THE EFFICIENT USE OF LABOUR, LAND AND ENERGY IN AGRICULTURE

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SUMMARY

Fossil energy-using agricultural systems may be defined as systems transferring tradeable energy resources in tradeable agricultural products by means of untradeable labour and untradeable land. The substitution of tradeable energy and untradeable labour is considered and it is shown that the energy efficiency of agricultural production systems increases with increasing control of production and increasing yields.

The main conclusion is that agriculture may contribute to a more sensible use of energy by developing in a direction where as high yields as possible per hectare are obtained from as small an area as possible.

TWO DEFINITIONS OF AGRICULTURE

Agriculture may be defined as the human activity that makes useful organic materials by means of plants and animals with the sun as a source of energy. The needed resources are few—a piece of land with some sun and rain and human labour. It appears that many soils enable subsistence in food, clothing, shelter and energy, but not very much more. Man, however, is an animal species with concrete as its natural habitat, the development of civilisation being very much intertwined with the development of urban centres. To maintain a substantial urban population, the labour productivity of the rural population has to be much larger than at the subsistence level and this is only possible if the urban sector supplies means of production—machines, fertilisers, biocides and so on.

Leaving the problem of capital accumulation aside, their manufacture requires labour, fossil energy and raw materials such as iron and phosphate. Of these, labour

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is the only genuine renewable resource. Labour is also the resource equally distributed amongst men.

Fossil energy, on the other hand, dissipates sooner or later in the production process, is very much unequally available to nations and is, moreover, exhaustable. The point of exhaustion is reached as soon as the mining of one unit of energy takes more than one unit of energy.

The other raw material resources are in principle inexhaustable because they do not dissipate during their use. Of course, they may become more scarce, which means that it may require more and more labour and energy to maintain a reasonable supply. This view emphasises the recyclability of all raw materials, except fossil energy. Easily mined deposits are not equally distributed amongst nations, but this complication is conveniently ignored for the present.

Expressing the cost of recoverable raw materials in terms of labour and energy necessary for their procurement, the number of resources is brought down to three—labour, land and exhaustable energy. These three resources may be combined in many different ways to grow the agricultural product and all these ways may be efficient, depending on the circumstances and the goal. But there is an important difference among the four entities involved. Two of them—labour and land—cannot be sold over national borders. They are non-tradeable in this respect. The other two—energy and the agricultural product—are, however, tradeable goods. Thus any energy-using agricultural production system could be redefined as a system used for the transformation of the tradeable energy resource into tradeable agricultural products by means of untradeable land and untradeable labour. This definition places the emphasis on foreign exchange as the most scarce resource, especially for poor nations without energy and mineral resources. And many problems of economic development can only be understood by analysing the use and misuse that is made of this scarce resource.

Governments have, in most cases, their power bases in the urban centres of the country so that most of the foreign exchange is used there, and then often for consumptive purposes. Since most foreign exchange of poor countries is made by selling agricultural products, the rural population is systematically shortchanged. The agricultural labour force is then in effect treated as a tradeable resource, although slavery in its most brutal form has been abolished.

SUBSTITUTION OF LABOUR AND ENERGY

Given a hectare of land to grow a crop with a given yield, it is clear that this can be done at the expense of little labour and much energy, or the other way around: the non-tradeable resource labour may be replaced by the tradeable resource energy without changing the yield. A guesstimated substitution diagram of labour and energy for the growth of 5000 kilogrammes of wheat per hectare in the Netherlands is given in Fig. 1. This figure includes not only the direct energy and labour use on the farm, but also the indirect energy and labour use for the manufacture of all inputs used during the production process. The sum of direct and indirect energy is called the added energy, added labour being defined in a similar way. The added energy concerns only the use of exhaustable energy calculated on a fossil oil basis. When horses are used, it contains the fossil energy to produce the horse food and not the

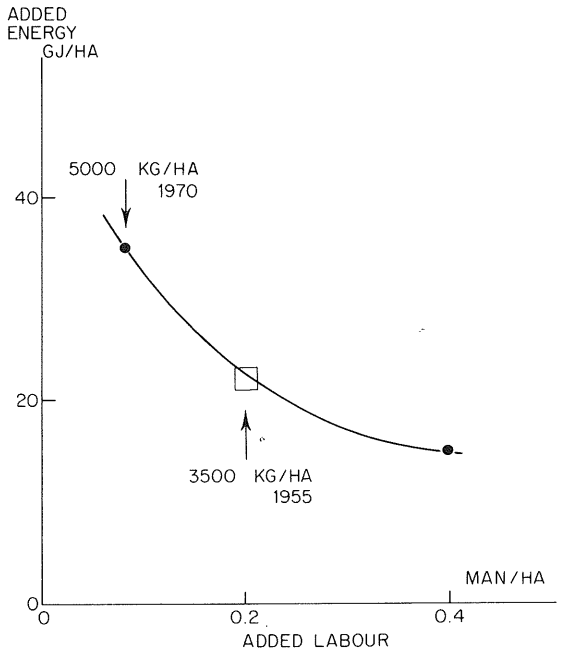

Fig. 1. The substitution diagram for the use of added energy and labour for the cultivation of 5000 kilogrammes of wheat per hectare on an arable farm in The Netherlands in 1970.

heat of combustion of the food or the horsepower of a horse. Adding calories indiscriminately, irrespective of their origin, is a futile exercise, as futile as the exercise of a banker adding kilogrammes of gold, silver and banknotes.

It appears that in 1970 about 35 GJ of added energy were used per hectare, about half directly and the other half indirectly, mainly as fertilisers. If the 5000 kg yield of wheat were burned, this would produce about three times more heat than the oil used in its production. Hence the so-called energy efficiency is larger than one, but this information is of small use since mineral oil cannot be consumed and wheat is not grown for burning.

Take transistor radios as a comparison. Their manufacture requires added energy but when thrown into the fire, their heat of combustion appears to be zero. But this zero energy efficiency does not mean that they should not be produced—that depends on how much these noise-boxes are appreciated. The energy efficiency of the production of roses in hothouses also approaches zero, but who cares as long as roses are not grown for burning? Of course with rising energy prices they may become expensive, but they may still be worth the money when used to please.

And what about milk? The energy efficiency of its production is smaller than one, but prices are such that the amount of added energy contained in one dollar's worth of milk is lower than in one dollar's worth of wheat; hence, with rising energy prices it is not the milk farmer but the wheat farmer who is going to be hurt first.

Let us return to the wheat. The added labour use in The Netherlands in 1970 was about 0·084 man per hectare of which the greater part was used directly on the farm itself. This gives one point at 35 GJ and 0·084 man per hectare on the substitution diagram. It would have been possible to grow wheat also by using only manual labour for working the soil, sowing, weeding, harvesting and so on, utilising as little energy as possible. Since for yields of 5000 kg/ha fertilisers are necessary, this should not decrease the added energy need to zero but to about 15 GJ/ha and would increase the added labour need to about 0·4 man per hectare. This gives another point on the substitution function. The curve-linearity is based on an admittedly rough cross-sectional analysis between countries and is qualitatively reasonable. After all, there are some farm operations which require small amounts of energy to mechanise and others that require larger amounts (de Wit & van Heemst, 1976).

The added energy and labour use in 1955 is entered on the same graph. This combination appears to be situated on the substitution curve for 1970. However, it yielded only 3500 kg/ha in 1956 whereas the same combination in 1970 would have yielded 5000 kg/ha. This difference in yield therefore quantifies the technical improvement of the production process in 15 years. The technical improvement may also be expressed as follows. In 1950 the energy productivity was 3500/23 = 150 kilogrammes of wheat per gigajoule and in 1970 5000/35 = 140 kilogrammes of wheat per gigajoule. This means that the energy productivity decreased slightly. However, the labour productivity increased about threefold in the same period.

Technological innovation would have taken another course if labour had been cheaper and energy more expensive. In that case, the energy productivity would have increased more and the labour productivity less. Relative scarcity of energy and relative abundance of labour in the future could very well induce such a development. Since means of production are likely to be taxed according to their scarcity, this development could then be enhanced by adapting the tax structure and the money transfer system to the non-working section of the population by decreasing the levies on the employment of labour and increasing the levies on the employment of energy. We are a long way from fully appreciating such consequences of a change in relative scarcity.

RESOURCE USE AND YIELD LEVEL

The increased efficiency of resource use in the course of time is closely correlated with an increase in yield per hectare and this suggests that further efficiency increases also may be induced by further yield increases. To evaluate whether this may be the case or not, the agricultural production process should be analysed in more detail, as is done in Fig. 2.

The rectangles in the top row of this diagram show the main boundary conditions of the production system at a given time. Climate and soil can hardly be influenced by man. Plant properties may be adapted by selection, but this hardly requires fossil energy. This is otherwise for land reclamation activities, but even when these are

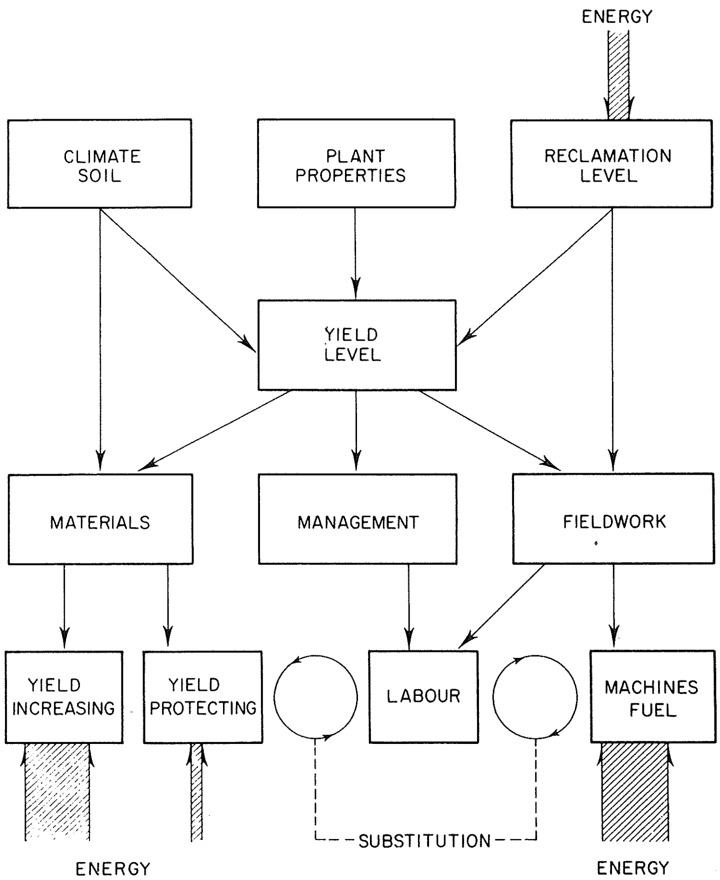

Fig. 2. A diagrammatic presentation of the elements that play an important role in the agricultural production process.

undertaken in a highly mechanised fashion, the energy expenditure is small since the reclaimed land is used for many years.

Climate, soil, crop variety and reclamation level determine the maximum yield level that can be achieved. Once the reclamation investment is made, the farmer's wisdom dictates that this maximum or pre-conceived yield level is approached. Otherwise it would have been more sensible not to have made the investment at all. The problem of agricultural research is not so much to determine the yield as a function of all possible input combinations but rather to find feasible combinations of inputs other than reclamation to achieve the pre-conceived yield level. Yield is thus treated both as a dependent and as an independent variable, this notion being reflected by the direction of the arrows in Fig. 2. Feasible combinations of these other inputs are, of course, adapted to increasing knowledge and to changing economic conditions, in general in heuristic fashion.

The inputs are conveniently distinguished as material inputs, management input and the input of fieldwork. The labour and machinery used for fieldwork may be substituted for each other, a certain amount of added energy being necessary at each mechanisation level. This amount of energy is to a large extent, independent of the yield level since many operations like ploughing, seedbed preparation and so on need to be executed anyway. The energy needed for harvesting is proportional to the amount of straw harvested but may be made practically independent of the yield level by adapting the amount of straw that is processed by the combine. Consequently, the amount of added energy use for this purpose per kilogramme of product decreases rather drastically with increasing yields.

The material inputs are either yield-increasing (fertiliser, water) or yield-protecting (biocides). Especially the use of herbicides reduces the on-farm labour needs drastically. The added energy content of yield-protecting inputs is practically zero. Their fabrication and use require especially intelligence and good management. But considerable amounts of added energy are necessary for yield-increasing inputs, especially nitrogen and water pumped from deep wells, and these inputs cannot be substituted to any large extent by labour.

On the basis of the law of diminishing returns, it could be argued that with increasing yields, any gain in energy efficiency on the machinery side is nullified on the fertiliser and water side. Such reasoning, however, does not take into account that this famous law holds only when the intensity of one production factor is changed, keeping all others at a constant level. This is not the case here because the fertiliser rate is adapted to the yield level which corresponds to the chosen reclamation level. For water, phosphate, lime and many other material inputs, the same input levels that are needed for medium yield levels are also practically sufficient for high yield levels.

But what is the situation with the energy-expensive nitrogen fertiliser? This is most conveniently analysed by presenting the results of fertiliser experiments according to the scheme of Fig. 3. The relationship between yield and fertiliser rate is

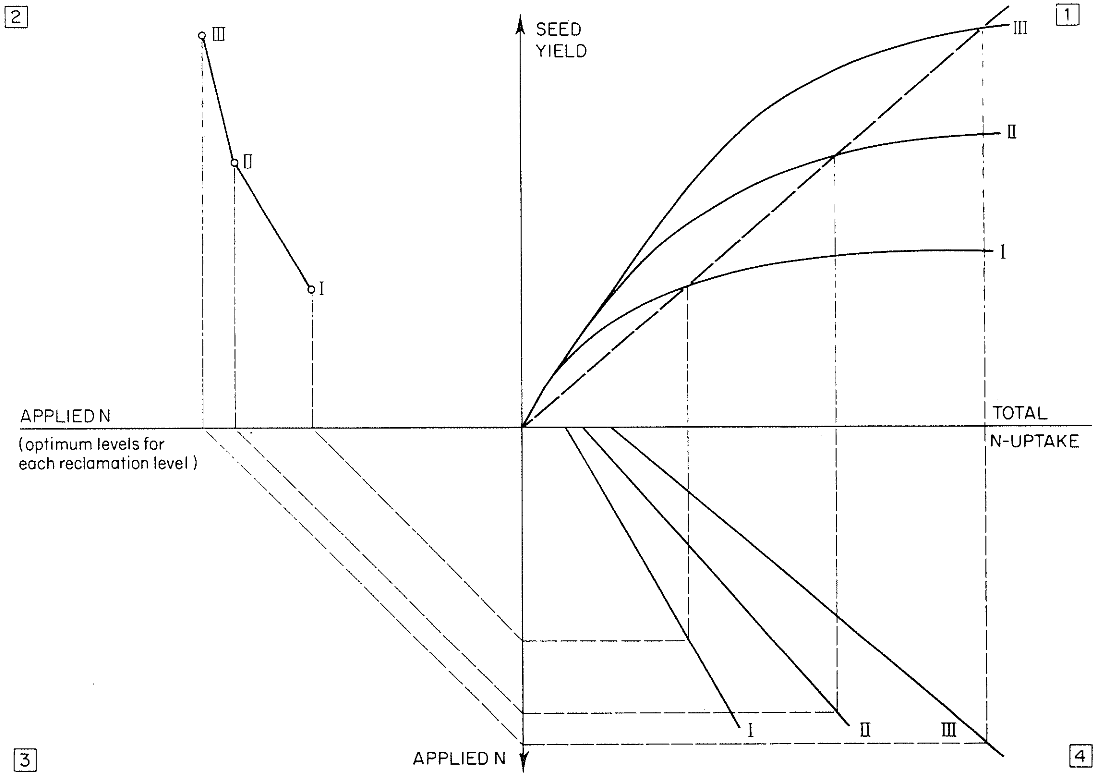

Fig. 3. A yield–uptake–fertiliser rate diagram for nitrogen (N) at three reclamation levels. Quadrant numbers are given within squares. The line in the second quadrant presents the relationship between yield and fertiliser rate when the latter is adapted to the reclamation level.

here subdivided into a relationship between yield and amount of nitrogen taken up by the crop and this amount of nitrogen and the fertiliser rate. Three reclamation levels are distinguished—poor drainage, proper drainage and optimisation of the water supply.

As long as nitrogen is in short supply, the crop dilutes the amount of nitrogen to the same minimum content which means that the initial slope of the N-uptake versus yield curve in the first quadrant of the figure is the same, irrespective of the reclamation level. In the case of small grains this slope is about 70 kilogrammes of seed per kilogramme of nitrogen taken up, irrespective of the place where the crop is grown and of the variety. In fact it is one of the most conservative properties of these crop species. The maximum yield that may be achieved increases, of course, with increasing reclamation effort and this results in the family of yield curves with diminishing returns, presented in the first quadrant of the figure.

Farmers tend to fertilise up to the lodging level which may be reached at approximately the yield/nitrogen uptake ratio given by the dashed lines. But what fertiliser rate is necessary for this purpose? This appears in the fourth quadrant of the figure, presenting the relationship between rate and uptake. In practically all cases there appears to exist over a rather long range a linear relationship between uptake and rate of fertilisation, the intercept with the uptake axis representing the nitrogen uptake without fertiliser application. This uptake increases somewhat with increasing reclamation effort. However, the most important effect is on the recovery of the applied nitrogen. In the case of poor drainage, this recovery is low, mainly because of denitrification and leaching. Denitrification, especially, is reduced by improving the drainage conditions but only with full control of the water supply is the course of growth so predictable that the proper amounts of nitrogen may be given at the proper time. These optimum conditions result in recoveries of the order of 70%, not counting the nitrogen in the roots.

What, then, is the optimal fertiliser rate with increasing reclamation levels? This relationship between yield and fertiliser rate is presented in the second quadrant of the figure and simply found by eliminating the uptake as an intermediate. The result is obvious; with increasing yield level, the amount of wheat obtained per unit of applied nitrogen increases and since the nitrogen in all fertiliser combinations represents by far the most added energy, it is shown in this way that this fraction of the added energy is also used more efficiently at higher yields.

Hence both the efficient use of energy in mechanisation and in fertilisation increases with increasing yield level. Somewhere a penalty has to be paid for the high energy productivity at high yields. Its achievement requires a still better knowledge of the production process, a considerable management effort and a good timeliness of all farm operations. In other words, more labour is needed, but this may be not undesirable at all, since useful and satisfying jobs are becoming more and more scarce in societies that are being automated.

CONCLUSIONS

Some conclusions may be drawn at this stage. If energy should become a very scarce resource, it would be possible to grow agricultural products without the use of yield-increasing inputs. This would lead to lower yields and would still result in an increase of the added energy use per unit product, unless the energy use for substitution of labour were minimised at the same time. It may be questioned whether the total production volume would then be large enough to cover the basic needs. It is, however, certain that under such circumstances all reclaimable soil would have to be taken into production and much labour would be needed on the farm: it would then be impossible to maintain the urban civilisation we seem to like.

However, although scarce, it seems likely that energy is available in at least reasonable quantities for a long time to come. In that case, agriculture may contribute to a sensible use of energy by developing in a direction where as high yields per hectare as possible are obtained from as small an acreage as possible by a reasonable number of highly skilled farmers per hectare. The spin-off from increasing energy productivity by higher yields per hectare and some substitution of energy by labour may be considerable: (i) less energy use per unit product; (ii) greater need for skilled labour in a society where many job opportunities are eliminated by automation; (iii) more land available for other purposes, but this may be a greater advantage in The Netherlands than in the USA; (iv) reduction of the environmental impact of agriculture because less resources are used per unit product and then in a more confined area; (v) last, but not least, a challenging task for agricultural scientists.

Finally, being a born optimist, I would end with the conclusion that some energy scarcity in the future may prove to be a blessing in disguise for agriculture.

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