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# The Economist and Farm People in a Rapidly Changing World

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# TRENDS AND PROSPECTS FROM THE STANDPOINT OF NATURAL SCIENTISTS

AS a natural scientist, I take it as a great compliment to be invited to contribute to the International Congress of Agricultural Economists. I must confess that the invitation not only pleased but also surprised me greatly, because I had not previously thought that economists were particularly interested in what those engaged in experimental work were doing or thinking. That I was wrong delights me, and can be taken as evidence of my ignorance both of economics and economists. To show how total is my ignorance and to be deliberately provocative, I will begin by saying that, if I were asked to define my idea of agricultural economics, I should have to reply that they are what too often seem either to prevent the results of experimental work being applied or make the consequence of applying them other than the experimenter would have wished.

I will try to expand what I mean, and show how I get this no doubt wrong idea, by saying a little about what has happened to the cocoa crop since I first encountered it in 1945. A virus disease, swollen shoot, was then killing vast numbers of the trees in West Africa, especially in the Gold Coast. Its effects were such that the future of the crop there seemed threatened and measures were taken to check the spread of the disease by seeking and felling all infected trees. It was in connexion with these necessary and costly measures that I paid my visits to West Africa. Although much impressed by the devastation caused by swollen shoot, I was even more so by the unthriftiness of the whole crop, which seemed simply to be growing wild, uncared for, unmanured and unprotected against the many pests and diseases that found it a happy hunting ground. My suggestions that the crop might benefit from being sprayed and given some fertilizer were usually received courteously, but I was left in no doubt that most people thought I was more than slightly mad to make them. Not only was I told that such measures could not possibly pay with a peasant crop, but even that fertilizers were likely to be harmful rather than beneficial. One grower, who was more apprecia-tive of the possibilities than some of the officials, did not deny my contention that yields could be increased at least threefold, but gave me an elementary lesson in what I take to be economics. We met at a time when cocoa prices were rocketing, mainly because of unjustified fears of buyers that because of swollen shoot cocoa would become increasingly scarce. Our conversation went something like this: He asked: 'Would this mean much work?' I replied: 'It would certainly mean more than the very little now done to the crop.' He then asked: 'What would happen to the price of cocoa?' To which I replied: 'I don't know. I am a pathologist not an economist.' At this he laughed and laughed, and then added: 'I see. We do three times as much work. We get three times as much cocoa and one-third as much money. No, no, no.' Sadly, his forecast proved nearly right, for when later the trees were sprayed and yields were increased, instead of the feared shortage of cocoa, production exceeded demand and prices plummeted.

Since then the considerable experimental work done on the crop has proved my suggestion, that yields could be trebled, to be a gross underestimate. By combining such measures as doing away with shade trees, which traditionally were essential for the survival of the crop, by giving fertilizers and by spraying against the major pests and diseases, yields of dry cocoa in experiments have reached thousands of pounds per acre instead of the hundreds from the untreated plots. Such experiments demonstrate what needs to be done, and perhaps ought to be done, to increase yields, but they cannot show what is economically or politically possible. However, there is no doubt that were these practices rapidly applied to the whole of the existing acreage, cocoa production would greatly exceed demand.

Cocoa is by no means exceptional either in fluctuating widely in price or in having the potential to yield very much more than is currently usually harvested. To quote only one other example of possible yield increase: Workers studying the control of cotton pests in Central Africa have recently shown that yields of seed cotton there can also be in thousands of pounds per acre instead of the customary hundreds. As food crops in many tropical countries get even less care and attention than cash crops, and mostly go unfed and unprotected against the ravages of pests and diseases, the scope for increasing their yields is obviously also immense.

### *The job of the natural scientist*

It is the role of the experimental scientist to identify the factors that are limiting yields and find how to overcome them. He must do this without being too trammelled by considerations of the possible economic consequences of his work. Although he may well be able to estimate the cost of applying practices that will increase yields, he is in no position to forecast with any certainty their profitability. He can only work on the assumption that knowledge of how to improve the health and productivity of crops and stock is a desirable thing and that, if not immediately then ultimately, it will be to the general benefit to increase yields. After he has succeeded in his task of identifying and removing a limiting factor, he can demonstrate what could be done, but whether it will be done depends on factors not only beyond his control but also that he cannot study experimentally. In other words, whether the results of his work get applied depends on such social and economic factors as whether growers have enough skill and capital to apply them, and whether there will be a commensurate financial benefit from doing so.

The theme of our conference is 'The Economist and Farm People in a Rapidly Changing World'. The world is changing rapidly because scientific and technological discoveries are being applied. The fact that conditions change faster in some countries than in others, and faster in some industries or activities than in others, simply reflects the differential rates at which the discoveries are being applied. That in some countries human populations are increasing faster than food production does not mean that more is known about how to improve the health of people than of crops or farm animals, but that discoveries in medicine are being applied before discoveries in agriculture. There are various reasons for this, of which perhaps the two most important are that governments are more prone to support public-health measures than agricultural changes, and that to apply medical discoveries usually requires only a few people with specialized knowledge, whereas to apply agricultural discoveries requires many. However, this disparity must not continue for too long, because although it is understandable that man should be more concerned with his own health than with the health of crops or stock, there is little point in protecting people from infectious diseases if they are to die from hunger. If, as is widely predicted, human populations do soon outstrip food production, this will not be because agricultural research workers have failed to find out enough about how to produce food, but because knowledge has not been fully used.

The changes with which we shall be mainly concerned, I assume, are those in agriculture itself, but the point must at least be made that changes in conditions outside agriculture are no less important in affecting the lives of 'Farm People', a phrase embracing people who differ so much in wealth, ways of life, technical knowledge, and in almost every respect, that their only common feature is that they are engaged in raising crops or cattle. Our purpose is presumably to consider how to improve the lot of all 'Farm People', but methods of doing this must obviously differ greatly when these people range from those who are operating large businesses entailing much capital investment and employing every technological aid to those who without any capital eke a bare subsistence from shifting cultivations done with primitive hand tools. The effects of developments in other industries and activities show most vividly in the generalization that agricultural methods are most advanced, and those engaged in agriculture most prosperous, in countries where the proportion of the population engaged in agriculture is the smallest. Indeed, it is difficult to avoid asking whether the development of other industries is not a necessary preliminary to a country improving its agriculture. Can a country combine a largely agrarian population with efficient agriculture? Perhaps, if the agriculture is based on some commodity such as rubber or cotton destined for use in other prospering industries, but can it otherwise?

*Changes in British agriculture*

As a natural scientist concerned with establishing the scientific principles underlying the production of healthy crops, I am fortunate in not being called on to answer such questions and I shall not pursue them further. Rather, with the knowledge that such principles when established will apply equally to countries where yields are small and food is scarce as to those where their application sometimes produces embarrassing surpluses, I shall turn to discuss some of the changes in British agriculture. I shall mainly confine myself to crops because I am not qualified to talk about animals. However, as dairy products, fat-stock, poultry and eggs account for two-thirds of our farm sales, I must at least stress that this side of farming is also changing rapidly, with production per animal and per person employed increasing greatly. Although Great Britain is not generally regarded as an agricultural country, agriculture is one of its largest industries and I am told the value of its agricultural products exceeds that of Australia and Canada combined. During the last 100 years, the proportion of the working population directly engaged in agriculture has greatly decreased, from more than one in four then to fewer than one in twenty-five now. The rate workers move to other industries has accelerated and since 1955 the number of farm workers has diminished by more than a third while production has increased by more than a third. Change at this speed almost justifies the word revolution and its achievement has entailed not only great capital investment in machines and buildings, but the adoption of many novel methods and techniques developed by research workers.

Let us look a little more closely at the changes with some of the arable crops. The most striking is the great increase in acreage of cereals, particularly of barley for cattle feed. The acreage of wheat changes little and of oats steadily diminishes. The total replacement of farm horses by tractors accounts for the diminishing oat crop and has released for other purposes at least 1 million acres that before the Second World War produced fodder for horses. Cereal-growing has become an intensive and specialist activity, with barley crops being taken with a frequency that shocks those brought up in the traditions of the Norfolk Four-Course Rotation or of the ley-farming school.

Many reasons contribute to this emphasis on growing cereals. First, investment in equipment as costly as combine-harvesters and grain driers calls for using it to its maximum capacity. Secondly, with labour dear and scarce, a large acreage can be cropped with few workers. In this context it is worth commenting that many changes in farm practices that have increased production have been adopted less because farmers actively wanted to change than because they were forced to because of the cost or shortage of labour. Thirdly, the control of broad-leaved weeds by spraying with herbicides, which has made it possible to grow cereals without the need for 'cleaning crops' to be interposed as often as when the cereal crops yielded less but added much colour to the countryside with the blue, yellow and red flowers of their traditional weeds. Fourthly, the use of fertilizers, especially of nitrogen, has allowed yields to be maintained without recourse to traditional practices for restoring fertility. How slowly some experimental results get applied is strikingly shown by the fact that Lawes and Gilbert were giving wheat at Rothamsted 6 cwt of sulphate of ammonia per acre in 1843 and the benefits from doing so have been evident on Broadbalk field every year since, but such dressings have only recently become practice in England and very much less is given in most other countries. Many factors have contributed to this increased use of nitrogenous fertilizers, such as short-strawed varieties less liable than the older ones to lodge when fed generously, a greater awareness of the response to fertilizers, and a price ratio of grain to fertilizer larger than ever before. Fifthly, new varieties have been bred that not only lodge less but yield more than the older ones. Sixthly, the losses from some pests and diseases have been diminished, either by growing resistant varieties or by using insecticides or fungicides, mainly applied to the seed.

Official figures for average wheat yields changed little in the 50 years before the First World War, but since have nearly doubled. However, the averages stated are little more than half the 3 tons of grain per acre we often harvest at Rothamsted, which there is no reason to consider approaches the maximum possible, so there is obviously still great scope for further increase. Yields are now limited less by inadequate manuring than by pests and diseases, particularly soil-borne ones that are encouraged by the frequent growing of wheat and barley, and by the grassy weeds that are not readily controlled by herbicides. Soil-borne pests and diseases not only pose the largest threats to intensive cereal growing, but partly explain the great increase in barley acreage instead of wheat, because winter-sown wheat suffers more than spring-sown barley from such fungus diseases as take-all and eyespot, and on land where several barley crops can be taken in succession profitably, several wheat crops cannot.

The experimenter can readily demonstrate the effects of soil-borne pests and diseases by showing how greatly yields are increased when land is disinfested with a pesticide, or after their incidence is diminished by a period while cereals are not grown, but it would be vain to pretend that he has yet solved the problem for the specialist cereal grower. There is no practical method of soil fumigation that can be recommended for use on a field scale with crops such as cereals, and to recommend a suitable rotation of crops is useful only to those engaged in mixed farming. Beans (*Vicia faba*) are a 'break crop' suited to the equipment and skills of the specialist cereal grower; they are useful not only because they decrease the incidence of soil-borne cereal diseases but also because they leave a residue of fixed nitrogen, so that the succeeding cereal crop needs less fertilizer than it otherwise would. Although an increase in bean growing could also add usefully to protein production, the crop remains unpopular, perhaps partly because of uncertainties about the profitability but also partly because of what should be out-moded ideas about difficulties in dealing with weeds and remembrances of past failures from aphid attacks. The crop need no longer be dirty or call for much labour to keep clean, because weeds can be controlled simply by herbicides, and aphid attack can be prevented easily by one timely spray with a systemic insecticide.

The two reasons underlying the traditional practices of mixed farming, with its long rotations of crops or leys interspersed between arable crops, were to conserve nutrients and control soil-borne pests and diseases. An adequate supply of nutrients can now be better assured by fertilizers, but until there are practical methods for disinfesting soil, monoculture will remain a risky practice and crops can be expected to yield much less than their full potential. Glasshouse crops such as tomatoes vividly illustrate the point; they can be grown year after year and yield bountifully provided the soil is frequently disinfested by steaming or by appropriate chemicals, but not otherwise. However, these practices are too costly to apply profitably to field soils growing cereals, and what is urgently needed to safeguard the future of intensive cereal growing are either cheap and effective methods of partial soil-sterilization or systemic pesticides that could be sprayed over the crops and kill pests that feed below ground. These would also be of great value for other purposes, because cereals are far from being the only crops that suffer from soil-borne pests and diseases; also, even traditional crop rotations do not prevent losses from all soil-borne pests and diseases, some of which have wide host ranges and can attack many kinds of both crops and weeds.

The yields of other arable crops have increased in recent years no less than cereals. Whereas before 1939 yields of potatoes at Rothamsted averaged about 7 tons per acre, they are now usually at least twice this and, in 1965, the average yield for the country exceeded 10 tons. A main feature in this increase has been the improvement in the vigour of the crop by ensuring supplies of seed tubers free from the viruses that used to be prevalent and restrict yields. The general health of many horticultural crops that are also propagated vegetatively has similarly been increased by the introduction of health-certification schemes, such as that first operated for potatoes, whereby growers can obtain planting material free from debilitating viruses. Other features that have led to the larger potato yields are increased use of fertilizers, sprouting of seed before planting, better cultivations and weed control, fewer losses from blight, and irrigation. The urgent need with this crop now seems less to increase actual yields than to safeguard the tubers that are produced. Losses of tubers from damage during harvest, or when roughly treated afterwards, probably exceeds any yield increases that can be expected in the near future from other changes in practice, and a mechanical harvester that does not bruise the tubers would be the greatest boon to potato growers.

Sugar beet, a crop originally introduced into British agriculture mainly for strategic or political reasons, is now fully competitive with sugar cane. During the last 20 years average yields of roots have increased from 9 to 15 tons an acre, and the manner of dealing with the crop has so greatly changed that this much greater yield is produced by many fewer workers. From all being harvested by hand, nearly all is now harvested by machines, and increasingly the hand labour previously needed to thin the crop and hoe out weeds is being replaced by mechanical thinners and spraying with herbicides. Fertilizer use has greatly increased, nitrogen by five times and potash by four, the crop is sown earlier than previously, which means more leaves to photosynthesize in the long days of May and June, and many crops are irrigated during dry weather. Yield increases have also come by diminishing the losses caused by various pests, seed-borne fungi, and the aphid-borne beet yellows virus. In years when aphids were abundant, this virus was a major factor limiting yields, but many measures have recently been instituted to check its prevalence, including a scheme whereby growers are warned that aphids are active and that their crops should be treated with a systemic insecticide. However, the control of this disease is still imperfect, and crops on light land also suffer losses from some other pests and diseases that as yet cannot be prevented. Although yields have increased already so greatly, there are obviously still ample opportunities for them to increase much further.

The crop that has changed least is the one that occupies by far the largest area in Britain, grass. This is not for lack of knowledge, for the increased yields produced by use of fertilizers, selective herbicides and irrigation have not only been fully demonstrated in experiments but are obtained by some dairy farmers growing leys for silage. Grass responds more than any other crop to nitrogen fertilizers and uses them more completely, yet much of the 12 million acres of permanent pasture gets little or none. It is to this area of Great Britain that we must look for any great increases in production by increased use of fertilizers, because the average amounts now used on arable crops are almost those indicated as the optimum by experiments.

Indeed, with arable crops the current need is less for more total fertilizer than for more discrimination in its use. Farmers tend to give a standard dressing, which saves thought and ensures against crop failure but does not necessarily produce the best results and often entails using fertilizers wastefully. Fertilizer requirement is not a fixed amount per acre for a given type of crop, but differs greatly according to circumstances and depends on previous cropping and manuring and the extent to which nutrients have been leached by winter rains. Unless allowances are made for these variable factors, fertilizers are likely to be wasted or less rewarding than they might be, with some fields getting more than they need to yield full crops and others getting less. Each year more of our pasture does get nitrogen in addition to the traditional lime and phosphate, but pasturalists tend to be more conservative than arable farmers and great changes are unlikely until they have greater confidence than at present that fertilizers can be used as profitably with pastures as with arable crops and until methods of conserving grass are greatly improved and cheapened. The limitations in development lie not in lack of knowledge about how to produce more grass, but in how to use it fully and profitably when it has been produced.

*The need for local research*

In most other industries a discovery made anywhere is likely to apply everywhere, but this is far from so in agriculture. The soils, climates and crops differ so greatly in different countries, and in different parts of some countries, that it is by no means certain that a practice proved beneficial in one place will be beneficial in another. Indeed, it may not only be useless but harmful. The basic principles of growing bountiful crops, of course, apply generally and can be simply stated as freedom from hunger and freedom from pestilence, but assuring these freedoms entails different practices in different places. To grow, plants need to be supplied with water, radiant energy, carbon dioxide and various elements, of which they need much more of some, such as nitrogen, potassium and phosphorus, than of others, such as manganese or boron, which indeed in large amounts are toxic to plants. To be fertile, soils need to contain all these elements in forms obtainable by plants, but none in harmful amounts, and not to be too acid or alkaline. Different plants differ in their ability to tolerate drought or acidity, in the amounts of the individual elements they need and in the range of temperature in which they can grow or survive. Such differences determine the different natural floras that develop in different places, with each species occurring not necessarily where conditions most favour it but where it can do better than other competing species. In natural conditions, the essential elements come from the weathering of rocks and they are continually recycled, returning to the soil when leaves fall or plants die, where micro-organisms change them back into forms again usable by plants. In these conditions, nutrient elements brought up by roots deep in the ground tend to accumulate in and enrich the top soil, so that although virgin land rarely contains nutrients in the amounts agricultural crops need to yield fully, when first cleared it is usually moderately fertile. However, its store of nutrients can soon be exhausted, often less by what is removed in the crops that are grown than by leaching or erosion when the top soil is exposed to heavy rain, processes that accelerate with continued cultivation as successive crops become thinner because the soil becomes increasingly impoverished. Hence the systems of shifting cultivation, exploiting and destroying natural fertility, that have in so many places justified the foresters' complaint that subsistence agriculture means cutting down wealth to sow poverty. The waste and inefficiency of exploitive agriculture were unavoidable until the principles of plant nutrition and of the conservation of fertility were discovered, but still continue long after these discoveries and the development of the fertilizer industry have made it possible, not only to maintain, but to increase intrinsic fertility. Fertilizers free agriculture from the limitations imposed by the natural compositions of soils, for they allow deficiencies of specific elements to be made good and elements to be given as required by the particular crop and soil. To do this, though, requires knowledge not only of general principles but of local conditions, which demands local experimentation to discover the requirements of individual crops and what nutrients or other factors are limiting yields.

Many of the soils in tropical countries are old, greatly weathered and deficient in plant nutrients, so responses to fertilizers can be expected to be even greater than in temperate countries. That they can be large has often been abundantly demonstrated, but there are also many reports of failures to increase yields by fertilizers. However, these reports usually come from experiments that made no attempt to identify the primary factors limiting yield, and were empirical tests of simple practices found beneficial elsewhere. The failure to improve a poor crop by giving a major nutrient such as nitrogen is usually no evidence that the crop did not need the nitrogen, but rather that some other factor—for example, greater lack of some other essential element—drought, acidity or some pest or disease—was preventing the crop from using the nitrogen. Such failures have no significance in deciding the nutritional requirements of a bountiful crop, but there is a significant conclusion to be drawn from them. It is that, although any general practice of fertilizing tropical crops will increase total yields, it will also lead to waste because the fertilizer will be applied in many places where conditions prevent it from giving a response.

But local experiments are needed for other purposes than to determine correct fertilizer use. The best varieties, the best sowing dates and the best spacings, these and many other things must be determined locally. So, too, must the methods of controlling pests and diseases, because a practice that is effective in one environment may not be in another. In different parts of such a small country as the United Kingdom, for example, different spray regimes are needed to protect potato crops from blight; also, whereas removing virus-infected plants as soon as they can be identified can maintain and improve the health of potato stocks in the north and west, it is a useless practice in the south-east, where the aphids that transmit the common viruses are active before the infected plants show symptoms and virus spread can be checked only by killing the aphids with insecticides.

Many more experiments will be needed in most tropical countries before confident recommendations can be made about the precise practices likely to be most rewarding in improving the lot of those people now engaged in subsistence farming. Obviously, however, this can happen only as it has elsewhere, by increasing yields per unit area of land, if for no other reasons than that the amount of cultivable land is limited and only a small area can be cultivated with simple tools. In generalities, though not in detail, the needs are evident. Where drought is the limiting factor, irrigation is clearly the first requirement. However, it is only the first requirement, for plants do not live by water alone, and to install irrigation schemes without also taking other measures to increase yields is to reap only a small part of the benefit that could derive from the water. As there is little benefit from irrigating a crop that will largely be eaten by pests, so there is none from giving fertilizers to one destined to die from drought. Practices that increase yields need to be combined, when the reward from each is likely to be much greater than when each is used alone.

Where drought is not a limiting factor, productivity of the subsistence farmer could probably first be increased by measures that entail neither extra skill nor work by him, such as providing him with seed of better varieties than his traditional ones and treated with chemicals to protect against seed-borne fungi and soil-borne pests. The next needs, more costly and calling for new skills, and already argued amply, are for appropriate fertilizers and for pesticides to safeguard the growing crop. The only further point worth making on these two requirements is that, in countries where fertilizers and pesticides are scarce, they should be used intensively, on the most productive land, for if spread widely and thinly they will be largely wasted. A change in type of crops, too, might be valuable. With current scarcity of food and especially of protein, a move from cereals to pulses could be dietetically desirable and, by supplying seed inoculated with nitrogen-fixing bacteria, might help to enrich some impoverished soils. Increasing yields, however, will not greatly improve the lot of the subsistence farmer unless he can safeguard the larger harvest he reaps. Indeed, if there is any single measure that on its own could alleviate current food shortages, it is likely to be the better storage of what is already harvested, to save for the grower the vast amounts now eaten by vermin or spoiled by pests and diseases.

*Future prospects*

The fears of Malthus that human populations would outstrip food production have so far gone unrealized. Indeed, although the world is never free from hunger and famine, it is probable that a smaller proportion of today's very much larger population goes hungry than did in his time. They have not been realized for two main reasons: first, vast new areas of land have been brought under cultivation; secondly, productivity in some areas has been greatly increased, largely because of advances in chemistry, of which the most outstanding single contribution is the fixation of atmospheric nitrogen in forms usable by crops. Whether his fears will continue to go unrealized will depend on the wisdom of people and governments in deciding whether to apply the knowledge provided by science and technology. Obviously, with no new continents to exploit, population growth continued unrestricted must lead to widespread famine at some point, but modern methods of contraception allow the growth to be checked before it need reach this point, provided modern methods of farming are also introduced, which means radical changes in practice in some countries and the slaughter of many sacred cows.

Except for some cataclysm, demographers forecast that the population will double by the end of the century, which means doubling food production simply to maintain current nutritional standards and increasing it still further if everyone then is to get a properly balanced diet. If we restrict our considerations to the rest of this century, and hope by then population growth will slow, there seems no technical reason why this should not be done. During the last 30 years, yields have been more than doubled in some countries by methods that have yet to be applied at all extensively in countries where hunger most threatens. Thus, doubling production where it is most needed, calls less for any entirely new discoveries or any great extension in the area of land given over to farming, than for adapting to local conditions and applying methods already well established elsewhere. Although doing it has its scientific and technological problems, the greater ones are sociological and economic.

But the increased production need not be looked for only in regions where agriculture is still primitive, because even the largest current yields from modern methods still fall far short of the calculated potential possible from the amount of radiation intercepted by crops. This potential sets the limit to productivity and until it is achieved increases are still obtainable. The application of science to agriculture is a recent happening and although it has achieved much it would be vain to think that there are not many major discoveries yet to be made. Pesticides and weed-killers have been studied extensively only during the last 25 years, and there can be little doubt that much better ones than those now in use will be discovered. Also, although plant breeding has already amply proved its value, it is still only in its infancy and can confidently be expected to produce new varieties that are not only better than current ones in resisting attack by pests and diseases, but also make better use of incident radiation and turn a larger part of the total dry matter they produce into forms suitable as food for people or stock. Increasing knowledge about plant physiology, too, is likely to show what determines the distribution of dry matter between different plant parts and may indicate methods whereby it will be possible to increase the ratio of grain to straw in cereals, or tuber to haulm in such crops as the potato. But methods will also be found of making use of plant parts that are now largely wasted, such as turning barley straw, by adding simple nitrogenous compounds, into a valuable feed for ruminants instead of simply a stomach filler. Protein supplements suitable for feeding people or non-ruminants could also be produced from leaves or by the culture of micro-organisms on various wastes and other media.

The amount of food needed by the year 2000 could almost certainly be met by applying methods already understood to the area of land now used to raise crops or stock, and greatly to the benefit of those now cultivating this land. There seems little need for such projects as putting large areas of cold countries under heated glasshouses or irrigating deserts with desalted sea-water, which may be technically possible but entail such large amounts of energy that their practicality is questionable. With energy coming from fossil fuels, obviously they could have no permanence and with energy derived from atomic power, the amount of radioactive wastes to be disposed of would be formidable. In this context of agriculture consuming energy, it is worth stressing that modern methods of intensive farming already entail living on capital reserves built up over the remote past. Science can do much, but it cannot work miracles; it cannot produce something from nothing and cannot take out of a system more than is put into it. For centuries, agricultural communities were self-sufficient systems, each living within its income of incident radiation transformed locally by the photosynthesis of existing plants into food and fuel for both people and animals. Modern methods have changed this: they make better use of the incoming radiation, but developments such as replacing draught animals and hand labour by machines, the use of fertilizers and pesticides, crop-drying and irrigation except where it is by gravity from stored rain-water, all entail introducing extra energy mostly derived from fossil fuels, the products of past photosynthesis. The capital reserves of fossil fuels are great and the amount used directly for agriculture is trivial compared to what is used for other purposes, but although ample to allow modern farming methods to meet the world's food needs in the near future, they are not inexhaustible and ultimately the world will again have to adjust itself to living within its energy income.

Meanwhile, their use for whatever direct purpose is likely to affect agriculture indirectly in two ways, one harmful, the other beneficial. The harm will probably be local, where the use of the fuels pollutes the air with substances toxic to plants. The benefit will be general by increasing the concentration of carbon dioxide in the air. During periods of bright light, the factor now limiting photosynthesis is the amount of carbon dioxide, and increases in light intensity increase transpiration without a compensating benefit by increasing the amount of dry matter produced. By the end of this century, things promise to be different and the extra carbon dioxide there will then be in the air may allow healthy and well-fed plants to produce a fifth more dry matter than they do today.