out of solar energy. This is an interesting challenge, because nitrogen fertilisers are badly needed everywhere, and storage of energy in this chemical form is very simple.

Nitrogen fixation. The traditional additional source of nitrogen for cropping is the biological process of fixation, mainly by means of leguminous species. This process does not need fossil fuel, but makes use of the living plant for performing the reduction. However, the cultivation and maintenance of the nitrogen-fixing species, only possible on part of the available soils, requires considerable skill, and produces yield levels that are considerably lower than is possible with N fertiliser. Hence, although biological fixation will remain an important source of nitrogen, it can hardly be developed into the only source.

Another source of energy is animal traction, which requires a considerable amount of labour and involves 10–20% of the land surface in growing feed for the draught animals.

To what extent these sources of energy will be actually used is difficult to predict, because each has its disadvantages. Some may not be too sound because their manufacture and maintenance is costing too much energy; some may require too much skill to operate; and some may turn out to be expensive or a nuisance. These are all unknown factors that are going to be weighted against the cost of energy from conventional sources and from nuclear energy, which is also unknown. However, their existence makes it at least difficult to stake a claim for agriculture on conventional energy sources.

The crystal ball

For various reasons, it is at present practically impossible to forecast the future claims that agriculture will make on the energy resources of the world. In the first place, the added energy of the main agricultural products, and the fraction that is used for replacement of labour rather than increase of yield, are only approximately known. In the second place, it is very difficult to estimate human needs, because the fraction of the diet that consists of animal products can vary considerably. In the third place, there are many unconventional energy sources on the farm which may or may not be exploited in the future.

Nevertheless, one can make some very simple guesses. If a world population of 7×10^9 people grows its food and eats as the Dutch do today, the claim on conventional energy sources will be about 4×10^{13} MJ/year by AD 2000. This high claim is reduced by 75% if standards are lowered towards a more rational level, where (*a*) one third of the plant products are consumed directly and two thirds after conversion into animal products, and (*b*) part of the food is produced extensively. The claim is again halved when the energy is used mainly for production, and not so much for the replacement of labour. The next reduction, also with a factor of a half, could be obtained when unconventional energy sources were to be applied on a large scale. The minimum estimate can therefore be reduced more than tenfold to $0{\cdot}25 \times 10^{13}$ **MJ/year, which is only twice the total fossil energy used in the Netherlands, and of the same order as that used in agriculture in the industrialised part of the world at present. However cloudy the crystal ball may be, it is obvious that many options are, nevertheless, open; but they are probably going to be used too little and too late for many people. Perhaps we should be less worried about the future and more about the present.**

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