Soils, Land and Food

Managing the land during the twenty-first century

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Prospects and uncertainties

11.1 POPULATION AND FOOD PRODUCTION

On 2 January 2000 the *Sunday Times* of London carried an article that included the following sentence: 'Some of the most intense debates of the coming century will be about ensuring, amid an exciting and empowering technological revolution, that we do not destroy our environment or forget the legions of the poor'. Within these 'intense debates' there is the issue of food production for a world population which is thought likely to increase by about 50 per cent to about nine billion by the middle of the century.

As shown in Chapter 9, food production in many developing countries will need to double, or more, to meet the demands of a larger population and improve dietary levels. Using more land and raising average yields of arable crops can both be used towards achieving the required production. Crucial questions are whether the increase will be sufficient and can be sustained, and whether there will be irreparable damage to the environment. First to be considered are the reasons for optimism that food production will be sufficient.

At a time when the population of England was increasing, Malthus (1798) postulated that population would outstrip food supplies and people would starve. History has shown otherwise; in the two centuries since, the world population has risen from around one billion to six billion and, although some severe local food shortages have occurred, still occur and seem likely to continue because of poverty, war, drought and floods, most of the extra five billion people are not short of food, for two reasons: more land has been cultivated and technological applications have raised yields (Grigg, 1993; Alexandratos, 1995; Evans, 1998). Much of the discussion in earlier chapters has been on the effect of these two factors, and especially of the technological changes associated with intensification.

Population and technology

Probably the most important reasons for the failure of the Malthusian theory are that it did not foresee the large increase in cultivated area in North America and elsewhere, the effect of population increase on technological change or the developments in the biological and physical sciences. In recent decades the development of modern birth control techniques and greater affluence in developed countries have reduced the size of families, a change that has in some countries been prompted by individual choice, and in others by national policy to control population growth. In agriculture the techniques put together in the Green Revolution (and before) provided food for the burgeoning population of the twentieth century. A larger population creates a bigger infrastructure (roads, schools, etc.), and employs more skilled workers and research and advisory staff. These and several other changes discussed by Boserup (1981, 1985) have lowered birth rates and helped to increase food production to satisfy the increased economic demand.

Application of technologies depends on the local conditions and adoption by the farmer. For example, to attain large yields a high-yielding crop variety needs to be adapted to the conditions of day-length and temperature where it is to be grown, and usually requires good cultivations, the application of fertilizers, and often also of pesticides, and water by irrigation. The principles for attaining large yields are known, as are the techniques that can be applied at specific locations, whether these be water conservation, drainage of irrigated land, addition of nutrients and their management, liming, erosion control, or more general techniques of land management. In all this the crucial person is the farmer.

Adoption of a new technology by a farmer depends on his assessing that it will lead to a reliable profit, for which he requires access to markets where the value of his extra production is greater than the costs of his extra inputs. How he can obtain a profit, and sometimes whether one can be obtained at all, depends on the local physical, biological and socio-economic conditions (Table 11.1). It is the wide range in these conditions that gives the great variety of farming systems of the world.

A farmer makes his decisions according to the local conditions, but some generalizations can be valid. For example, to raise production

Table 11.1. *Four economic and social conditions ('the four I's') for agricultural development*

(1)	*Incentive for the farmer*: profit on investment from the sale of products, requiring markets and access to them, and a reliable supply of inputs and their efficient use
(2)	*Information*: passed from research and extension workers to farmers by way of demonstration plots, radio, leaflets, etc.; also, costs of inputs, expected market prices for products and opportunities for co-operatives
(3)	*Investment*: national or other sources of investment in the infrastructure, including schools, institutes for training farmers, universities, hospitals, roads/railways and food storage facilities; price support for inputs and products
(4)	*Innovation*: techniques from research institutes and universities and from other countries to improve efficiency of use of inputs; new crops and crop varieties; alternative farming systems

the Chinese farmer uses the same inputs on his small paddy as are used for large-scale rice production in California, although he uses more labour and has less scope for mechanization – so 'Chinese agriculture will always show Chinese characteristics' (Xu Guohua, 1991). His inputs may include fertilizers, irrigation water, pesticides and modern crop varieties. With other farming systems not all these inputs may be needed, or indeed be available or economic to use, but the principle of raising yields by managing one or more of these inputs, or their alternatives, is a general one (see discussion in earlier chapters).

Population and economics

Generalizations can also be made about the economic conditions for agricultural development. Although they have not been discussed in detail they were referred to in relation to agricultural development in England (Chapter 8), where the conditions are well documented. They are summarized in Table 11.1. An outline of the much debated macroeconomic policies for agricultural development is given in Section 11.4.

The conditions that are usually required for development are now being met to a varying degree in many developing countries, although not all follow the same pattern. Two examples discussed in Chapter 8 – Machakos in Kenya and maize development in Zimbabwe – were driven by groups of farmers. Two different schemes were irrigation in the

Sudan Gezira (Chapter 8), which was the product of the colonial policy of the British government, and secondly, the growth of rice production in China since the middle of the twentieth century (Chapter 10), which was largely determined by the actions of the national government. Viewed retrospectively, in the examples referred to, and others, agricultural production has met the increasing demand when farmers were able to make their own management decisions and the four economic/social conditions (Table 11.1) were in place. It seems safe to assume that the same requirements will apply in the future if there are customers able to pay for the produce.

11.2 IMPLICATIONS OF THE CHOICE: MORE LAND OR LARGER YIELDS?

Until around the middle of the twentieth century agricultural production in the world was increased to a large extent by cultivating more land. Urban spread, degradation of land, particularly by erosion, and protected ecosystems and leisure areas have, on balance, stopped the expansion worldwide (Chapter 9): in 1998 the harvested area of all cereals in the world (700 Mha) was the same as in 1970. More land is being brought into cultivation in the more sparsely populated parts of Africa and South and Central America, where there is potential for expansion. Less is being used in China, where there is urban spread and little potential for expansion, and also in some European countries, where it is cheaper to import food than to grow it.

Raising yields

Annual crop yields can be increased by raising yields per harvest and by increasing the number of harvests per year (cropping intensity) averaged over a rotation (see Section 9.5). With irrigation two or three crops can be harvested each year from the same land, but where there is a bare or bush fallow in the rotation the cropping intensity is very much lower.

Yield per harvest depends on three factors, discussed in earlier chapters: (i) the potential of the crop, (ii) the potential of the site, and (iii) the level of management. Modern, short-strawed varieties of cereals have raised the crop potential by increasing the harvest index (grain biomass/crop biomass) and their resistance to lodging when receiving applications of nitrogen fertilizer. The site potential includes the depth and physical, chemical and biological properties of the soil, and climate (the amount and seasonal distribution of rainfall, temperature, solar radiation and day-length), and water for irrigation. Management includes cultivations to prepare the seedbed (or wet land for rice plants), timely planting of seed, application of fertilizer, water conservation or application of water for irrigated crops, and control of weeds, insect pests and disease, requirements discussed in Chapters 4, 6, 7 and 9. The farmer's aim is to achieve the most profitable yield at the least risk, which depends on the economic conditions at the time and his experience of risks.

Although more land will probably be brought into agricultural use (mainly in sub-Saharan Africa and South and Central America) the general trend, as in the past, is towards increased yields (see Chapters 9 and 10). This trend will become more pronounced as less land becomes available and natural (and semi-natural) ecosystems receive more protection. The intensification that is needed to raise yields in developing countries requires the same environmental monitoring of food and water that is used in developed countries to ensure their safety and to avoid damage to the environment (see Section 9.8).

11.3 PROTECTING THE ENVIRONMENT

As a component of the environment, land, and particularly soils, have important functions that affect the environment. The most obvious function of soils is that they support plant growth. They are also the medium in which leaf litter and other plant residues are decomposed so that they sustain the recycling process for nitrogen and other mineral nutrients and carbon.

Soils both hold water against gravity and reduce its rate of flow into streams and rivers, thereby reducing the risk of floods, particularly flash floods. They buffer changes in temperature and changes in pH, creating better conditions for soil-inhabiting organisms and plants. They are effective ion exchangers, at least for cations, which allows them to hold and provide ammonium, potassium, magnesium, calcium and other cations to plant roots; they absorb many organic substances, including pesticides. Over the Earth's surface soils differ considerably, however, in their properties and hence in their effectiveness as environmental filters and buffers. Further, they leak nitrate, aluminium when acidic, and phosphate when overloaded with phosphate from organic and inorganic manures. These environmental functions of soils have been discussed by Wild (1993). Their influence on the composition of the atmosphere is discussed below (Section 11.4).

Soil quality and soil health

These two terms came into use during the 1980s in recognition of the need to show that soil functions both as a component of the environment and as the medium in which crop plants are grown. There have been several definitions of the terms. The broad definition of Karlen *et al.* (1997) of soil quality is: 'the fitness of a specific kind of soil to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation'. Definitions of soil health give more emphasis to the biological properties of soils, although the two terms are often used interchangeably. For example, 'Soil health is the continued capacity of soil to function as a living system, with ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments and maintain plant, animal and human health' (Doran and Safley, 1997).

Essential when using these terms is to state the intended use of the soil and its physical and economic environment. For example, a soil rich in nutrients may have a high rating to grow grass cut for silage, but a low rating as a natural ecosystem because it would contain few plant species. Several publications discuss the concepts and applications of soil quality and soil health, and how soils might be rated (e.g. National Research Council, 1993b; Doran *et al.*, 1994, 1996; Carter *et al.*, 1997; Gregorich and Carter, 1997; Pankhurst *et al.*, 1997; Huang, 1998; Pierzynski *et al.*, 2000).

Protecting land and soil

The history of land use emphasizes all too clearly that we should not be complacent about future development. About 1200 Mha of land in the world is described as moderately to excessively degraded, mainly by erosion (see Chapter 5). The area is greater than that of the USA. The proportion from agricultural activities, as distinct from natural soil erosion, is uncertain because the two are interlinked, but it is probably well over half. The land can generally be protected from erosion, and good management prevents physical and chemical degradation (Chapter 5). Before new land is brought into cultivation the risk of erosion and salinization needs to be assessed (from land surveys) and appropriate action taken.

Protecting natural and semi-natural ecosystems

There are two separate issues. Firstly, there is concern that ecosystems should be conserved for utilitarian and ethical reasons; utilitarian because they may contain organisms, or are themselves, useful to man, and ethical because we should be guardians of our heritage and avoid the extinction of species.

The utilitarian argument is usually more persuasive. Two early examples of benefits to man are quinine from the bark of the cinchona tree, a native of South America, that was used to treat malaria, and the antibiotic streptomycin derived from the soil bacterium *Streptomyces coccus*. More recent examples are given by Beattie and Ehrlich (2001). Many ecosystems, however, have not been investigated, large numbers of species have not been identified and, for example, the ecology of organisms involved in the decomposition of leaf litter and in soils is poorly understood. It would be foolish to destroy what might prove to be of value. Further, whole ecosystems are of economic value in reducing the rate of runoff of rain water, as discussed above, and many attract tourists who bring foreign currency and create opportunities for employment.

The second issue is the function of natural ecosystems, particularly of forested land, in the carbon cycle between land and the atmosphere. FAO estimates that gross deforestation in the tropics was about 15 Mha per year between 1980 and 1990 (Alexandratos, 1995). Globally, 56 Mha of forest were lost between 1990 and 1995, the greatest loss occurring in Latin America, at a rate of 5.8 Mha per year between 1990 and 1995 (GEO-2000, 1999). The significance of the carbon cycle to climate change is discussed below (Section 11.4).

In regions where the number of people is increasing and land is available and cheap it will be used to produce food. Ecosystems and their range of species (biodiversity) are therefore at risk of destruction. 'Settlement for agriculture is the main cause of extinctions, because fragmentation, habitat loss, introductions, and hunting all follow from this' (Tinker, 1997). These effects of the use of more land for agriculture can be made less if annual yields are increased.

11.4 UNCERTAINTIES IN MEETING FUTURE FOOD REQUIREMENTS

Since its beginnings about 10 000 years ago agriculture has changed by adaptation to the prevailing conditions of the land (climate, terrain and soil) and to social and economic demands. When it has failed to adapt, especially to climate change, civilizations have collapsed. The early civilizations of the Indus valley, the city states of Sumer in southern Mesopotamia and probably the Mayan civilization of Central America are examples (see Chapter 3).

More commonly agriculture evolved to provide food, fibre and animal products such as wool and leather for local use and trade. Production increased as the human population increased, in earlier periods largely by increasing the area of land devoted to agriculture and later, particularly in the latter half of the twentieth century when the world population increased from 2.5 billion to six billion, largely by raising yields. Uncertainties in the future are how agriculture will adapt to changed conditions in this century, and centre around four issues: (i) the size of the increase in population in regions and individual countries; (ii) the effect of climate change; (iii) the resources (water, soils, crop varieties and inputs including energy, fertilizer and pest control) required for greater production; and (iv) the macroeconomic conditions.

Increase in and distribution of population

The population of a country is measured by a census. The numbers may themselves be unreliable, but a greater uncertainty in the future is the rate at which the fertility (birth) rate will change. The general trend is downward: the world average of children per woman was around 5.0 in 1955–1960 and 2.9 in 1990–1995. If the rate falls by 2050 to 2.6 (high variant), 2.1 (medium variant) or 1.6 (low variant) the population increase from 1995 will be 5.0 billion, 3.2 billion and 1.7 billion, respectively. The corresponding increases by 2025 are 2.7 billion, 2.2 billion and 1.6 billion (Fischer and Heilig, 1997; United Nations, 1999). These numbers will become more accurate as the trends of fertility and increased life expectancy become better established and the effect of pandemics such as AIDS is better known.

Almost certain is that the biggest increase in population by 2050 will be in India, followed by China, Nigeria, Pakistan and Ethiopia which, with several others, have been classified by FAO as developing countries. It is in developing countries where increases in food production will need to be substantial (see Chapters 9 and 10). However, developing countries differ considerably in population, density of population, and natural resources. In China, for example, the birth rate has fallen rapidly so that the population is predicted to be almost stable by

2025, whereas in Nigeria it will increase rapidly to over 300 million by 2050 and probably continue to increase.

Developing countries also differ in size, urbanization, development of infrastructure, gross national production per capita, and natural resources (including actual and potential agricultural land per capita). Agricultural development to meet the needs of increasing populations must therefore take account of the conditions in individual countries, a requirement that is outside the scope of this book. Two generalizations can be made, however: (i) that more land can be used for agriculture, particularly in sub-Saharan Africa and South and Central America, and (ii) that in these regions and throughout the developing world there is a need to increase annual yields of crops.

Climate change

Much has been written about climate change, its causes and its effects (e.g. Bolin *et al.*, 1986; Bouwman, 1990; Scharpenseel *et al.*, 1990; Rounsevell and Loveland, 1994; American Society of Agronomy, 1995; Houghton, 1997; Lal *et al.*, 1999; IPCC, 2001a,b; O'Neill *et al.*, 2001). The account that follows, which relates only to the changes that might affect agricultural production in the future, is based mainly on Houghton (1997), IPCC (2001a,b) and Fischer *et al.* (2001). Four changes are predicted to affect agricultural production: increased temperature, increased concentration of carbon dioxide in the atmosphere, changes to the geographical distribution and intensity of rainfall, and a rise in sea level.

The projected rise of globally averaged surface temperature during this century is in the range 1.4–5.8 °C (IPCC, 2001a). This temperature rise will be uneven over the Earth's surface, being greatest at northern latitudes and less pronounced at lower latitudes. The temperature increase may shift the northern limit of arable agriculture 500–1000 km northwards. Problems from pests and diseases of crops are expected to increase as the temperature rises.

A rise in temperature will increase evaporation of water from the sea, soils and plants. The hydrological cycle will become more intense, causing more rainfall and more erosive rainstorms. The change in rainfall will vary, however: mid-latitude regions, which generally have low rainfall at present, are predicted to receive less in the future, and high latitudes to receive more in winter. The models on which these predictions are based are not sufficiently refined to predict the size of the change, the rate of change or the changes over small regions. The effects of the change in rainfall on agricultural production in individual countries are therefore uncertain, but some regions are likely to be at risk of lower production because of more frequent droughts while elsewhere crops may be damaged by more floods.

Increased concentrations of carbon dioxide increase photosynthesis. The growth response of C3 plants (wheat, rice, barley, soybean) is greater than that of C4 plants (maize, sorghum, millets, sugar-cane). The response varies with temperature and other environmental conditions, and also differs between species, but growth response and crop yield can be expected to increase.

The fourth effect of climate change is a rise in sea level, which is predicted to be 5 mm per year with a range of uncertainty of 2–9 mm per year. The rise relative to the land surface depends on the local rise or fall of the land itself; for example, in the two areas likely to be most affected – Bangladesh and the Nile delta – land subsidence is predicted to be 0.7 m and 1 m, respectively, by 2050 (Houghton, 1997), compared with an average rise in sea level of 0.25 m over the same period. Other low-lying areas in Europe and elsewhere will lose land, and some of the low-lying islands and coral atolls of the Indian and Pacific oceans may be lost entirely. Inland intrusion of salt water will also affect more land.

Based on one model of climate change, Fischer *et al.* (2001) have assessed its quantitative impact on the production of cereals. Of the major producers, production will increase in Canada and Russia and decrease in France, the Ukraine and the USA, resulting in little change in the world as a whole. In Africa, Kenya and South Africa will benefit but several other countries, including Angola, Cote d'Ivoire, Sudan and Tanzania, will lose production. Elsewhere, China will benefit in its northern region whereas India will lose some of its rainfed production. It should be noted that there are several models of climate change, each of which may give different quantitative changes of cereal production. However, the global distribution of changes in temperature and rainfall referred to above are generally accepted.

Summary

Of the four effects of climate change, increase in temperature will probably shift the northern limit of arable agriculture in the northern hemisphere and increase the risk of flooding in low-lying areas at high latitudes. In mid-latitudes droughts are expected to become more common. Increase in atmospheric carbon dioxide, considered to be the main cause of climate change, will probably increase crop yields, although it is not yet known to what extent. In the world as a whole agricultural output might not be affected, with some countries producing more and others less; the losers are expected to be countries that currently have a low rainfall.

Available resources

The requirements for resources have been discussed earlier: land in Chapter 9 and Section 11.2, fertilizers in Chapter 6, and water in Chapters 2 and 7. Mineral reserves in the world are likely to be adequate for the manufacture of phosphate and potassium fertilizers to meet the expected demand during this century, and for urea the only eventual limit to its manufacture might be a source of cheap energy. Availability of water and productive land is another matter. Shortage of water for arable and tree crops and pastures is probably the biggest biological and physical limitation to agricultural development in developing countries. Rainfall can be conserved by reducing runoff (see Chapters 5 and 7) and irrigation can usually be made more efficient (see Chapter 7), but several countries depend on supplies from rivers that cross country boundaries, creating the difficulty of having to reach international agreements on water use. As mentioned above, supplies of water may become less or greater as a result of climate change.

Finally, areas of land that might be developed for agriculture are known at least approximately (see Chapter 9). Much more needs to be known, however, from soil surveys and pilot experiments of land's potential for agricultural production in both the short and long term. Assessment is also needed of the risk of degradation of the land, particularly by erosion, and of the inputs that will be required.

Macroeconomic conditions

To be successful, agricultural development requires both the application of technology and favourable economic conditions. Neither is successful without the other. Most of this book has concerned itself with technological developments, with some reference to local social and economic conditions (see Chapter 8 and Table 11.1). A few comments are also needed on national and international economic policies that affect agricultural development and particularly international trade.

Governments of most countries provide support for agriculture directly, as subsidies on inputs, guaranteed prices of products or cheap loans, or indirectly, by providing infrastructure including roads, railways, electricity, grain storage, etc. and financing research and extension work. They may also finance the building of water storage dams, the development of irrigation and other settlement schemes and the reclamation of degraded land. This support, which is provided to a different extent in individual countries, is justified by the benefits from the production of food and fibre for internal use or export.

The support provided in Europe, North America and elsewhere in developed countries has often changed as economic conditions have changed. The requirements for government support in developing countries are the same, but with rapidly rising populations they need to be flexible. The difficulties of many of the countries are made more severe by the limitations of their natural and financial resources.

Since the second half of the twentieth century the means of stimulating agricultural growth in developing countries has been debated by economists concerned with the possibility of industrialisation, the effects of international loans, taxation policies, responsibilities of governments and other issues (Alexandratos, 1995). There is no single requirement, but rather a package is needed comparable to that of technological inputs in the Green Revolution, which will differ between countries. The economic requirements include 'price stability, a competitive exchange rate, and an interest rate that reflects the balance between credit and savings' (Alexandratos, 1995).

One uncertainty in the future for each developing country is its exchange rate on the international money market, which sets a limit to imports and exports if a long-term balance is to be achieved. Countries importing cereals depend largely on exports from North America and to a lesser extent on those from Australia and Europe. Apart from the exchange rate, the cost of imported food depends on the surplus available from the producer countries, which is affected by drought, the level of price support, and the amount held in storage. The conclusion must be that developing countries with limited scope for exports, or for generation of foreign currency by such means as tourism, should, where possible, aim for self-sufficiency in food production, thereby reducing their dependence on the uncertain cost of imports.

11.5 SUMMARY

(1) Among the few certainties of the future is the substantial increase in the world population. Most of the increase will be in countries classified by FAO as developing, with the largest absolute increases

projected for India and China and the largest growth rates for Africa. The challenge that lies ahead is to provide sufficient food for this burgeoning population by increasing agricultural production in the developing countries themselves. Some may be able to import it from the few countries that can produce a surplus over their own requirements. The greater agricultural output will need to be sustained throughout the twenty-first century and probably beyond.

(2) The countries classified as developing vary greatly in size, land, climate and human resources, and in extent of economic development. The requirements for agricultural development must therefore be based on the specific conditions in each country.

(3) Production of cereals, the main component of the human diet and considered here as an index of agricultural production, can be increased by raising annual yields or by increasing the area of land under cultivation each year. Since 1970 production in developing countries as a whole has been increased by both means (see Table 9.2). In Africa (omitting Egypt and South Africa) increased area has contributed more than increased yield. By contrast, in India there has been little increase in area and in China the area has decreased, production being raised in both countries by larger yield. It seems probable that these trends will continue. In many African countries poverty and slow economic development may limit the increase in food production.

(4) Estimates of unused land that might be taken into production have been made by FAO, although the potential yields and the sustainability of production are not known. This area of land, assuming average yields, will become insufficient to meet the food requirements of the projected population of developing countries if calorie intake is increased and the trend towards the increased consumption of animal products continues (see Section 9.4). Where it is available and cheap more land will be used, but in most countries, and probably all developing ones, higher yields will be needed sooner or later. As a corollary, the less land that is used, the greater the protection of natural ecosystems and the less will be the area of land at risk of degradation.

(5) Annual yields per unit of land area can be increased by larger harvests per crop and by growing more than one crop per year. Appropriate techniques depend on the local physical, biological and economic conditions and especially on an incentive for the farmer. Insufficient or unreliable rainfall, and drought in particular, will

however limit production in several parts of the developing world, making periodic food shortages inevitable.

(6) Uncertainties in the future include (i) the populations of individual countries in the next 25–50 years, which will depend mainly on the rate of fall of birth rates (which cannot be predicted with any certainty); (ii) effects of climate change, which at present lack precision for individual countries; (iii) the extent of support for agriculture by the state, international organizations and non-governmental organizations; and (iv) the exchange rate between countries, which affects trade and thereby affects decisions about whether to aim for self-sufficiency in food production or import food against exports.

(7) There are strong indications that most developing countries have the potential to provide sufficient food for their people if water is available, the land is properly managed, inputs are used efficiently and crop varieties with higher yield potential are developed. However, shortages can be expected in countries subject to droughts. The farmer is the key figure, but it usually requires all four essentials listed in Table 11.1 for production to be increased.

(8) The extra production resulting from the Green Revolution helped to feed the increased population of the second half of the twentieth century. It is predicted that in some countries populations will continue to increase until the middle of this century and beyond. It is therefore necessary for increased production to be sustainable. The history of land degradation (see Chapter 5) shows that sustainability should not be assumed. Land should be surveyed, risks assessed and any protective measures put in place before it is brought into cultivation. Soils should be monitored to detect signs of erosion, acidification, organic matter and nutrient depletion and, where relevant, salinization.

(9) Under-pinning agricultural development are economic requirements. They include investment in the infrastructure and technological developments that come from research and the extension of these to farmers. The research should aim to improve our understanding of the long-term effects of farming systems on the environment (and on soil fertility in particular) that might find application to the farmer, and should include testing of innovations by field experiments on research stations and on farmers' fields by farmers themselves. To ensure sustainability of farming systems it will be necessary for some field experiments to be

continued for several years. These requirements depend on there being a base of general economic development.

(10) Finally, since the beginnings of agriculture about 10 000 years ago it has evolved to suit local environmental conditions. When soils became unproductive farmers moved on or let the land rest under a long fallow before using it again. In the future food production will depend increasingly on raising and sustaining annual yields.

We now know how to make soils more productive and how to keep them productive. The more we understand about soil properties and processes in a given environment, and apply what we know, the more certain it becomes that the land will support the greater agricultural output which will be required by the increased population of the twenty-first century.