CHAPTER 1

Introduction

Few scientists think of agriculture as the chief, or the model science. Many, indeed, do not consider it a science at all. Yet, it was the first science – the mother of sciences; it remains the science which makes human life possible; and it may well be that, before the century is over, the success or failure of Science as a whole will be judged by the success or failure of agriculture

André & Jean Mayer (1974)

Preamble

The success or failure of agriculture may be judged in many ways but the most significant criteria will continue to be the adequacy, reliability and quality of our food supplies as the human population continues to increase. Most of our food comes from a small number of crop plants, and the improvement of their yield has been the main source of greater food production in recent years, and will continue to be so over the next decades. It remains the key to greater global carrying capacity, to freedom from hunger, to enhanced development in Third World countries and, in the light of the quotation above, perhaps even to the judgement of science.

In many developed countries, however, this latter proposition is likely to be little recognized and even less accepted. The proportion of their population engaged in agriculture is small, as is the proportion of income spent on food, the supply of which is varied, reliable, of high quality and taken for granted by the largely urban populations. Surpluses rather than deficits are the problem, so both the public and their political leaders see little need for research towards still greater crop yields. Currently, in fact, there are strong pressures in the opposite direction associated with the government subsidies that exacerbate these surpluses from high yields, the consumption of scarce resources in their production, and their environmental consequences.

In this context, agricultural research in these countries has been almost too successful. At the end of the eighteenth century the Reverend Thomas Malthus had expounded his view that whereas human populations could increase geometrically, their means of subsistence could increase only arithmetically. So he would have been surprised by the subsequent rise in the yields of wheat in England and rice in Japan, illustrated in Figure 1.1. Indeed,

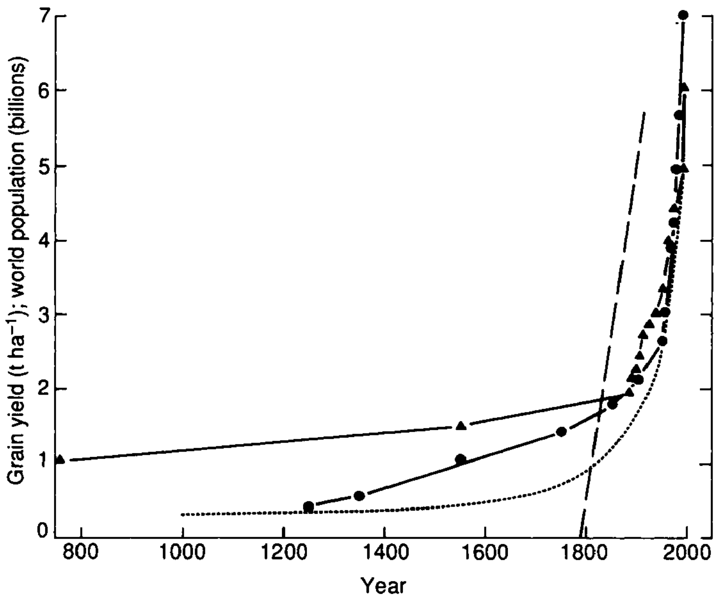

Figure 1.1. Historical trends in world population (......), and in the grain yield of wheat in England (●) and of brown rice in Japan (▲) compared with the limiting rate of improvement assumed by Malthus (1798) (——). Based on data assembled by Borrie (1970), Gavin (1951), Matsuo (1959), Stanhill (1976) and FAO Production Yearbooks.

for several European countries in recent years, food supplies could have increased geometrically whereas population has increased only arithmetically, if at all. Such a reversal of the Malthusian metric surely highlights the success of agricultural science, as does the downward trend of 1% per annum in the real price of wheat and other staple foods over the past 100 years. Nevertheless, Calder wrote in 1967 that ‘agriculture is simply failing us’, and went on to suggest that the world would have to rely on alternative food-producing systems such as aquaculture, single-cell protein and synthetic foodstuffs. Since Calder made his claim, the world has not only continued to rely as heavily as ever on agriculture for food, feed and fibre, but has also looked to it increasingly for fuel, feedstocks (Ng *et al.*, 1983) and pharmaceutical precursors.

Why then must further increases in yield be sought? In most developed countries arable land continues to be lost from agriculture for urban development, highways, airfields, water catchment, recreational parks, conservation areas, afforestation, etc., so yields from the remainder must be made able to increase. Indeed, only rising yields will permit the diversification of land use and the protection of vulnerable areas and of biological diversity which are likely to become more prominent issues in the future. Most deforestation is due to the spread of agriculture. The cost-price squeeze experienced by farmers continues its apparently inexorable course, and rising land prices can accompany cheaper food only by the further raising of yields. More intensive crop production will also be needed to enhance the stability and quality of food production, and will be encouraged by the rise in atmospheric CO_2 level. Above all, while developed countries may take assured food supplies for granted, this is not the case in developing countries. In these, most of the people still live in rural areas, and food accounts for a high proportion of their income. The yield of their crops is a subject of great interest: feast or famine depend upon it. Moreover, their populations are still growing rapidly, and rising yields are needed to meet local food requirements. Food aid and trade may help out in crises, but are no substitute for local self-sufficiency when transport and communication systems are poorly developed. Only with a substantial rise in crop yields are they likely to achieve their demographic transition.

Thus, the yields of crops, and ways of increasing them further, are likely to be as important in the long-term future as they have been in the past. They have been considered in many books dealing with individual crops, countries or regions or from the perspective of particular disciplines, quite apart from the writings of a long line of prophets of doom, whose prophecies have been overtaken even before they were forgotten (e.g. Paddock & Paddock, 1968).

The aim of this book is to attempt a more comprehensive approach and to develop a more rounded picture of crop yield and its improvement. Although it draws heavily on the staple food crops for examples, many others both temperate and tropical are also referred to. Several disciplines are invoked – while recognizing the hazards of such a broad approach – but the central perspective is that of a crop physiologist rather than of a plant breeder. The core of the book deals with the physiological nature of crop domestication, adaptation and improvement, and the picture that emerges has important implications. It bears, for example, on the relation between plant breeding and agronomy, on the role of inputs and on the likelihood of significant advances in yield under low input or adverse conditions. Enthusiasm for plant breeding programmes for such conditions would be tempered by a better understanding of the nature of what has been achieved so far, as would many criticisms of 'the Green Revolution'. The perspective also bears on the relative advantages of breeding for wide adaptability as against more specific adaptation, on the reliability of yields, and on strategies for agricultural research. Empirical selection for yield will no doubt continue to succeed in the future as it has so effectively in the past, despite the periodic claims that we have reached the yield plateau. But if the promise of biotechnology and molecular plant breeding is to be translated into yield gains, the nature of the yield-limiting processes in crops needs to be better understood.

Because the book ranges rather widely, this introductory chapter traverses its overall structure and arguments. Before that, however, we should consider the various criteria of crop yield.

Criteria of crop yield

When our ancestors harvested the fruits, seeds or tubers of wild plants, they were probably more concerned with the variety, ease of harvest or preparation, and transportability of the foods available to them than with their yield. Since the beginnings of agriculture about ten thousand years ago, however, yield has been an important attribute of crops, although the yield criterion of most immediate interest has changed.

For those who gathered grain from the wild cereal stands in the Fertile Crescent of the Near East, the most appropriate criteria were likely to have been how quickly the grain could be harvested before it was shed on the ground, and with what effort. Harlan (1967) gathered over a kilogram of clean seed per hour from wild wheat stands in Turkey, using only his hands or a flint-bladed sickle and concluded that 'A family group . . . working slowly upslope as the season progressed, could easily harvest wild cereals over a three-week span or more and, without even working very hard, could gather more grain than the family could possibly consume in a year . . . a very attractive alternative to living by the chase'. Harlan would have gathered about 50 calories for each calorie he spent on harvest, but not all wild plants yield such an abundant return. Those with larger seeds, with more seeds per inflorescence, or with more compact or uniformly ripening panicles, features that increase the speed of harvest, may have been preferred. For example, although oats, wheat and barley are found together in wild stands, wheat and barley can be harvested more quickly than oats with its smaller grains and less compact and evenly maturing panicles, as Ladizinsky (1975) has shown, and they were domesticated sooner.

Once the sowing of crops became established practice, a new criterion of yield became important, namely the ratio of seed harvested to seed sown. This is the measure of yield mentioned in the Bible, by Roman writers such as Columella, and throughout the Middle Ages (cf. Slicher van Bath, 1963; Titow, 1972). In fact, this is the measure of crop yield that has been used throughout most of the period since agriculture began, and was used by Malthus (1798) as a metaphor for the power of geometric increase in populations. Its significance, especially in times of shortage, was that the grain set aside for sowing had to be foregone as food, entailing considerable discipline when yields were often only 3–4-fold and fell as low as 1.8-fold, which happened for wheat in England in the thirteenth century (Slicher van Bath, 1963). No wonder Peter Kalm, a student of Linnaeus, was so impressed by maize when told it returned at least 300-fold that he called it 'the lazy man's grain' (Oxholm & Chase, 1974). Millets are supposedly so-called because thousands of grains are harvested for each one sown. Even wheat and barley could return 'an hundred fold' as in the parable of the sower (Matthew 13:8), but such high ratios probably referred to individual plants although modern record crops of wheat can return ratios of more than 160.

As long as the ratio of seed harvested to seed sown was an important criterion of yield, cereals may well have been unconsciously selected for abundant tillering, large inflorescences, small grains and weak seed dormancy. However, as the supply of arable land came under greater pressure, yield per unit area per crop became a more important criterion, and remains so. Much of the discussion in this book is concerned with it and with characteristics enhancing it, which may be quite different from those giving a high seed return ratio.

Rising pressure on the supply of arable land may, where climate and water supply permit, lead to more intensive multiple cropping. In tropical regions particularly, more frequent cropping is an important component of greater crop production, and under these circumstances yield per hectare per crop becomes less important than yield per hectare per day. With this latter criterion of yield come new selection pressures, particularly on the speed of reproductive development and its sensitivity to seasonal daylengths. Among Philippine rice varieties, for example, grain production per hectare per day has increased more strikingly than grain yield per hectare per crop (Evans *et al.*, 1984; Khush, 1987).

As pressures on the area of arable land continue to increase – as they will do for many years to come – irrigation, fertilizers, pesticides and other inputs are used to an ever greater extent as substitutes for land by raising yield per hectare. When these other agricultural resources in turn become limiting, crop yields may be assessed not only in terms of land area but also in terms of the amount of water or phosphorus or energy used in their production. In the longer term, the capacity to yield under high ultraviolet radiation or atmospheric CO_2 or pollution levels may also be important. In countries where wages are high, output per worker may be of as much consequence as yield per hectare. Geertz (1963) points out that although both Japan and Indonesia raised the yield of rice per hectare, only Japan also raised the output per farm worker, thereby avoiding 'agricultural involution'.

Thus, yield criteria for crops in the future, as for those in the past, may differ from those currently being emphasized, and as they change so may the yield-limiting processes and the characteristics for which crops are selected. In self-sustaining life support systems for space exploration, for example, yield per unit volume per day is an important criterion.

Moreover, given the preoccupation with crop yield throughout this book, it should be made clear at the outset that the raising of yield as measured by any of the criteria discussed above is not always the most urgent task of the plant breeder. Simply maintaining yields at previous levels in the face of onslaughts by new forms of pest and disease organisms may be more urgent, as may better survival in adverse conditions or the reduction of labour or other costs. Nevertheless, many surveys, like that for rice by Hargrove (1977), have found greater yield potential to be the plant breeder's most common objective.

Crop yields and the world's food supply

In the next chapter we focus on the crucial part played by the improvement of crop yields in raising world food production in recent years. As Figure 1.1 illustrates for both wheat in England and rice in Japan, it is only in the past century or so that the national yields of these staple cereals have risen rapidly, from less than 2 to more than 6 tonnes per hectare, while world population has risen from less than 2 to approaching 6 billion people over the same period.

Throughout the preceding millennia the food requirements of the growing world population could be met by putting more land under crops. Comprehensive statistics for crop area, yield and production in the world were not collected regularly until the International Institute of Agriculture in Rome, beginning in 1908 and followed by the United Nations Food and Agriculture Organization (FAO) after World War II, began publishing them. Only then could global housekeeping begin in earnest, although some earlier writers had attempted to estimate world production, most notably Crookes for wheat in 1898. Estimates of crop areas and yields are also made by other agencies now, to circumvent some of the problems of official statistics, while dietary surveys extend the production figures to estimates of human consumption, taking account of post-harvest losses and alternative uses such as animal feed.

However, it is the variation in food consumption between social groups, and between years or even seasons, that is particularly significant in assessing malnutrition and the need for more food. Changes to official nutritional standards (e.g. FAO/WHO, 1973) also have a profound effect not only on estimates of the number of hungry and malnourished people in the world, but also on the relative emphasis given to energy as against protein supplies. In turn these influence the relative importance attached to energy-rich crops such as the cereals vis-à-vis the higher-protein legumes. Both the statistics and the nutritional standards have their shortcomings, and these should be borne in mind throughout this book. Figure 1.2 illustrates the geography of dietary energy supplies per head.

Although increase in crop area has been the main source of increased food production since agriculture began, this is no longer the case in the more densely populated developed countries, in some of which the arable area is beginning to decline. Even in these countries, however, cultivation may be extended to new areas as a result of plant breeding and new agronomic practices. For example, the breeding of varieties more tolerant of adverse soil or climatic conditions may extend the arable area, while the introduction of minimum tillage techniques sometimes allows steeper slopes to be safely cultivated. It is no simple matter, therefore, to estimate how much additional land could be brought into cultivation, and on this important issue optimists and pessimists differ almost as much as they do on the estimation of ultimate crop yields.

Our perception of the driving force in agricultural development also influences our expectations of crop yields. In the Malthusian analysis that was so crucial to both Darwin and Wallace, population growth is dependent on increase in the food supply. By contrast, Boserup (1965, 1981) argues that population growth is the independent variable and a major factor in determining agricultural progress. She believes, as does Clark (1967), that this is a more realistic and fruitful assumption, and she presents examples of its operation. Howell (1987) suggests that it was population pressure which led to the spread of agriculture through Neolithic Europe, and many other examples of it being a driving force in agricultural change have been suggested (cf. Flannery, 1972). The drive to increase food production in Asia in the 1960s, often referred to as the 'Green Revolution', and the efforts currently being made in Africa to reverse the decline in per capita food consumption associated with rapid population growth, illustrate Boserup's thesis. However, there are also instances where population pressure is not the driving force (see, for example, Bronson, 1977). Modern European agriculture is a case in point.

Besides greater area under crops and greater yields, two other components contribute to rising food production. The first is of greatest significance in more tropical regions where either rainfall or irrigation can support crop growth throughout the year. Under these circumstances, intensification of cropping, i.e. harvesting more crops each year from the same piece of land, may enhance local food supplies as much as increased yields can, and may be easier to realize. The contribution made by crop intensification is not easy to

Cambridge University Press
978-0-521-29558-1 - Crop Evolution, Adaptation and Yield
L. T. Evans
Excerpt
More information

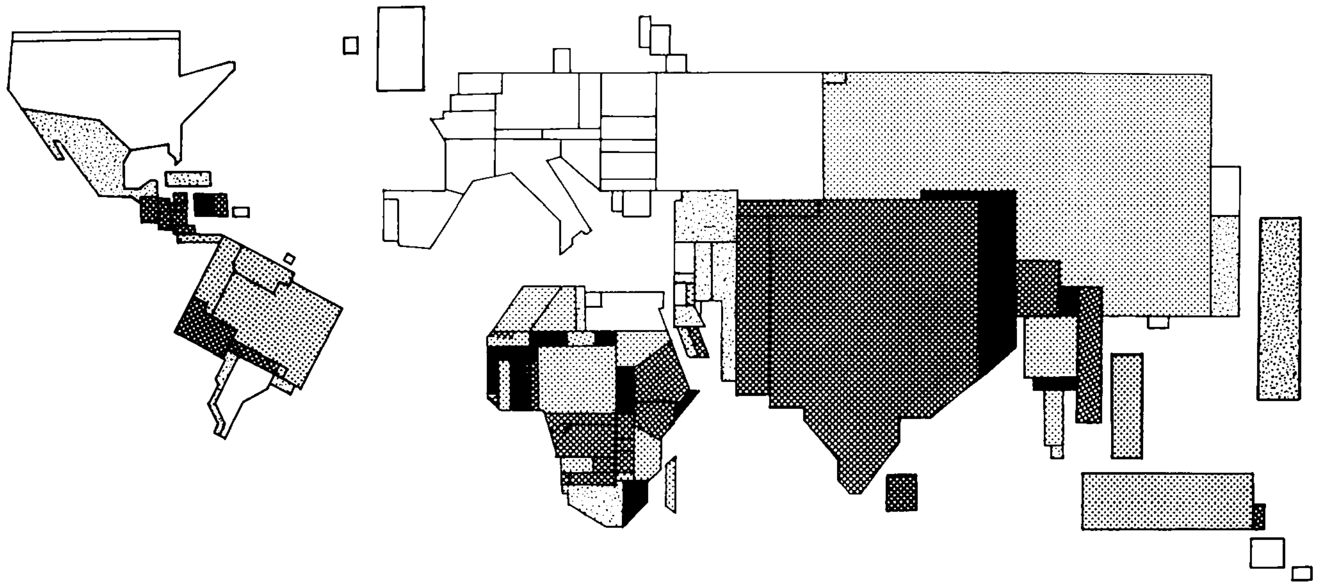

Figure 1.2. The geography of dietary energy supplies per capita, 1979–81 (adapted from FAO, 1987). The relative size of countries is shown in proportion to their population, while their hatching indicates average calorie intake, ranging from over 3000 (no hatching) through progressively heavier hatching to less than 2000 (solid black) kilocalories per head per day.

extract from official statistics. Unlike greater yield per crop, it depends on the shortening of crop life cycles, but shares with it the need for greater use of inputs such as irrigation, fertilizers, pesticides and herbicides.

The other component of rising food production is the shift towards relatively greater dependence on a small number of staple food crops. These tend to displace other traditional crops because of their higher yielding capacity, wider adaptability or greater reliability, and despite the possible disadvantages of a reduced variety of foodstuffs, lower nutritional status or more vulnerable and depletive farming systems. Of the large number of species domesticated by mankind, many are no longer cultivated or have become much less significant, such as Job's tears (*Coix lachryma-jobi*) and several species of *Amaranthus*. The world's food supply is now dominated by three cereals and a few other crops (Figure 1.3). Even the major pulses are being displaced by cereals in countries, such as India, where they are important both nutritionally and for their role in the farming systems. The staple crops are, more and more, being selected for performance in environments beyond their previous range: for example wheat and potatoes for the hot tropics, rice for cooler areas and maize for drier ones. So significant are these few staple crops to mankind that the basis of their productivity and adaptability merits a greater understanding than we currently have.

Although increases in arable area have been more important in the past, and increases in cropping intensity may be important in the future, it is greater yield per crop which has been the key to greater food production in recent decades and is likely to remain so in the coming ones. The extent to which yields of the major cereals have risen in many developed countries has been a remarkable achievement. Malthus (1798) suggested that even 'the most enthusiastic speculator' could not expect British wheat production to increase by more than the then current level of production in a period of 25 years. The yield of wheat in England at that time was about 1.6 t ha^{-1}, and since 1950 it has increased at a faster rate than Malthus allowed his most enthusiastic speculator, as may be seen in Figure 1.1. This rate of improvement may seem modest by comparison with many other improvements, such as the functions per computer chip (Meindl, 1987), the efficiency of illumination (Starr & Rudman, 1973), or the yield of penicillin (Aiba *et al.*, 1973), yet it remains the key to the solution of the world food problem.

The why, when, where, what and how of domestication

Chapter 3 begins with a consideration of hunter-gatherer societies, as a background to the processes of plant domestication which began about 10000 years ago. Whatever our views of hunter-gatherers – and these have ranged from Rousseau's 'noble savages' all the way to the 'living fossils'

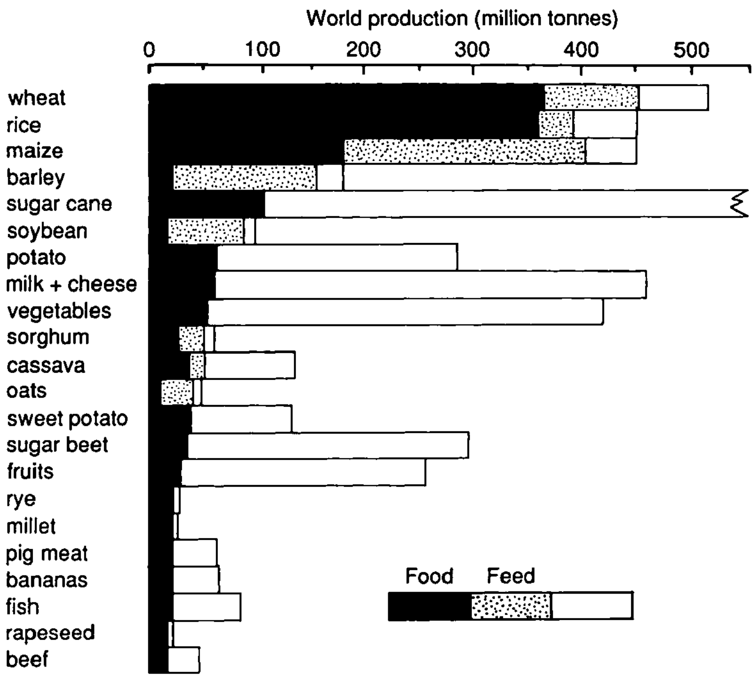

Figure 1.3. World production of the major foods in 1987. The overall length of each bar is proportional to the harvested weight of the commodities, based on data from the FAO Production Yearbook; the dotted bars indicate the amount used for feed, where known (Sarma, 1986), and the solid bars the amount available for food, in terms of estimated edible dry weight. The harvested weight of sugar cane is about one billion tonnes.

portrayed by Victorian biologists and then back to 'the original affluent society', in Sahlins' (1968) phrase – the development of agriculture was a crucial step in human evolution because in domesticating plants and animals mankind was also domesticated. The area of land needed to support each person was greatly reduced, settlements could be permanent, and complex civilizations became possible.

As keen observers of nature, hunter-gatherers were probably well aware of the facts of plant life long before they were put to use in agriculture. Although aboriginal people in Australia did not domesticate any plants or practise cultivation, they recognized the relation between seeds and plants, and when gathering wild millet they sometimes scattered seed about to ensure next