Land Transformation in Agriculture
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CHAPTER 2
Agricultural Land Use in Space and Time

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2.1 THE WORLD LAND AREA AND ITS USE

The land area of our planet is 14.9 billion hectares. This is 29% of the earth's surface, 71% being water. A part of the land area (1.4 billion hectares) is permanently covered by ice. Consequently 13.4 billion hectares is used as arable land, grassland or forests (Table 2.1).

A considerable part of this land area is used for growing food for human beings, feed for domestic and wild animals, biological raw materials for industrial and medical products, cooking, heating etc. Moreover land is used for other purposes such as housing and urban services, industries, mining, communications and recreation. Originally there was only natural vegetation with wild life and some people, who lived by food gathering and hunting, using some wood for shelter and cooking. About 10,000 years ago women began to manipulate nature by cultivating land in order to get more food and to be less dependent on what nature could supply. The number of people was gradually increasing, so more land had to be cultivated for growing food crops. Some natural grazing land was improved in order to get more food for an increasing number of domestic animals, and some cleared forest land was replanted with special tree varieties to provide for timber wood, fuel wood, wood for the paper industry, and so on. More land was needed for non-agricultural purposes, because of the ever-increasing world population, particularly during the last half century, when the population increased exponentially. There were about 165 million people in the year 0, 1 billion in 1820, 2 billion in 1930, 3 billion in 1960, 4 billion in 1976, and there will probably be 5 billion in 1988 and over 6 billion in the year 2000.

The most striking feature of the projected population growth is that the share of world population living in developing countries will increase from the present 72% to 87% in the year 2110, that is 9.1 billion out of the total of 10.5 billion. Within the developing world, differences in fertility levels and a decline of birth rates will entail a marked regional demographic diversity. The

Table 2.1 General land use of the world (FAO Production Yearbook, Vol. 32, 1978)

Category	1961–65 (Mha)	1977 (Mha)
Arable land	1 379	1 462
Grassland	3 054	3 058
Forest land	4 132	4 077
Other land	4 508	4 476
Totals	13 073	13 073

The category 'other land' is mainly land in polar regions, desert land, stony and rocky land in mountains.

stable population of various regions will be reached in different years, ranging from 2030 for Europe to 2110 for Africa. Proportionally, the largest increases are expected in Africa (fivefold) and in southern Asia (threefold)—in the latter case, however, from a much larger 1980 base. Africa and southern Asia together, with 6.3 billion people, will account for over 60% of the world's total population at the time of stabilization (Salas, 1981).

It is evident that the transformation of land with a natural vegetation into arable and grazing land has become an important subject for discussion.

2.2 FUNDAMENTAL ISSUES

Before we begin the discussion of land transformation, some initial comments are needed:

(1) The figures quoted in this chapter are based on the best statistical data. However, these figures are often approximations or estimations, because there are no exact and accurate figures for many countries.
(2) Some figures are over-estimated (for example, because they are published in order to get more foreign aid), while some are under-estimated (data on yields of the main food crops in some countries are at least 10–15% under-estimated, for example).
(3) Figures are often averages (for example, those of yields per hectare). Such averages hardly occur in practice.
(4) The definitions of many words are different in various publications. For example, *desertification* is an expression that sometimes refers to a gradual drying out of land, but sometimes it is also used to refer to all land that is degraded to such an extent that it has become useless for agricultural production (through soil erosion, salinization etc.).
(5) The figures presented here are from various publications (mainly FAO and other international and national organizations). It is, however,

impossible to mention them all, so reference is made only to those articles and books that are relevant and which present more details and references for further studies.

There are four main categories of land use:

Arable land is cultivated and used to grow annual and perennial crops. The main crops are food crops, in particular cereal grains (wheat, maize, rice, etc.). The average yields are rather low in many countries and high in a few countries. This is the result of various modes of production. In many countries the technology applied in growing crops is still low; in some industrialized countries the level of technology is high. It has to be realized that only a rather small proportion of the land area is suitable for growing crops, because of various limiting factors to be dealt with later in this chapter. Moreover, the productive capacity of land suitable for growing crops is very variable, even if the most appropriate technology is applied. Each crop has its specific conditions for optimal growth, and although these conditions can be influenced by various management practices, the ecological conditions remain different all over the world. It is therefore worth while to study land use potentials for various crops.

Grassland is where annual and perennial grasses grow. It may be natural grazing land, where herds of domestic animals or only wild animals are grazing, but it also includes pastures with specific species of grasses that are grown with technological inputs. This indicates a high variability in feed production and use intensity. It is estimated that only a very small proportion (5%) is used rather intensively. Most land in this category produces according to the rules of nature.

Forest land includes all land where trees are growing. Here, too, the intensity of growth is very variable: there are very dense forests with high trees, but also land with only some trees where open spaces are covered by grasses. It is a matter of definition which land is grassland and which is forest land. In the densely populated, industrial countries most forests are artificial, the trees having been planted. However, in many countries forests are the result of natural growth influenced by the action of man, who cuts trees for timber, firewood or for paper factories. There are only a few plantations. Here, too, there is a wide variety in use potential, because there are thousands of tree varieties with different stands and different qualities for various applications.

Non-agricultural land is used for non-agricultural purposes. This category includes land for:

(a) housing and urban services (offices, churches, hospitals);
(b) industry (factories, storage buildings);
(c) mining (open mines, gravel pits, brickworks);

(d) man-made water reservoirs (for electricity, irrigation, drinking water);
(e) waste disposal (urban waste, old cars);
(f) communication (roads, railroads, airports);
(g) recreation (parks, sports grounds).

In very remote areas, where only farming families live and where there are only a few simple roads, the non-agricultural use of land is only a small proportion of the land used for agriculture. In densely populated countries the non-agricultural use of land has increased tremendously, particularly during the last few decades. As the world population is rapidly growing this category of land use will increase rapidly in the near future. One-half of the world's population will soon live in towns and big cities that have nuclei in areas with highly productive land; and it is particularly the land around these nuclei that is generally used for non-agricultural purposes.

The history of land use will not be discussed here, except for the last century during which most important transformations have taken place. There have been various stages of agricultural development in different countries. Such stages and the mode of production can still be observed and studied in various parts of the world. There are even now 200 million people applying the simplest modes of production (shifting cultivation). They clear a small area in the forest to grow some food crops for a few years. The natural productivity of this land decreases rapidly, and so the people have to move to another piece of forest land. About 15–20 ha of land are needed to feed one person. On the other hand there is land where three crops per year can be grown, which means that less than one twentieth of a hectare can produce food for one person.

The way man has used and is still using land is not very satisfactory. The productivity and use possibilities of large land areas have declined. Much land has gone out of production because it has been misused. Some land has been eroded, other land has become too saline and has finally been abandoned. There is land that has been degraded to such an extent that its present production capacity is only a fraction of what it could have been. On the other hand man has also developed new techniques to improve the productive capacity of land, for example by irrigation, drainage and reclamation. Unfortunately, though, misuse of land is still increasing and improvement of land is only a small fraction of what it could be. This problem will be dealt with in somewhat more detail in section 2.4.

The subject of agricultural land use cannot be understood without some technical knowledge of growing conditions of crops, including grasses and trees. The main factors determining the suitability and productivity of land are:

(1) *Crop characteristics*. Each crop has various stages of development, and in each stage it needs a specific amount of water and nutrient. It also needs a specific temperature and amount of oxygen.

(2) *Weather conditions*. There are important seasonal variations, particularly in precipitation.
(3) *Soil conditions*. These often vary over short distances. They are important for the development of an optimal root system, because the growing conditions of crops depend on the moisture, nutrient, biological, temperature, air and mineral regimes of a soil.
(4) *Mode of production*. A farmer can to a certain extent manipulate crop production (e.g. by preparing the seedbed, by using manure or chemical fertilizers, by weeding, by plant protection).

The way man can manipulate crop characteristics, weather and soil conditions will be dealt with in section 2.3. There are, however, a number of factors that can hardly be manipulated. The crop production constraints are given in Table 2.2.

Most important is the arable land, which produces almost all our food (92% on a dry-matter basis) except meat, milk etc. (7%) and fish (1%). Cereal grains are the most important crops (79%), followed by tuber crops (7%), sugar and other food crops (6%). The main cereals are wheat, rice and maize. Table 2.3 gives some figures for cereal grain crops and Table 2.4 for root and tuber crops.

Details on land use and crop production are published annually in the FAO Production Yearbooks. Figure 2.1 gives general information on changes in land use since the year 900.

The above technical information is needed to understand that there are

Table 2.2 Crop production constraints of the land area of the world

Constraint	Area (Mha)	Percentage
Ice-covered	1 490	10
Too cold	2 235	15
Too dry	2 533	17
Too steep	2 682	18
Too shallow	1 341	9
Too wet	596	4
Too poor	745	5
Subtotal	11 622	78
Weakly productive	1 937	13
Moderately productive	894	6
Highly productive	447	3
Subtotal	3 278	22
Totals	14 900	100

Table 2.3 World production, area harvested and average yield of cereal crops (data from FAO for the year 1978)

Crop	Area harvested (10^6 ha)	Production (10^6 t)	Average yield (t/ha)
Wheat	266	450	1.9
Rice (in husk)	145	386	2.7
Maize	118	364	3.1
Barley	94	194	2.1
Sorghum	52	69	1.3
Oats	28	51	1.8
Rye	16	32	2.0
Millet	55	36	0.7
Totals	774	1582	

various categories of land use and that there are various factors—such as weather and soil conditions and the ability of the cultivator of the land—that determine how land can be used. Much more important, however, are social, cultural, economic and political factors. They significantly influence not only the way in which land is used, but also how much is produced. Every farmer (all those who cultivate land are called farmers) uses land to provide a living for his family and relatives and members of the social unit to which he belongs.

Long ago almost everyone was directly or indirectly engaged in farming, and fewer than 10% were non-farming families. This can still be observed at the present time in some remote areas. In such a situation basic food crops have to be grown, if land is more suitable for other crops. Since the beginning of the eighteenth century, when industrialization gradually became an important factor in human life in Western Europe and North America, much has changed. More and more people found themselves in non-agricultural sectors for whom food had to be produced, so there was a development of trade and

Table 2.4 World production, area harvested and average yield of root and tuber crops (data from FAO for the year 1978 at 14% water content)

Crop	Area harvested (10^6 ha)	Production (10^6 t)	Average yield (t/ha)
Potatoes	18	55	2.9
Cassava	14	49	3.5
Sweet potatoes	13	34	2.6
Yams and others	4	7	1.8
Totals	49	145	

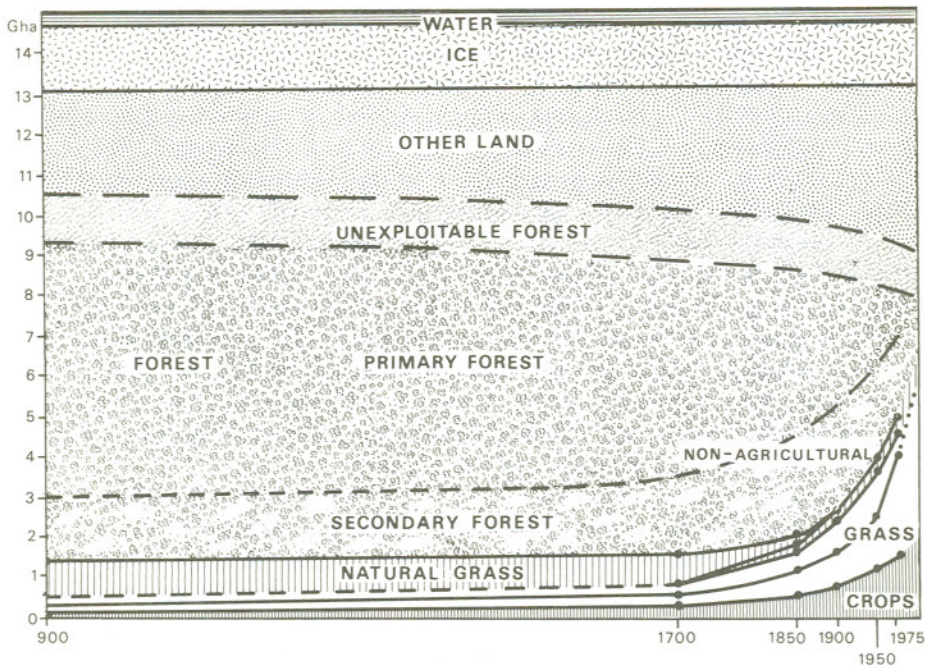

Figure 2.1 Transformation of land in the period 900–1977. Small differences cannot be shown at this scale. It is clear that most important transformations took place during the last 200 years.

of transport of products not only of industrial but also of agricultural products. The development of sciences and of techniques, the education of the people and many other factors have stimulated agricultural production. Most important for agriculture were probably, first, the introduction of ley-farming, which allowed a permanent use of arable land without fallow once in two or three years; later on the introduction of chemical fertilizers, which increased the production per hectare; and then the introduction of mechanization, which not only eased farmwork but also increased the land area for food production, because tractors were replacing horses, a farmer needs approximately one hectare of land to feed one horse.

Mechanization also meant that some tracts of land (e.g. land on rather steep slopes, or stony land) could not be cultivated any more and had to be abandoned. On the other hand, land that previously could not be used for agricultural production became suitable for it; for example, the introduction of the diesel motor made it possible to irrigate land which could not be irrigated before, when all water had to be lifted using simple tools.

As a result of the development of chemical technology some agricultural products like cotton, wool and rubber could be replaced by industrial products. This does not apply to food products.

One of the consequences of the development techniques to increase production has been a much greater diversification in value of land. At a high level of technology similar land can produce five to ten times more than when only a low level of technology is applied. In fact industrialization was in the beginning mainly based on agricultural raw materials (wool, cotton, dye crops, oil crops, flax, rubber, etc.). With the introduction of new means of transportation (railways, steamships) raw materials could be grown at large distances from the industrial centres. Refrigeration meant that products like fruits, vegetables, milk and butter could be transported over large distances. Such developments have had an important influence on land use throughout the world. India produced cotton, Australia wool, Argentina meat, etc., for people in other continents. These and other factors have stimulated agricultural production, land use and land use intensity.

From an economic point of view there is a difference in development of land use between densely populated countries (e.g. Western Europe) and those with much sparser populations (e.g. the USA), because of available labour and consequently labour costs. In Europe production per hectare is important, but in the USA production per man. In less than one century these countries, which once were agricultural, have been transformed into industrialized countries, where agriculture has become a less important sector of the economy.

Using land more intensively means more input of labour or capital or both. In a simple farming system only a few tools are used; but as soon as farming becomes more complicated and various types of technology are introduced, inputs from outside the farm are needed. A farmer needs money to buy these inputs and this money is earned by producing more with lower costs. Farming at the highest level of technology means more dependence on other parts of the economy, and on the availability of energy.

The subject is interesting not only historically or from the economics standpoint, but also from the point of view of land use, because it is evident that all changes in social, cultural, economic and political conditions have influenced the way land is being used. Many developments are hardly possible without the help of a government, particularly in the fields of research, education and extension in agriculture. Moreover, the governments of many countries interfere in the way land is used by land use planning, although this is not always done in favour of agriculture: in many countries this type of planning is done to guide the non-agricultural use of land.

In some countries it is now realized that planning of land use should include the protection of valuable, productive agricultural land, called 'prime land'. Another important factor is the regulation of prices of the main agricultural products by governments. If, for example, more sugar is needed, an increase in the price of sugar will stimulate the cultivation of sugar cane or beet. The price of the basic food crops is often rather low because governments want cheap food for the many poor people (developing countries) or for the labourers in industry (industrial countries) in order to promote the export of industrial products. In the USA the government provides incentives to farmers *not* to grow cereal crops, because of high surpluses of cereal grains; and in the United Kingdom the other West European countries farmers had to transform some pastural land into arable land during the Second World War.

The foregoing examples demonstrate the influence of government policies on land use. From time immemorial the ruling class has forced farmers to produce specific crops, to increase production, and to use land in a specific way.

It is a generally accepted idea in discussions of foreign aid for developing countries that these countries should at least try to produce the basic food crops they need on land in their own countries. This means that a large part of arable land has to be used for cereal grain crops. It is doubtful whether this is wise, because land—particularly in countries in the tropics—may be more suitable for growing products like cocoa, tea, rubber and other perennial crops, that cover the land surface permanently. If these products could be exchanged for foods produced in countries that are more suitable for growing these crops, much land in the world could be used in a better way.

It may be concluded that indeed it is farmers who use the land, but land use is heavily influenced from outside the agricultural sector, these influences being social, cultural, economic and political. Power may be in the hands of landlords, churches, the 'upper class', local or national governments or international organizations. All of these forces determine whether land is well used or misused today. It is, however, difficult to discover the reasons why land is used in a particular way in a specific area. It is certainly true, though, that much land is not used for purposes for which it is most suitable and that it is not used to its optimal productive capacity. Farmers know the risks of weather conditions, plant diseases, plagues, price fluctuations etc., so they are often more interested in minimizing risks than in maximizing production.

Readers interested in the history of land use and land transformation are referred to the books by Slicher van Bath (1963) and Grigg (1982).

The conclusion is, that all people, and not only those who are engaged in agriculture, are responsible for how land is used. Studies on land transformation in various countries have to be based on exact data. In Western Europe such data are only available of the last one hundred years, in many countries they are not available at all. It is extremely difficult to give a reliable explanation of land transformations, because they are influenced by many, often unknown factors.

Richards, Olson and Rotty (1983) have made a worldwide study on land transformation for the periods 1860–1920 and 1920–78 in order to estimate the releases of carbon dioxide arising from the conversion of land with a natural vegetation to agricultural land. Although they admitted that there were several uncertainties in their estimation, the conclusion was that the net expansion of the cultivated land area was 432 Mha in the period 1860–1920 and 419 Mha in the period 1920–78. In the first period most land was converted in North America (164 Mha) and the USSR (88 Mha). In the second period, Africa (90 Mha), southern Asia (67 Mha), South America (65 Mha) and the USSR (63 Mha) were the most important regions.

2.3 POTENTIAL LAND USE

In most developing countries the mode of agricultural production is still traditional and similar to that in industrialized countries almost two centuries ago. The reasons for this have been explained, and some figures were given in Tables 2.3 and 2.4. The question is now: what is the potential land use?

The word 'potential' has been given many definitions. In this section ecological and technical agricultural management practices will be taken into account, but not the socio-economic conditions: it is necessary to know first what the technical possibilities for agricultural production are.

As cereal grain crops like wheat, rice and maize are the main food crops, most attention will be given to these. Figure 2.2. shows the average wheat yields in selected countries over an extended period (5- or 10-year averages). It is most remarkable that all these countries show an increasing average wheat yield. Moreover there have been and still are important differences. For example, there was an increase in the average wheat yield in the Netherlands from 1 to 2 t/ha in the period 1800 to 1900, and then the increase was rather rapid (excluding the war period). Various factors were responsible for the increased production per hectare. In the period 1800–1900 the main factor was the introduction ley-farming without fallow; after 1900 it was mainly the application of chemical fertilizers followed by the introduction of new wheat varieties, better management as a result of education, extension and research. Finally, biocides and advanced technology, including mechanization, have been applied.

The changes in modes of production causing the increases in the average wheat yields were influenced by industrialization and other factors—in particular the ever-increasing part of the population not working in agriculture who needed food to be produced on the farms. The reasons for increasing agricultural production are still a fruitful research subject for agricultural historians. Hypotheses and explanations that may be correct for one country do not necessarily fit for others.

Differences between the average yields in various countries in the same years are the result of differences in environmental conditions and in modes

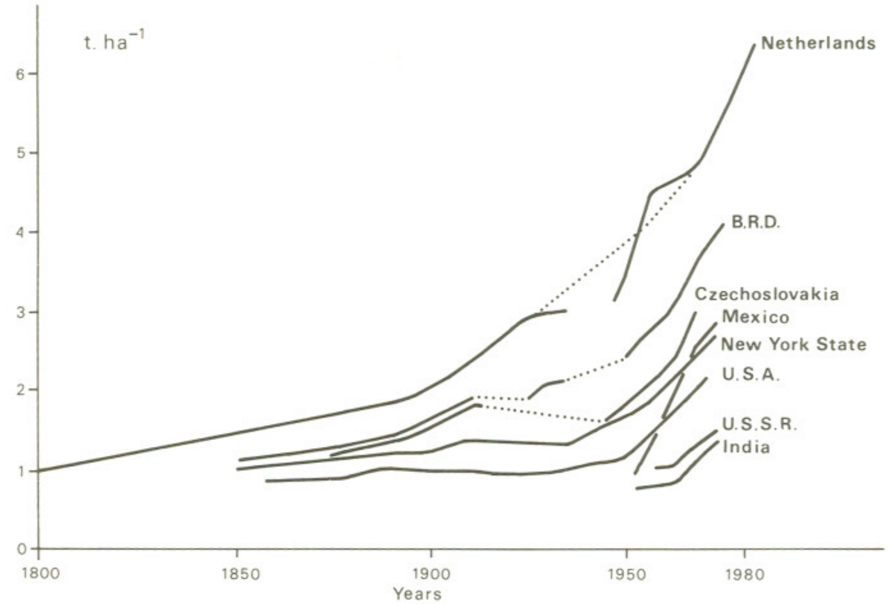

Figure 2.2 Wheat yields in selected countries, 1800–1980

of production. Owing to relatively high precipitation that is well distributed over the growing season, farmers in the Netherlands can apply large quantities of fertilizers in order to get a high production per hectare. In the USA the production per person working in agriculture is more important. The curves for India and Mexico show the influence of the 'green revolution'. Although there are these important differences between countries, this does not mean that farmers getting high yields per hectare earn more than farmers getting much lower yields.

Figure 2.3 shows the average yields, the price and the gross income per hectare of wheat in the Netherlands for the period 1900–80, all based on the year 1900 as index. During this period the yield has increased more than three times and the price more than five times, but the gross income has increased by only about 20%.

The information in Figure 2.2 also indicates three important stages in the Netherland's modes of production (viz. 1800–1900, 1900–50 and 1950–). In other countries these stages may begin and end somewhat later or earlier: they depend in general on the technology applied by farmers.

A similar increase in production per hectare can be observed for other food crops. Figure 2.4 presents data on average rice yields. Here the case of Japan is used to show the increase over a long period, and the present average rice yields of various other countries are indicated on that country's yield curve.

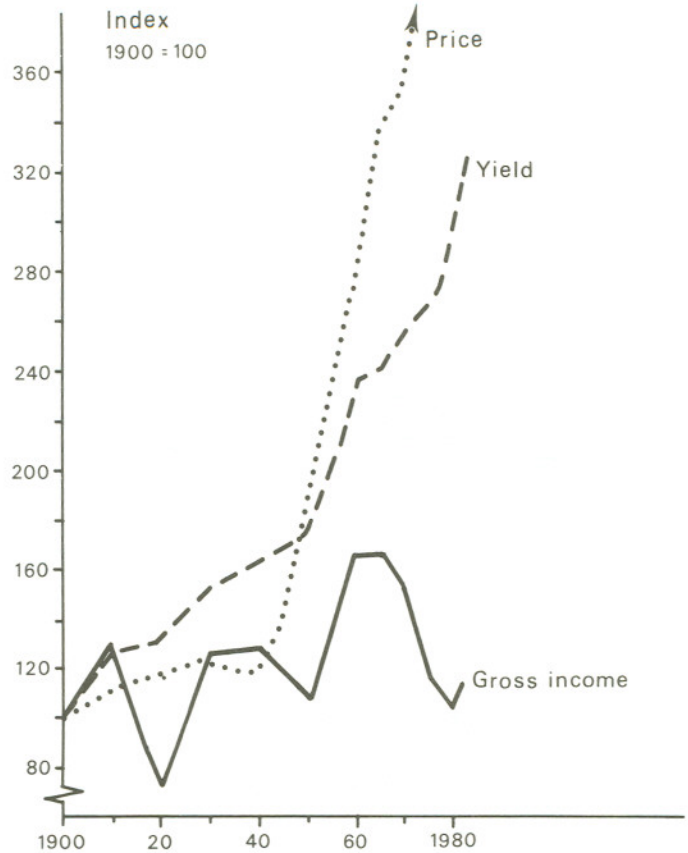

Figure 2.3 Figures for Dutch wheat yields for the period 1900–80, based on 1900 as the index year

Here, too, we see important variations and various stages in the increase of production. Figure 2.4 may suggest that the average rice yields in many countries could be increased to the present, high average yield of Japan. This is not true, because ecological conditions in the various countries are different, although it is clear that production of rice could be considerably increased in many countries.

In order to get an idea of potential land use we also have to know the characteristics of the crop to be grown and of the site (weather and soil conditions) where the crop has to be cultivated. Field experiments have to be carried out. Ratios of the actual average yield and the yield obtained by the best farmers (or a standard yield as obtained in experiments) may be used to get an index for potential land use, and such an index indicates how much the

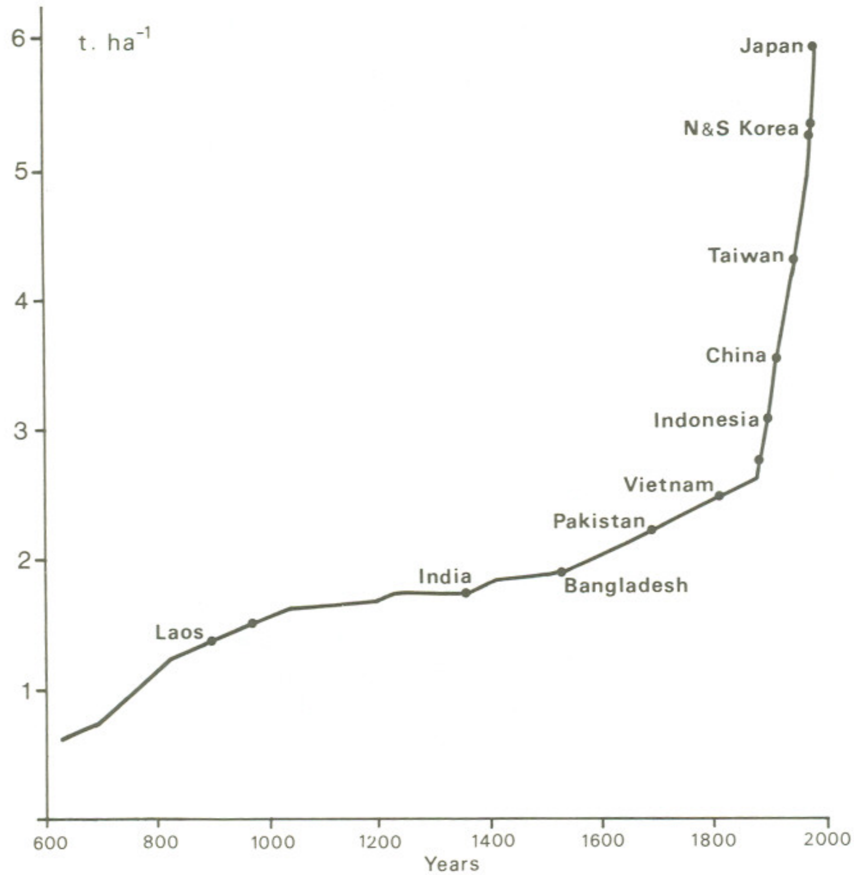

Figure 2.4 Average rice yields today in selected countries, projected on the yield curve of Japan for the period 600–1975

yields of a specific crop can be increased in a particular area. These studies become difficult, however, when predictions are being made of potential land use for regions in which soil conditions are not yet intensively investigated, or in which almost no results of field experiments are available (particularly in young developing countries). In these countries land used for carrying out field experiments is often only representative for a small part of the country, because of variations in weather and soil conditions; in such cases estimates have to be made. In this connection reference can be made to studies carried out by FAO (see, for example, Dudal *et al*., 1982). Interesting figures on a global scale are presented in Tables 2.5 and 2.6.

Studies of potential land use are not new. In a speech in 1898 the president

Table 2.5 Land use and population (areas in million ha) (Dudal *et al*., 1982)

	Developing countries	Developed countries	Total world
Land area	7 619	5 773	13 392
% of world's total	(57)	(43)	
Population (1979, millions)	3 117	1 218	4 335
% of world's total	(72)	(28)	
Potentiable cultivable	2 154	877	3 031
% of land area	(28)	(15)	(22)
% of world's potential	(71)	(29)	(100)
Presently cultivated	784	677	1 461
% of potential	(36)	(77)	(48)
% of world's total	(54)	(46)	(100)
Persons per ha presently cultivated	4.0	1.8	3.0

of the British Association for the Advancement of Science, Sir William Cooks, stated that the area of virgin land that could be reclaimed for growing crops was very small, and he predicted a worldwide famine for the year 1930 unless nitrogen fertilizers could be made. In 1923 an article on land utilization in the United States was published by Baker (1923). He concluded that within a few years more agricultural products would have to be imported than could

Table 2.6 Land use and population in developing countries (areas in million ha) (Dudal *et al*., 1982)

	Africa	S.W. Asia	S.E. Asia	Central Asia	South America	Central America
Land area	2 886	677	897	1 116	1 770	272
% of world's total	(21)	(5)	(6)	(8)	(13)	(2)
Population (1979, millions)	427	153	1 232	947	239	119
% of world's total	(10)	(3)	(28)	(22)	(6)	(3)
Potentially cultivable	789	48	297	127	819	75
% of land area	(27)	(7)	(33)	(11)	(46)	(27)
% of world's total	(26)	(2)	(10)	(4)	(27)	(3)
Presently cultivated	168	69	274	113	124	36
% of potential	(21)	(144)	(92)	(89)	(15)	(49)
% irrigated	(4)	(16)	(24)	(44)	(6)	(18)
Persons per ha presently cultivated	2.5	2.2	4.5	8.4	1.9	3.3

be exported, because of the increasing population in the USA. There are more examples like these.

The main breakthrough was made when the President's Science Advisory Committee (PSAC, 1967) published a study based on knowledge of climate and soil conditions of the world. It was stated that the area cultivated was 1406 million hectares, and that the potential area was 3190 Mha (respectively 11% and 24% of the non-ice-covered land area). The conclusion was that approximately nine times more food could be produced.

The first computer model by Meadows *et al*. (1972) showed less hopeful results. In the framework of a model on international relations in agriculture (Linnemann *et al*. 1979) a study was made by Buringh *et al*. (1975) of the maximum food production capacity of the world, when all known, modern agricultural technology was applied on land suitable for crop production (3419 Mha or 26%). In the last study the new Soil Map of the World (FAO/Unesco, 1974–81) could be used as a basis for studying soil conditions. Table 2.7 shows the figures of the American and Dutch studies.

Another study (Buringh and van Heemst, 1977) showed that, even at the present time, not enough food for the present world population could be produced if all suitable land of the world were cultivated and a traditional mode of production applied.

The publications of the American, Dutch and FAO specialists have had two important consequences. First it was clear that the potential cultivatable land area of the world is approximately 23% of the total land area. At present 11% of the land area is cultivated, so there is a reserve of some 12%, now being used as grassland or forest land. Secondly it was made clear that the world food production could be increased some ten times, and that agriculture can produce enough food, when appropriate modern technologies are

Table 2.7 Comparison of American and Dutch calculations on potential agricultural land (PAL)

	American data (1967)					Dutch data (1975)	
	A	Cultivated		PAL		PAL	
	(Mha)	(Mha)	(%)	(Mha)	(%)	(Mha)	(%)
S. America	1 750	77	4.4	681	38.9	596	33.5
Australia	820	32	3.9	153	18.7	199	23.2
Africa	3 010	158	5.2	734	24.4	711	23.5
Asia	4 420	689	15.6	894	20.2	887	20.2
N. America	2 110	239	11.3	465	22.0	627	25.9
Europe	1 040	211	20.2	263	25.3	399	37.9
Totals	13 150	1 406	10.7	3 190	24.2	3 419	26.0

applied. The problem of world hunger and under-nourishment is not attributable to agricultural limitations but is a problem of cultural, socio-economic and political conditions causing poverty. Another conclusion was that it will be better to intensify agricultural production on the presently cultivated land than to reclaim more land.

These conclusions were not entirely new, because they had been expressed earlier by other scientists. However, the studies mentioned above were based on extensive research work. Reference can also be made to more recent studies (e.g. FAO, 1981; Barney, 1981).

It is worth while to undertake global studies, but for many purposes they are too general and do not differentiate enough. Therefore more detailed studies of specific countries have been made. The introduction of computers has facilitated the work. In this connection investigations made by a Dutch group will be mentioned, because of a new approach, developed by de Wit (e.g. de Wit *et al*., 1974). This approach is based on a theoretical calculation of the maximal photosynthetic production of a specific crop, growing on a specific site (known soil and weather conditions) (Centre for World Food Studies, 1980). Use is made of systems analysis and simulation techniques. The growth of a crop is simulated at all stages in a computer model. The system includes the main factors of the systems plant growth, weather conditions, soil conditions and level of agricultural technology—calculation is made, during various stages of development of a crop, of the maximum photosynthetic production taking into account the specific characteristics of a crop, weather conditions before and during the growing season, as well as soil conditions, particularly available water for crop growth, assuming no other limiting factors. This is followed by a calculation in hierarchic sequence of factors that can limit crop production (such as nutrients and weeding). The model is constantly verified, using data from various field experiments. The main advantage of such an approach is that one learns about the real production potential. It is possible to investigate why such a maximal production does not occur in practice. A similar approach has been and is continuing to be developed in countries cooperating in the International Institute for Applied Systems Analysis (Meadows *et al*., 1982). Although significant progress has been made during the past decade, it is evident that much more research work has to be carried out and that models have to be simplified in order to make them suitable for practical application.

We now come back to the information presented in Figures 2.3 and 2.4, because the new calculation procedures provide the possibility of learning the maximum average wheat or rice yields in various countries. This was, for example, calculated for the Netherlands, and the conclusion was that an average yield of approximately 7.5 t/ha will be the maximum average yield, applying the best techniques and using the best wheat varieties, and cultivating the same land for growing wheat as is used at present. New farming techniques, and new wheat varieties that make a more efficient use of the sunlight, may increase wheat production more. If only the best land (some with a production of 10 t/ha) were used to grow wheat, the average would also increase. However, most productive land in the Netherlands is used to grow seed potatoes, sugar beets, onions, etc., and wheat is mainly grown for crop rotation purposes, and to spread the work-load. This example is given here mainly to demonstrate that even the potential yields of crops depend on many factors. Potential land use also depends on how and when the farmer manipulates the growing conditions of a crop. The manipulation technique depends on the experience and knowledge of the farmer, but also on possibilities of input of labour and capital and of marketing prices and facilities to sell the products. A subsistence farmer in a remote area almost without infrastructure has few opportunities to sell the produce which he does not need for his family. On the other hand a farmer in a densely populated, industrialized country has to produce for many people not working in agriculture, who are willing to pay for the agricultural products. This will give him the opportunity to use capital (fertilizers, machines, etc.), particularly when labour is scarce. A comparison of traditional farming and modern farming shows a great difference in potential land use.

Traditional farming is defined here as farming in a traditional way, with only limited input from outside the farm. Yields depend on the natural fertility of soils and the availability of manure, consequently on the presence and number of farm animals, for which feed has to be available from grazing land. In this situation local crop varieties that are not very sensitive to diseases are used. All work in the field is done with simple tools, most of them made by the farmer himself. There may be some animal traction. It is clear that the possibilities for manipulating growing conditions of crops are very limited, that average yields are rather low, and that improvements will take much time.

Modern farming, on the other hand, is defined as farming with high technological input from outside the farm. For example, the farmer buys seeds of proper high-yielding varieties, chemical fertilizers, biocides to kill weeds or to protect crops from diseases. He has machines to prepare seedbeds, to apply fertilizers and biocides, to harvest and to thresh, and tractors to transport the products. Such a mode of production is rather costly and consequently the average yields per hectare have to be much higher than when farming is done in a traditional way; moreover the farmer needs much more knowledge and he has to be educated. Many machines are too costly on small farms.

Under traditional agricultural conditions the best farmers can get a maximum of 1 t/ha of wheat, under modern agricultural conditions probably 5 t/ha on similar land. In the traditional situation the maximum photosynthetic production is approximately 1.4 t/ha, in the modern situation 9 t/ha.

This example demonstrates that potentialities depend strongly on the level of technology applied—and that costs of production are much lower in a traditional mode of production than in a modern mode of production. Many other, similar examples could be given.

There are also possibilities of manipulating crop characteristics, climate and soil conditions. Some examples will be given. Plant breeders can breed new crop varieties that are better adapted to environmental conditions or to new farm management practices. Glasshouses can be built in order to get the most favourable climatic conditions for some expensive crops. Supplementary irrigation can correct a shortage of rain. Drainage can correct too high a precipitation or too high groundwater. Sloping land can be terraced. Land with a less favourable layer below the ploughed layer can be improved by subsoiling or deep-ploughing. Proper management is highly improved by tractors and machines, because work in the field can be done much more easily and quicker, and consequently at the proper time. This short list of manipulation techniques can be extended. However, there are limitations which are partly natural—for example a shallow soil cannot be transformed into a deep soil, for normal crops weather conditions cannot be changed, and often the costs of introducing a new technique are too high. Maybe the most limiting factor is the farmers themselves, because often many are illiterate or have very little education and there are no governmental research stations and extension services.

The introduction of new and better modes of crop production takes time and costs money, a lot of money (FAO, 1981). Most farms are very small, some even smaller than a few hectares. It is difficult to improve production on these farms because of the risks.

The conclusions are that there is a large potential for increasing the area of cultivated land and similarly the potential for large increases in production per hectare when better modes of production are applied. The problem is not technological in that sense. Rather the problems are socio-economic and political.

2.4 INCREASES IN NON-AGRICULTURAL LAND

In all countries much agricultural land is lost and much land is degraded, which means its production capacity decreases. This is partly the result of mismanagement, resulting for example in erosion or salinization, and partly because agricultural land is used for non-agricultural purposes.

The transformation of agricultural land into non-agricultural land is rapidly increasing. Continuous losses and degradation mean that new land has to be reclaimed in order to be able to produce the same quantity of food. Moreover, new land is needed for the increasing population of (80 million people each year). The result is that the reserve of land with potential for growing food crops is rapidly decreasing, a subject to be discussed in section 2.5.

Only a few countries have reliable data on various types of losses and degradation of agricultural land. For most countries the information is rough and figures in the popular press are often exaggerated or copied wrongly, e.g. on desertification. There are almost no figures on the quality of the land that is lost. It makes, for example a great difference whether unproductive land or land with a high productive capacity is lost. A loss of 100 ha of dry, poor grazing land, which can feed some cows (producing 5 kg of meat per hectare per year) is less important than the loss of 100 ha of land where three food crops can be grown annually. Some land that has been eroded may not be suitable for growing crops, but it can probably still be used as grazing land or forest—this is not a total loss.

The example indicates that the subject of losses and degradation is not as simple as is often assumed. Farmers who cultivate their own land will take care of that land in order not to loose the basis of their living and that of the following generations. However, there are some very large farms owned by corporations who are more interested in gaining a profit in a short period than in conserving the land for future use. Farmers who rent their land may be less careful, particularly if they are not sure that they can cultivate the same plots for many years. The same applies to communal land, because no-one feels personally responsible for its misuse. In regions with a high population pressure farmers may reclaim new land that is unsuitable for cultivation (e.g. when it is situated on too steep slopes). Such farmers can hardly be blamed because they do not have any choice. In some countries much land has been misused because the government has introduced land registration for tax purposes, claiming that all land not cultivated is owned by the state. Good grazing land has therefore been ploughed and transformed into useless cropland, because of a too dry climate and severe wind erosion.

A further danger that is not fully recognized is the silting up of water reservoirs that are used mainly for producing electricity and irrigation water for agricultural land. As a consequence of soil erosion in the catchment area, large quantities of silt are continuously deposited in reservoirs. In the end (it may take 50 or 100 years or more) such reservoirs are filled up with silt, which means that large areas of land can no longer be irrigated.

The problem of the non-agricultural use of land has become serious in many countries. Almost all cities are situated in areas with very productive land on which for many centuries food has been produced for the city population. Soon half of the world's population will live in urban areas. In the year 2000 non-agricultural land will amount to approximately 400 Mha, and this will be mainly prime land. In some industrialized countries this problem now gets more attention.

Much land on hills and mountain slopes is seriously eroded and deep gullies are formed when the original forest vegetation has been taken away. A less spectacular type of erosion, sheet erosion, may be even more serious. Sheet erosion often occurs on slightly sloping land from which every year a very thin soil layer (a few millimeters) is eroded. After a few decades the rooting depth of crops may become limited and land productivity decreases.

Besides erosion, reduction in land productivity may also result from certain farming practices. Where an efficient use of fertilizers is not practised chemical degradation may take place through a decrease of nutrient content (leaching of nutrients, carrying off of nutrients with the harvest) and decalcification. Physical degradation may occur through soil surface compaction and the decline of soil structure when inappropriate tillage is applied. Biological degradation may occur through a decrease in biological activity of soils, which is often the result of a decline in organic matter content. The processes that occur in soils are rather complicated, particularly the biological processes that are governed by soil flora and fauna.

A new type of degradation is the result of air pollution that has become a real problem in industrialized countries in recent years. Special attention is currently given to 'acid rains'—more appropriately expressed as 'acid deposition'—where significant amounts of S and N oxides are added to the natural CO_2 components of the air. Olson (1983) considers that likely deleterious effects on soils include reduction of pH, increased activity of various elements with toxicity potential, accelerated mineral weathering, leaching of reserve soil nutrients and undesirable changes in the microflora. Areas with greatest potential for soil damage from deposition are in close proximity and downwind from large coal burning plants, especially on soils which have a low buffering capacity or are inaccessible for corrective measures to be applied. Olson's assessment, however, is that for most of the agricultural regions of the world, the N and S fallout products are more beneficial in supplying needed plant nutrients than they are detrimental. This acidification capacity is insignificant in comparison with that of natural N and S transformation in soils or that induced by conventional fertilizer programmes of farmers. The situation is different, however, for perennial vegetation and forests which may be severely damaged by the cumulative effect of successive acid deposition.

It should be stressed that there is not only loss and degradation of land, there is also reclamation of land and improvement of land productivity, although there are only a fraction of losses and degradation. Examples of reclamation of new land are the drainage of marshes, inland lakes and reclamation of land from the sea in coastal regions. Improvement of productivity can be obtained by drainage, land levelling, terracing etc. Infertile land can be substantially improved through an appropriate application of fertilizers, organic manures, lime or trace elements.

In various countries attempts are now being made to protect land from being eroded and to restore the eroded land. This is also sometimes done with land that has become saline (mainly in arid regions)—that is, irrigated without drainage. Soil conservation is, however, very expensive and it needs the cooperation of many people living in a conservation project area. This means that the national government has to initiate, execute and guide such projects, for which it needs the cooperation of all land owners and land users in a project area, a difficult objective to achieve. The costs are generally too high for farmers, so part of those costs has to be paid by the government and loans have to be provided for the farmers. A further problem is the settlement procedure for newly reclaimed land, which is often the main reason why projects are less successful than anticipated. Farmers in new settlements often do not have enough experience to make use of the new facilities, so the yields are much lower than expected. It is well known from early land reclamation work in various industrialized countries that, very often, the first and even the second generation of farmers are adjudged bankrupt. Such failures can be avoided by creating a special government authority for a project area, responsible not only for initiating a project, but also for the farming for some years until farmers are trained and able to handle the land with supervision and advice provided as needed.

Many specialists have tried to quantify the various losses and types of degradation of land, both on a national and on a global scale. Unfortunately the figures do not indicate the important differences between the areas or regions. In a report for an FAO/UNEP/UNESCO conference almost all the available literature with the most reliable figures was studied, to get at least an idea of the area of land that is lost. Here the general results are given, but more details can be found in Buringh (1982). The base year in this study was 1975 and computations were made for the expected situation in the year 2000. The five main types of land use considered were crop land, grassland, forest land, non-agricultural land and other land. Moreover, four classes were distinguished (high, medium, low and zero), indicating the potential productive capacity of all land not covered by ice.

As a result of erosion, toxification (mainly salinization and alkalization), desertification (drought) and non-agricultural use of land, the potential capacity of land and/or the type of land use can change. As the world population will increase (an average 75 million people each year for the period 1975–2000) a large area of additional crop land will be needed. Taking into account the various losses, changes in and intensivation of land use, and the reclamation of new crop land for the period 1975–2000, the land use per land class is expected to alter considerably (compare Tables 2.8 and 2.9). Although a number of estimates had to be made the figures can be considered to be good working figures.

It turns out that about 200 Mha of agricultural land will be converted into non-agricultural land, 50 Mha will become seriously toxified, and 50 Mha will become desert: a total of some 300 Mha of presently agricultural land in a 25-year period, or an average of 12 Mha per year, or 23 ha per minute. The main reason is the expected loss of agricultural land to non-agricultural use

Table 2.8 Land use (1975) per land class ($\times 10^6$ ha)

Land use	Land class				
	High	Medium	Low	Zero	Totals
Cropland	400	500	600	0	1 500
Grassland	200	300	500	2 000	3 000
Forest land	100	300	400	3 300	4 100
Non-agricultural land	0	0	0	400	400
Other land	0	0	0	4 400	4 400
Totals	700	1 100	1 500	10 100	13 400

(66% or 200 Mha or 8 Mha per year). The total loss of land as a result of mismanagement is about 100 Mha in 25 years or 4 Mha per year (a rather low figure, because it is often assumed to be 5–8 Mha). Not all land is highly productive. When taking into account the four productivity classes mentioned above, the following conclusions are drawn for the 25-year period:

(1) About 4% of all potential productive agricultural land will be lost; however, of all highly productive land 25% will be lost.
(2) The reserve of crop land which is now used as grassland or forest will decrease by 24%; however, the reserve of highly productive land will decrease by 33%.
(3) The total forest area will decrease by 15%. The area of forest on productive agricultural land will decrease by 55%; however, 70% of the forest on highly productive land will disappear.

These figures do not give optimistic assessments of what can be expected in the near future. A comparison of the results with figures presented by various other authors reveals that the figures in this study are rather low. Important,

Table 2.9 Land use (2000) per land class ($\times 10^6$ ha)

Land use	Land class				
	High	Medium	Low	Zero	Totals
Crop land	345	745	710	0	1 800
Grassland	170	320	510	2 000	3 000
Forest land	30	100	230	3 140	3 500
Non-agricultural land	0	0	0	600	600
Other land	0	0	0	4 500	4 500
Totals	545	1 165	1 450	10 240	13 400

however, is the introduction of the four classes of land productive capacity in order to get information on what may be expected to happen with highly productive land. It is repeated once again that the investigation was done on a global scale, that it was based on real data and on assumptions, and it was an important first approximation. A global assessment of land degradation (first phase: northern half of Africa and the Near East) has been made by FAO, UNEP and UNESCO (FAO, 1979) and it was concluded that at the end of this century the developing countries may loose up to 20% of the productive capacity of their land resources. Similar calculations could be made on a country by country basis in order to alert governments.

As can be seen from Table 2.8 the total area of land use in 1975 for non-agricultural purposes is 400 Mha for 4000 million people (average 0.10 ha per person). In the period 1985–2000 the world population is expected to increase by 2000 million people, who will need at least 200 Mha of land for non-agricultural purposes. The average of 0.10 ha per person seems to be realistic (the areas mentioned in various publications generally vary from 0.075 to 0.15 ha per person). In Australia it is 0.5 ha per person. The total annual loss of land to non-agricultural use is 8 Mha. In the USA alone this loss is already 1.2 Mha per year, of which some 37% is highly productive land. Italy is losing 45 000, the United Kingdom 23 000 and France some 65 000 hectares each year, according to the OECD. Table 2.10 gives an idea of the purposes for which the non-agricultural land is used in the Netherlands and in Japan.

A FAO/UNFPA/IISA study (1982) makes a preliminary quantitative assessment of the losses in potential production from unchecked soil erosion if, as at the low input level, no conservation measures are undertaken (Table 2.11). The methodology used for estimating rates of soil loss was a parametric approach using rainfall and wind erosivity indices, soil, topographic, texture

Table 2.10 Examples of annual losses of land to non-agricultural land use in the Netherlands and Japan

	The Netherlands		Japan
	(1950–58 average)	(1977)	(1968–74 average)
Losses (ha)	4 455	6 668	54 873
Land used for (%):			
Housing, urban services	46	42	54
Industries, mining	11	13	13
Communications	27	23	14
Recreation	16	21	19

Table 2.11 Effects of unchecked soil erosion on production potential at low input levels (FAO/UNFPA/IIASA, 1982)

	Africa	Central America	South America	South-east Asia	South-west Asia	Totals
	(% of total production potential)					
Loss in area of rain-fed crop land	16	30	10	36	20	18
Loss in rain-fed crop production	29	44	23	39	35	29
Loss in total potential production[a]	25	25	21	12	5	19

[a]From rain-fed crop land, irrigated land, and the increased area suitable only for grassland.

and land use factors. In addition to quantification of degradation phenomena it was necessary to translate soil losses into decreases in potential productivity. The relationships which have been employed to obtain the figures shown in Table 2.11 are described in the FAO/UNFPA/IIASA (1982) study on potential population supporting capacities of land in the developing world. The loss would in the long run reduce the potential area of rain-fed crop land by 18% and the production of the rain-fed area by 29%. There would be an overall loss of 19% in the combined potential production of rain-fed and crop land, irrigated land, and the increased area suitable only for grassland. Such losses would be particularly serious in Africa and Central and South America. The intermediate input level assumes a 50% reduction in these losses, and the high level their reduction to acceptable proportions.

2.5 RESERVES OF PRODUCTIVE AGRICULTURAL LAND

The present area of crop land is a little more than 1500 Mha, or 11% of the world's land area. Specialists in various countries and the international organization FAO have investigated how much of the land not yet used to grow crops is still available and suitable for food crops. The figures vary from 1700 Mha to 1900 Mha. This means that the reserve of crop land is some 12% of the total area.

Such a figure looks rather optimistic, but there are two factors that should be mentioned. The first is that most of this land has a moderate or low productive capacity, because in most countries the best land has already been reclaimed. Secondly, much newly reclaimed land is needed for the increasing world population, to compensate for the land that is lost to erosion, salinization and degradation, and to compensate for land that is completely lost mainly because of the increase of non-agricultural land use.

In the foregoing section a general idea of these losses was given and special attention was paid to the quality of land for food production. Tables 2.6 and 2.7 give a general idea of the area of potentially productive land in various regions, and Tables 2.12 and 2.13 of the potentials of soil orders and soil units.

In Table 2.12 the world land area is grouped according to soil conditions that are classified according to the US Soil Taxonomy. The total area of potentialy arable land is some 3120 Mha, or 23.7% of the world's land area. Table 2.13 lists the major soil units of the world as presented on the FAO/UNESCO Soil Map of the World. Here the area of potentialy arable land is 3270 Mha, or 24.8%. It should be kept in mind that both tables give approximations because soils in large areas of the world have not yet been fully investigated. Moreover there may be some differences in interpretation. There is often some confusion on the suitability of various soils in tropical regions, particularly the old tropical soils. Various experiments have clearly shown that many deep tropical soils can be permanently cultivated if an appropriate management is applied: the main problem of these soils is not irreversible hardening or laterite formation, as often is believed, but the aluminium toxicity that can be corrected by liming. A poor nutrient status is corrected by appropriate fertilization.

The figures on potentially arable land presented above are valid if modern technology is applied. It is evident that this requires rather large inputs (FAO, 1981). Most reserves of land are located in Africa and South America, where respectively 21% and 15% of the potential agricultural land is currently used (Dudal, 1982). Most specialists, however, argue that reclaiming new land is hardly necessary in many countries, because yields of crops grown on the

Table 2.12 World land area in different soil orders (Mha) (source: USDA Soil Geography Unit, Soil Conservation Service, 1973)

Soil order	Potentially arable	Non-arable but grazeable	Non-arable non-grazeable	Total	Percentage
Alfisols	640	690	400	1 730	13.1
Aridisols	80	250	2 150	2 480	18.8
Entisols	150	290	650	1 090	8.2
Histosols	1	20	100	120	0.9
Inceptisols	230	230	710	1 170	8.9
Mollisols	630	340	160	1 130	8.6
Oxisols	650	350	120	1 120	8.5
Spodosols	100	210	250	560	4.3
Ultisols	270	330	130	730	5.6
Vertisols	140	60	30	230	1.8
Mountain soils	230	910	1 670	2 810	21.3
Totals	3 120	3 680	6 370	13 170	100.0
Percentages	23.7	27.9	48.4	100.0	

Table 2.13 Major soil units of the world

	Totals		Potential crop land	
	Area (Mha)	Proportion (%)	Area (Mha)	Proportion (%)
Acrisols	1 050	8.0	300	9
Andosols	101	0.8	80	2
Cambisols	925	7.0	500	15
Chernozems, Greyzems, Phaeozems	408	3.1	200	6
Ferralsols	1 068	8.1	450	14
Fluvisols	316	2.4	250	8
Gleysols	623	4.7	250	8
Histosols	240	1.8	10	0
Lithosols, Rendzinas, Rankers	2 264	17.2	0	0
Luvisols	922	7.0	650	20
Planosols	120	0.9	20	1
Podzols	478	3.6	130	4
Podzoluvisols	264	2.0	100	3
Regosols, Arenosols	1 330	10.1	30	1
Solonchaks, Solonetz	268	2.0	50	2
Vertisols	311	2.4	150	5
Xerosols, Kastanozems	896	6.8	100	3
Yermosols	1 176	8.9	0	0
Miscellaneous land units	420	3.2	0	0
Totals	13 180		3 270	

presently cultivated land are low and it is not very difficult to increase yields by introducing better management practices. This seems not only less expensive, but it is also better from a point of view of conservation and protection of the environment—and moreover there should be reserves of land for coming generations.

In Section 2.4 it was stated that in the period 1975–2000 some 140 Mha of potentially productive agricultural land will be lost, being 4% of the total of that land area. This figure is rather low in comparison with figures presented by some other authors, who ended up with figures of 5% and 6%. The conclusion that the reserve of land will be enough for a very long time is, however, not correct. First, the figures are given for the whole world, but regionally there are very important differences. For example, Egypt has almost no reserves while Brazil has very large reserves. Secondly, there is the difference in productive capacity of land: although the total loss is only 4%, the loss of highly productive land is 22% in the 25-year period.

The figures presented in section 2.4 also show that the reserves of highly productive crop land (now being used as grazing land or forest) will disappear at a high rate. If no special measures are taken global reserves of highly productive land will be lost in about 75 years. Specialists in the USA have indicated that in that country this category of land will be used up within 25 years. According to our calculations the area of forest land will decrease at a rate of 15% in 25 years (0.6% a year), a figure that is lower than the figure calculated by various foresters. Forest land that is highly productive for growing food crops will decrease by 70% in 25 years. This means that such land will be deforested in about 40 years. Without going into more detail, it should be noted that the figures presented here are low compared to those mentioned in some reports. We have tried not to exaggerate an already very bad situation. One should realize that man has already used land for some 10 000 years and there never has been a shortage, and now it is observed that all reserves will have gone within a few decades or so. In some countries there are no known reserves at the present time.

During the last decade various investigations of land use, land use potentialities, losses and misuse of land, land reserves, etc., have been made. It seems worth while to make this type of investigation in all countries, taking into account the productive capacity of the land. Such an investigation could start with an overall survey made in a short time period, to be improved by more detailed surveys at a later stage.

One conclusion is that the reserves of productive agricultural land are limited (particularly those of highly productive land) and should be protected. As land reserves in many countries are very limited it is worth while to investigate the various problems related to land use and to show on a map where real problems may be expected. Another conclusion is that the cost of production and the use of energy in agriculture will gradually increase, and consequently the costs of food products will increase.

2.6 PROJECTIONS TO MEET FUTURE NEEDS

Projections made at the end of the last century and at the beginning of this century turned out to be wrong, which may be a good reason to distrust projections made in recent years. However, recent projections are based on the availability of much more information. This information is regularly updated and trends can be studied, although these trends can change rapidly because of new technologies. Agricultural production, on the other hand, never changes rapidly: introducing new technologies over large areas and reclaiming land in large projects takes several years. Projections for the next 20 years may therefore have some value, assuming that there will be no disasters.

It is expected that the world population will increase to a total of at least 6000 million in the year 2000. In section 2.4 calculations have already been quoted for:

(1) the area needed for non-agricultural land use;

(2) the area needed to produce food for the people who are annually added to the world population; and
(3) the area needed to compensate for agricultural land that is lost annually.

In addition, the degradation of the productivity of the presently cultivated land should be taken into account, and furthermore one can expect an improvement in the living conditions for at least some of those people whose living conditions are currently rather poor. These two factors are difficult to evaluate. They are therefore neglected for the time being in order to avoid too much speculation. On the other hand an improvement of production technology in agriculture, and consequently an intensification of production, may be expected at least in some areas. In most projections this factor is taken into account.

In recent years various projections have been made—for example, projections of the consumption and production of chemical fertilizers (regularly published by FAO), of the increase of the irrigated land area, of the world labour force and of the world's food production. Although such projections are valuable and should be made, and although the information is often given for individual continents, groups of countries or specific countries, they should be interpreted very carefully. For example, although the figures for a particular country showing transformations in land use over a certain period may be reliable, it is difficult to explain the reasons for these transformations, because one also needs to know changes in population, professions, and cultural, socio-economic and political conditions. Unfortunately all these data may be unreliable for political reasons. Very often this is not admitted and figures presented are merely assumptions instead of real figures. Also, the grouping of figures for statistical purposes is often done in different ways, even in different parts of the same country. Various international organizations, particularly those of the United Nations, produce regularly updated information on various subjects related to land transformation, population, food problems, etc. Usually this information is the best there is, and consequently it is used by most specialists. It is hardly surprising, therefore, that their conclusions are very similar, but not necessarily correct. Moreover, the basic information must come from farmers themselves who, for understandable reasons, may not provide accurate data when it can be used to calculate their income and capital.

There are various projections of the consumption of chemical fertilizers in the near future, but all specialists expect a continuous increase of fertilizer application. Most countries have to import these fertilizers. Storage and transport facilities and financial factors are important.

The irrigated land area, being now over 200 Mha, can be extended to some 400 Mha, but the availability of suitable irrigation water sets a limit. In this connection the increasing need for water for human and animal consumption and the constimption by industries must be mentioned. It takes about 20 years to plan and execute an irrigation project.

Taking into account the possibilities for intensifying the use of currently cropped land and the possibilities for increasing the area of cultivated land, it is easy to calculate that enough food can be produced not only for the present population but also for the population in the year 2000 and far beyond. If the land resources are used in an appropriate way, there should be no problems in growing enough food for a world population of 1200 or 1300 million people, the number of people who are expected to live on earth in the middle of the twenty-second century. From the point of view of agricultural technology the food problems can be solved. However, as explained before, the food problem is not a technical but a cultural, socio-economic and political problem. Moreover the world is not one unit, and there are very important regional differences. Therefore while global projections may suggest optimism, practice is different. It seems to be much more worthwhile to make projections for individual countries. If all countries could make their own projections and those results could be combined, much better global projections could be made. Unfortunately most countries have only a small number of specialists who could make such national projections and they are often occupied with other work.

The World Bank and other international agencies have made studies of several countries, mainly to assist in economic planning, it is well known that this can create problems similar to those a housewife has if some guests are interfering in the household business, but projections to meet the needs of the actual population can best be made by the countries themselves. As agriculture, particularly food production, is a part of the total economy of a country, projections of the needs of the population have to be made on a much wider basis than agriculture alone. Consequently the whole subject of 'projections' is much more complicated than making projects of food, fertilizers, irrigated areas, etc. The needs of the population are more than the needs for food, clothing and housing, although these may have a high priority. In the total economy various options can be recognized. Not all wishes can be fulfilled at once or in the same period: choices have to be made and priorities have to be set, which shows the importance of government policies.

Most countries have economies based on agriculture. Some specialists claim that more attention should be given to agricultural development, while others believe that industries should be developed or that the infrastructure should be improved.

Developing a country is an extremely complicated and difficult task. Furthermore it has to be realized that many problems are interrelated and the economy of a country also depends on the economy of other countries. In order to get an insight into such matters economic models are being developed and intensive use is being made of computers. Such models can be used to show that a certain policy should be followed. However, the outcome depends on the input and programming of the computer. If computer models are used to calculate the possible results of various options, of various types of measures to be taken, policy makers can have an idea of the effects of the planned policies on the economy. This may enable them to take the most appropriate decisions. Economic models used in this way and made by competent, independent scientists may be of great value for administrators and policy makers. Such models do not predict the future, they only try to indicate what may happen under specific conditions.

New light is thrown on the foregoing in a study recently carried out by FAO, in collaboration with the International Institute for Applied Systems Analysis (IIASA), with the support of the United Nationals Fund for Population Activities (UNFPA). The study makes the first detailed assessment of the potential population-supporting capacities of lands in the developing world, in comparison with their actual and projected populations (FAO/UNFPA/IIASA, 1982). The study takes as its starting point the FAO/Unesco Soil Map of the World (FAO, 1971–81) and the FAO Agro-Ecological Zones Project (FAO, 1978–81). It covers 117 developing countries in Africa, Central and South America, and south-east and south-west Asia. East Asia is not included in the study because of insufficient climatic data for China at the time it was prepared.

The methodology developed to assess potential population-supporting capacities is based on an overlay of a specially compiled climatic inventory on to the 1:5 000 000 FAO/Unesco Soil Map. The assessment considers 18 crops, to ascertain maximum potential calorie production, at three levels of inputs. The land resources of countries, expressed in terms of soil and climatic conditions, are matched to the soil and climatic requirements of crops to determine suitability classes. These suitability ratings allow the computation of crop-specific land productivity potentials, which can in turn be converted in calorie–protein production potentials. Then potentials can be compared to country-specific calorie–protein requirements so that the degree of self-sufficiency can be determined for various levels of inputs and different population densities.

The global results of the study confirm that the world as a whole should have enough cultivatable land to feed far more than the maximum population it is ever likely to have to support. These global results, however, presuppose massive movements of food, and probably also population, on a scale that seems hardly feasible. Land resources are very unevenly distributed in relation to population, both between and within the different countries and regions.

It is, therefore, more realistic and instructive to examine the results of the study at lower levels of aggregation. The results for individual countries come closest to political reality, in that greater self-sufficiency in food is being

Table 2.14 Critical countries with population-supporting capacities less than 1975 or projected 2000 populations, at different input levels (FAO/UNFPA/IIASA, 1982)

	Africa	Central America	South America	S.E. Asia	S.W. Asia	Totals
Number of countries	51	21	13	16	16	117
1975						
Total population (millions)	407	106	216	1 118	136	1 983
Critical countries with						
Low inputs	22	11	–	7	15	55
Intermediate inputs	7	4	–	1	11	23
High inputs	2	1	–	1	9	13
2000						
Total population (millions)	828	215	393	1 937	265	3 638
Critical countries with:						
Low inputs	30	14	–	6	15	65
Intermediate inputs	13	7	–	2	15	37
High inputs	4	2	–	1	12	19

sought as a major policy objective at this level. The data by country imply the more realistic assumption of the free movement of food and population within each country.

The study identifies 55 'critical' countries whose potential population-supporting capacities at the low level of inputs are less than their actual 1975 populations (Table 2.14). The countries include 22 out of the regional total of 51 in Africa, 15 out of 16 in south-west Asia, 11 out of 21 in Central America, and seven out of 16 in south-east Asia. Raising the level of inputs has a very marked effect, reducing the total number of critical countries to 23 at the intermediate level and 13 at the high level.

To summarize these country data in another way: 52 out of the 117 countries could, by using all their potentially cultivatable land, feed from domestic production populations of the size projected for the year 2000 at the low level of inputs; 28 could do so only at the intermediate level and 18 only at the high level; and 19 could not do so even at the high level of inputs (Table 2.15).

Irrigation contributes a substantial share of the total production potential, especially in Asia and Central America (Table 2.16). Its share falls as inputs are increased on the rain-fed land, because the irrigated land is assumed to be at present or projected input levels. Irrigation is assessed on the basis of the actual area and production in 1975 and that projected for 2000. If the full irrigable potential could be assessed, its contribution would be still larger.

Table 2.15 Countries classified by lowest input level at which they are to feed from domestic production populations of the size projected for 2000

Input level	Africa	Central America	South America	South-east Asia	South-west Asia	Totals
Even at low level	21	7	13	10	1	52
Only at intermediate level	17	7	–	4	–	28
Only at high level	9	5	–	1	3	18
Not even at high level	4	2	–	1	12	19

Figures are derived from Table 2.14.

It is clear that various projections are needed to construct such models. Projections to be made for the agricultural sector of the economy can be made in a realistic way, at least when they are made for a period of one or two decades.

Little attention has been given here to projections of energy consumption in agriculture, a problem that has attracted much attention in recent years. The introduction of new technologies into agriculture has greatly increased the use of energy, directly and indirectly. The replacement of draught animals by tractors, the introduction of diesel pumps and motor transportation, and particularly the application of large amounts of nitrogen fertilizers, for which production much energy is needed, have increased energy consumption. However, agricultural production is only a modest consumer of energy in comparison with transport or industry. It accounts for only 4.5% of total commercial energy use in the developing countries and 3.5% in the developed

Table 2.16 Contribution of irrigation to total production potential, actual area and production in 1975 and projected in 2000 (FAO/UNFPA/IIASA, 1982)

	Africa	Central America	South America	South-east Asia	South-west Asia
			(% of total production potential)		
1975					
Low inputs	9	38	6	39	80
Intermediate inputs	<5	14	<5	14	49
High inputs	<5	5	<5	8	32
2000					
Low inputs	20	64	13	73	89
Intermediate inputs	5	33	<5	41	66
High inputs	<5	14	<5	28	49

Table 2.17 Commercial energy use in agriculture for 90 developing countries

	Total (Mt oil equiv.)	Fertilizer (%)	Machinery (%)	Irrigation (%)	Pesticides (%)
1980	36	54	31	12	3
2000	178	56	38	4	2

countries, excluding food processing, storage and transport. The use of commercial energy in the developing countries in agricultural production is only about one-quarter of the amount used in farming in the developed countries.

The comparatively limited use of commercial energy in agriculture in developing countries holds down the productivity of land and of labour. If farm yields and earnings are to rise, there must be a steep increase in the use of commercial energy. In order to double production in 90 developing countries, it is estimated (FAO, 1981) that total commercial energy consumption in agriculture should rise from 36 million tonnes of oil equivalent in 1980 to five times as much, or 178 million tonnes, in year 2000 (Table 2.17). Fertilizer accounts for practically 60% of the total increase in energy mostly in the Far East, where land scarcity enforces dependence on raising yields. The next largest increase comes in machinery, particularly in the more land-abundant areas of Latin America.

The intensification of developing-country agriculture through an increased input of commercial energy may seem a paradox in an age of energy shortages and high prices. It is, however, essential if agricultural production is to increase adequately, and in view of agriculture's very modest share in total energy consumption it is also a very reasonable increase. If it should come to a choice of priorities in allocating scarce energy supplies, agriculture must be assured of its supplies at equitable prices.

One more subject should be considered when making projections, and that is the decreasing proportion of the working population engaged in agriculture and consequently the decreased importance and interest being accorded to agriculture. In industrialized countries often less than 7% of the working population is engaged in agriculture, and it is often not realized how much this small group contributes to the economy. Many people take for granted that each day plenty of food of all types is available at rather low prices. They spend some 20 percent of their disposable income for food. However, in less industrialized countries where most people still work in agriculture and where often, more than 50 percent of the income is needed for food, the situation is quite different. Even there, however, the significance of agriculture to the economy is often not realized.

2.7 AN OVERVIEW

The world as a whole has enough land to produce food for present and future populations. However, with the uneven distribution of land resources, populations and agricultural inputs, food production falls short of requirements in a great number of countries. In order to avoid dependency on external supplies, these countries will need to increase their domestic food production.

When planning for a higher degree of self-sufficiency, it is essential that differences in land resource endowment and in crop production potentials be fully appreciated. In some countries, land reserves are such that cultivation can be expanded to meet national requirements, and even beyond. In other areas the limits of cultivatable land have already been, or are about to be, reached and most of the increased production will have to come from the intensification of agriculture on land already cultivated. Certain countries with unfavourable soil and climatic conditions may not have means to meet the food requirements of their populations, even if the level of inputs were to be optimized. Furthermore, other needs also have to be met, such as fibre for clothing, raw materials for housing and industry, lumber and fuel wood, environmental conservation and possibly export crops. Therefore a balance should be established within each country, matching needs with the suitability of the land base for various types of use.

The precarious food situation in a number of developing countries indicates that the mere availability of land is not sufficient to fill the gap between demand and supplies. Incentives need to be created for the farmers to remain on the land and to make it produce. Priority has to be given to rural development in terms of investment, pricing policies, energy allocation, access to inputs, technology transfer, transport and credit, training and research. This intensification of agriculture is crucial in many developing countries where land resources are insufficient, at a low level of inputs, to meet the food needs of their present or future populations. The solution to the world food problem is, in the first instance, self-reliance of every nation in accordance with its production potential. With the identification of critical areas in various parts of the world, it clearly appears that food security will also have to rely on international cooperation.

2.8 REFERENCES

Baker, O. F. (1923) Land utilization in the United States: geographical aspects of the problem. *Geogr. Rev*., **13**, 1–26.

Barney, G. O. (1981) *The Global 2000 Report to the President: Entering the Twenty-First Century* (Council on Environmental Quality and the Department of State), Washington.

Bivas, M. R., and Bivas, A. K. (1978) Loss of productive soil. *Int. Jrnl. Envir. Studies*, **12**, 189–197.

Buringh, P. (1982). Potentials of world soils for agricultural production. *Trans. 12th Int. Congr. Soil Sc.*, Vol. 1, Plenary session papers, 33–41.
Buringh, P. (1984) Organic carbon in soils of the world. In: G. M. Woodwell, *The Role of Terrestial Vegetation in the Global Carbon Cycle* (SCOPE Publ. 23). John Wiley & Sons, Chichester, New York, 91–109.
Buringh, P., and van Heemst, H. D. J. (1977) *An Estimation of World Food Production based on Labour-oriented Agriculture*. Agr. Univ., Wageningen, the Netherlands.
Buringh, P., van Heemst, H. D. J., and Staring, G. J. (1975) *Computation of the Absolute Maximum Food Production of the World*. Agr. Univ., Wageningen, the Netherlands.
Centre for World Food Studies (1980) *The Model of Physical Crop Production*. Research Report SOW-80-5, Amsterdam-Wageningen, the Netherlands.
Dudal, R. (1981) Land resources and production potential for a growing world population. *Proc. 12th Congr. Int. Potash Inst. Bern*, 277–288.
Dudal, R. (1982) Land degradation in a world perspective. *Jrnl. Soil and Water Conservation*, **37**, (5), 245–249.
Dudal, R., Higgins, G. M., and Kassam, A. H. (1982) Land resources for the world's food production. *Proc. 12th Int. Congr. Soil Sc.*, New Delhi.
FAO (1971–81) FAO/Unesco Soil Map of the World, 1:5 000 000, Vols. I–X. Paris.
FAO (1978–81), *Reports of the Agro-ecological Zones Project*, Vol. 48/1–4, Rome.
FAO (1981) *Agriculture: Toward 2000*. Rome.
FAO/UNEP/Unesco (1979) *Provisional Methodology for Soil Degradation Assessment*. Rome.
FAO/UNFPA/IIASA (1982) *Potential Population-supporting Capacities of Lands in the Developing World*. Rome.
Grigg, D. (1982) *The Dynamics of Agricultural Change*. London.
Hopper, W. D. (1976) The development of agriculture in developing countries. *Scient. American*, **235**, (3), 197–205.
Linnemann *et al*. (1979) A Model of International Relations. Amsterdam.
Meadows, D., *et al*. (1972) *The Limits to Growth*. New York.
Meadows, D., *et al*. (1982) *Groping in the Dark: the First Decade of Global Modelling*. John Wiley & Sons, Chichester, New York.
Olson, R. A. (1983) The impacts of acid deposition on N and S cycling. *Environmental and Experimental Botany*, **23**, (3), 221–223.
President's Science Advisory Committee (PSAC) (1967) *The World Food Problem*, Vol. II. Washington, D.C.
Richards, J. F., Olson, J. S., and Rotty, R. M. (1983) *Development of a Database for Carbon Dioxide Releases Resulting from Conversion of Land to Agricultural Uses*. Oak Ridge Ass. Univ., Oak Ridge, Tennessee.
Salas, R. M. (1981) *The State of the World Population, 1980*. United Nations Fund for Population Activities, New York.
Slicher van Bath, B. H. (1963) *The Agrarian History of Western Europe, AD500–1850*. London.
Wit, C. T. de, and Goudriaan, J. (1974) *Simulation of Ecological Processes*. Simulation Monographs, Pudoc, Wageningen.