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Managing land for food production in the twenty-first century: an outline

1.1 POPULATION AND FOOD REQUIREMENTS 1

Agriculture is often seen as conservative in the sense that it changes only slowly. There are good reasons why this change is slow: agriculture is a complex activity that has to be adapted to particular environmental conditions, there must be no risk to food for the family, and the farmer has to perceive a material and usually financial benefit of any changes. It is nevertheless reasonable to assume that from the start of agriculture change has taken place in response to change in demand. The gradual change from hunting and gathering that supported limited, mobile populations to an increasing dependence on settled agriculture led to more and more people needing more productivity from the land.

Archaeological and historical records tell us about early innovations, for example the evolution and spread of the deliberate production of crops in different parts of the world aided by the introduction of such techniques as the animal-drawn plough, irrigation and terracing. Up until the last few centuries changes to agricultural practices occurred slowly. The changes became more rapid with the expansion of cultivation into new lands, with an increase in the human population and, especially from the sixteenth century, with the spread of crops between continents and countries and the development of more farm implements.

In the nineteenth and twentieth centuries the increase in demand for agricultural products was met by the use of more land, the introduction of higher-yielding crops and domesticated animals, and the use of fertilizers and pesticides. Of fundamental significance was the application of scientific methods. Farming no longer had to rely solely on experience and tradition. It could be made more secure by assessment of the natural resources, experimentation in the field and

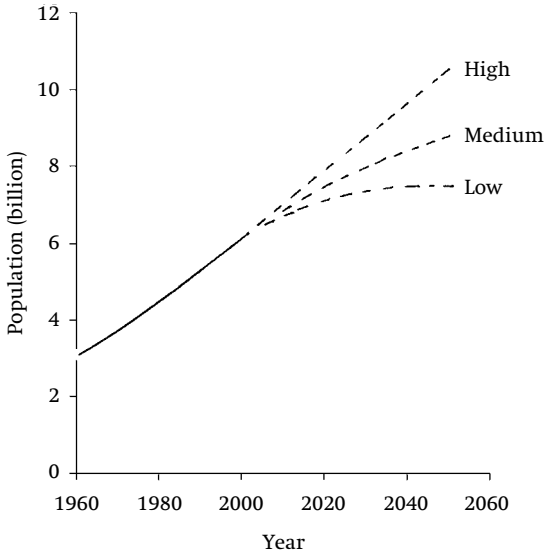

Figure 1.1. World population to 1995 with high, medium and low projections (variants) to 2050. Data from United Nations (1999).

laboratory, investigations of parts of the agricultural system and of the system as a whole, and monitoring the effects of the introduced changes. Although not always used, these methods have become more important as the increasing world population has resulted in the need for more productive and more efficient forms of agriculture in both rich and poor countries.

The upward trend in the world population since 1960 is shown in Figure 1.1. Depending on the assumptions made (the main one being by how much birth rates will change), the increase will continue until around 2040 or beyond 2050. In the medium variant the increase from 1995 is 2.15 billion people by 2025 and 3.24 billion by 2050 (United Nations, 1999). However, there is considerable uncertainty as projections are made further and further into the future: for example, the increases by 2050 are 1.67 billion and 5.0 billion in the low and high variants, respectively. Most of the growth will occur in Asia and Africa, as discussed in later chapters.

The demand for more food and other necessities of life will inevitably increase. If this increase is proportional to population, food production in the world as a whole, using the medium variant for the projection of population, will need to increase by 38 per cent between 1995 and 2025 and by 57 per cent by 2050. On the same basis the required increases in the less developed countries are 47 per cent and

72 per cent, respectively. These estimates do not take into account the clinically desirable need to raise calorie intake in poor countries or the trend, with urbanization, to greater consumption of animal products. If developing countries as a whole are to raise their nutritional levels and attain self-sufficiency in food production, the increase will have to be much higher. Imports by trade, or possibly as aid, from countries with surplus agricultural production will reduce the requirements, if the requisite foreign currency is available.

Food production can be raised by cultivating more land, increasing the yield of each crop, growing two or three crops per year on the same piece of land, or by a combination of these possibilities. Each can have problems. The best land, that is the land that is most productive, is usually already under cultivation. Most of the rest is forest or used for extensive grazing; further, conversion to agriculture results in loss of natural or semi-natural ecosystems. The other possibilities require more intensive methods of production, for example use of fertilizers and pesticides, irrigation, planting of higher-yielding crop varieties and mechanization. The conversion of land into agricultural use and intensification can cause both soil erosion and pollution of water supplies, although they need not, and deforestation to create more land for agricultural use adds to global warming.

Intensive agricultural practices have been subjected to public criticism in Europe, North America and elsewhere for several decades. To a large extent the criticism has been met by exercising greater control over the use of fertilizers and pesticides. More stringent regulations are now applied to the quality of water, food and air. Clear-felling and slash–burn of forests are criticized because of loss of plant and animal species and land degradation. Some of the important natural ecosystems are now protected. These are global issues that reached a wider audience with the publication of the Brundtland Report (World Commission on Environment and Development, 1987) and that will need more action as the demand for food increases.

The current trends in developing countries of rising crop yields and the use of more land for agriculture are expected to continue (Alexandratos, 1995). To cope with these continued increases successfully will require research, extension work, informed farmers and supportive policies from governments. Although this book deals mainly with the technologies required to support greater agricultural production, these are interwoven with several socio-economic requirements (Figure 1.2). Two examples of these requirements will suffice: firstly, fertilizers will not be used if the extra yield has less value in the market

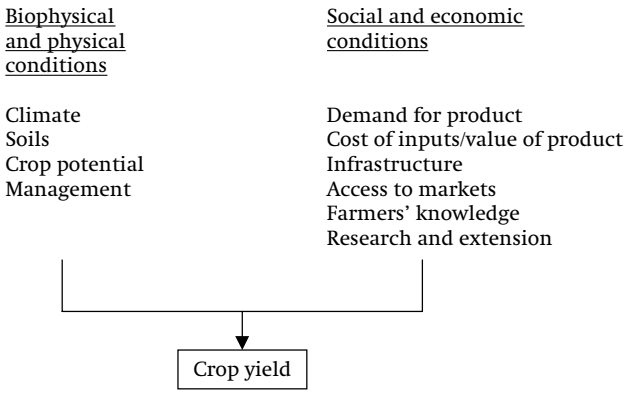

Figure 1.2. The conditions that determine crop yield.

than the cost of the fertilizer; secondly, a farmer with no land rights will move to new land, if there is any, rather than try to sustain production year by year. Two essentials for agricultural development, assuming suitable climate and soils, are that there is an incentive for the farmer and that the technological tools are available.

Returning to the population momentum, predictions indicate no significant decrease in the world population during the twenty-first century. Much greater agricultural production has therefore to be not only achieved but also sustained. Management must ensure that the land remains productive and, at the same time, that there is minimum damage to the environment. These are subjects for later chapters. First, some definitions are needed.

1.2 DEFINITION OF TERMS

The definitions given below are intended to prevent possible misunderstanding of the topics to be discussed, because not all authors attach the same meaning to the terms.

Land is the solid surface of the globe that usually supports biological production. Its components are soil, vegetation, animals and microorganisms; terrain (the physical features of land) is included in its description. When assessing land resources for agricultural development, the components also include climate, particularly rainfall and temperature, number and distribution of people, crops, domesticated animals, machinery, roads and markets.

Soil is the loose material composed of weathered rock and other minerals and also partly decayed organic matter and humus that covers

Table 1.1. *Examples of generalized farming systems, excluding intensive animal systems*

World farming systems (Grigg, 1974)	Farming systems of the tropics (Ruthenberg, 1980)
(1) Shifting agriculture	(1) Shifting cultivation
(2) Wet-rice cultivation	(2) Semi-permanent rainfed cultivation
(3) Pastoral nomadism	(3) Permanent rainfed cultivation
(4) Mediterranean agriculture	(4) Arable with irrigation
(5) Temperate mixed farming	(5) Perennial crops
(6) Dairying	(6) Grazing
(7) Plantations	(7) Regulated ley farming
(8) Ranching	
(9) Large-scale grain production	

large parts of the land surface of the Earth. In the context of arable farming it supports crop growth and can be tilled.

Agriculture includes all the economic production systems that depend on terrestrial plant biomass, that is, annual and perennial crops including herbage and pasture for human food and animal feed, livestock and animal products, timber and fuel wood, and materials for industrial and pharmaceutical use. The required resources are natural, human and economic.

Agricultural system (farming system) refers to a particular form of agriculture. Two lists of several systems, each of which has many variations, are shown in Table 1.1.

Agricultural development refers to increases in the output of the products from agriculture.

Land management is the management of land primarily for agriculture. Land on which commercial production is not profitable, or subsistence is not possible, is left for leisure activities, nature reserves or other purposes.

Environment, as used here, has four compartments: aerial (atmosphere, climate, weather), edaphic (soil), biotic (vegetation, animals, microorganisms), and aquatic (rivers, lakes, seas). Environmental conditions are all the chemical, physical and biological conditions that affect the growth, health and survival of plants, animals including man, and microorganisms.

Sustainable agriculture (reported by Harwood, 1990) is achieved by management of the land to produce, and to go on producing,

outputs that meet human demands as these increase, at the same time conserving natural resources and not causing irreversible damage to the environment.

Farming communities, dependent as they are on the land for their survival, have usually, but not always, been careful to leave it in as good a condition as they received it. Concern over the last few decades is that intensification of land use and the cultivation of new land, both of which are expected to increase in the future, might result in forms of land use that cannot be sustained or could cause permanent damage to the environment. However, the term 'sustainability' is often used loosely, without reference to space or time (Bell and Morse, 1999).

Management for sustainable land use (derived from Smyth and Dumanski, 1993) will simultaneously (i) maintain or increase output, (ii) reduce the risk of output failing, (iii) avoid irreversible damage to the environment and degradation of the land, and (iv) be economically viable and socially acceptable to farmers and customers.

This definition takes into account the economic and social requirements of land management, important issues which will be referred to in later chapters when agricultural development is discussed. Because there is no time limit on sustainability (it implies forever, which cannot be known), it is more useful in practice to define management that *cannot* be sustained rather than management that is sustainable.

Unsustainable land management leads to irreversible biological and physical changes affecting the ability of land to produce equally as well in future cycles of land use, or where the costs of reversing the changes are prohibitive.

1.3 IMPORTANCE OF SUSTAINABLE LAND AND SOIL MANAGEMENT

The use of land for agriculture affects all the natural resources to a greater or lesser extent. Mineral nutrients are removed from the soil in harvested crops, but can be replaced by applying fertilizers. Loss of soil by severe erosion, by contrast, is almost impossible to reverse, because of the prohibitive cost. Loss of soil organic matter, which usually occurs when land is brought into cultivation, causes management problems, especially in soils of the tropics, and is difficult to reverse. Another advantage of defining unsustainable rather than sustainable land management is that it focuses on what can go wrong.

The various forms of degradation that occur can be recognized at an early stage by monitoring the system, and remedial action can then be taken.

With increasing populations it is necessary not only for agricultural output to be raised, but also for that output to be sustained by appropriate methods of land management. Developing countries will address the problem of large increases in population (a doubling in some countries during the next 30–40 years) by using more land and raising crop yields. Sustaining this increased agricultural output will not be easy, because many of the countries have little high-quality land to develop and there will be a high risk of soil degradation. As discussed in later chapters, to be successful these countries will need financial investment, research, extension services, a thorough understanding of the diverse environments of farming systems and direct support for farmers.

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Natural resources for sustainable land management

2.1 INTRODUCTION

To function successfully, terrestrial ecosystems require light, water, air, a supply of essential mineral nutrients and a suitable temperature. All agricultural systems also have these biological and physical requirements, but in addition depend on socio-economic conditions, referred to in later chapters.

Both natural and agricultural systems are adapted to local environmental conditions and they therefore vary greatly over the Earth's surface. Their nature depends on climate, including solar radiation, temperature and amount and seasonal distribution of rainfall, supply of soil water and type of soil. These are natural resources that determine the way the land is managed, the agricultural system used and the system's productivity, including crop yield. The total production from arable agriculture depends on both annual crop yield and the area of land that is cultivated; in turn, these are determined by the demand for products.

2.2 AREA OF LAND

Of the total land area of the Earth about 10 per cent (14.8 million km^2) is cropland, and in any year about two-thirds of this area grows a crop. Part of the rest is used for grazing by domesticated animals. The remainder supports natural vegetation (more usually, secondary or derived vegetation), is desert, is covered by snow or ice, or is too steep or too cold for any agricultural use. Although the total land area is not constant, the rate of change is very small over a time span of 100 years.

The biggest change resulting from natural processes since farming began has been the loss of land caused by the rise in sea level,

counterbalanced to some extent by uplift of land masses. Since the Last Glacial Maximum around 18 000 years ago, global warming has raised the sea level by about 120 m (Fairbanks, 1989; various other estimates are in the range 60–180 m). Sea level reached about −25 m around 8000 years ago (Goudie, 1995) and may have risen between 2 m and 5 m during the last 2000 years. The causes of the rise in sea level were the melting of ice and the expansion of water caused by the rise in temperature.

Uplift occurred in northern latitudes when the load of ice melted. As the rate of ice melting slackened, other processes that caused uplift and subsidence of the land became important, for example uplift caused by plate tectonics. These effects can cause different local changes: for example, in the south and east of England the sea level is rising by up to 2 mm per year whereas in western Scotland there is uplift of the land at about the same rate (Goudie, 1995).

Earthquakes and volcanoes destroy land and create it, but more important is the land created by rivers, for example the deltas and valley alluvium of the Nile, Huang Ho, Yangtze, Ganges and Brahmaputra. The human influence has been to create new land from the sea, especially the polders in the Netherlands, and to lower the land surface by drainage and oxidation of organic matter, as in the Fens of eastern England (Richardson and Smith, 1977), and also the extraction of oil and water. The biggest human influence, however, has been to lessen the area fit for cultivation by urbanization and land degradation. The latter, some of which can be reversed, is discussed in Chapter 5.

2.3 CLIMATE AND VEGETATION

Vegetation zones of the Earth are determined primarily by climate, in particular by annual rainfall and its seasonal distribution, and by seasonal and day/night temperatures. The length of the growing season for rainfed agriculture is largely determined by the balance between evaporation of water from plants and soil and the rainfall during periods when the temperature is suitable for crop growth. Other factors are the presence of ground water, as in valley bottoms, and water storage in soil, the amount of which is affected by properties such as soil depth and particle size distribution.

For natural ecosystems the classification of Walter (1985) recognizes nine climate zones (zonobiomes), each with its characteristic vegetation (Table 2.1). Within each zonobiome there are orobiomes, at high altitudes, and pedobiomes, where soil properties have a greater effect

Table 2.1. *The nine zonobiomes of Walter (1985)*

	Climate	Vegetation
ZBI	Equatorial with diurnal climate, humid	Evergreen tropical rain forest
ZBII	Tropical with summer rains, humido-arid	Tropical deciduous forests or savannas
ZBIII	Subtropical-arid (desert climate), arid	Subtropical desert vegetation
ZBIV	Winter rain and summer drought, arido-humid	Sclerophyllous woody plants
ZBV	Warm-temperate (maritime), humid	Temperate evergreen forests
ZBVI	Typical temperate with a short period of frost (nemoral)	Nemoral broadleaf-deciduous forests (bare in winter)
ZBVII	Arid-temperate with a cold winter (continental)	Steppe to desert with cold winters
ZBVIII	Cold-temperate (boreal)	Boreal coniferous forests (taiga)
ZBIX	Arctic (including Antarctic), polar	Tundra vegetation (treeless)

on the vegetation than climate. For each biome Walter gives descriptions of the main types of vegetation and their associated climate on each of the continents. The area of each biome has become of increased importance because of the current loss of biodiversity. There is also concern that change of land use, especially deforestation, can change the rate of release of carbon dioxide into the atmosphere.

Changes in the past

Climate and changes in climate have largely determined the distribution of natural vegetation and soils, and agriculture has been similarly affected. However, there is little accurate information about the climate of any part of the world before the twentieth century. Although the first few measurements of temperature and atmospheric pressure were made in Europe in the seventeenth century, it is only during the last 100 years that climate measurements have been made over most of the land area and extended globally by observation from satellites.

Reconstruction of earlier climates and associated changes has instead depended on proxy data: movements of glaciers, the width of tree rings, records of pollen and insect remains, carbon-14 dating of peat bogs and a range of other methods. In addition, from more recent times, there are written records of extreme events such as very cold or