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Part III

Food Production

Chapter Seven

The Natural Environment and Food Production

Pieter Buringh

Studies on Food Production

In a speech in 1898 the president of the British Association for the Advancement of Science, Sir William Crooks, stated that the area of virgin land that could be reclaimed for growing crops was very small. He predicted a worldwide famine for the year 1930 unless chemical nitrogen fertilizers could be made by using nitrogen from the air. (Russel, 1954; Baade, 1960). During World War I chemical nitrogen fertilizers were manufactured, and plant genetics and plant breeding had produced new crop varieties. There was no worldwide famine in 1930, and now it is known that the acreage of land suitable to be reclaimed is even larger than the acreage of land cultivated.

In 1923 Baker published an article on land utilization in the United States. He believed that within a few years more agricultural products would have to be imported than could be exported, because of the increasing population, and he anticipated that food from tropical countries would come to American markets in increasing quantities.

These two examples demonstrate that it is difficult to predict the future. It is wiser not to predict but instead to study the problem of food production and find out how national and international policies could be changed to prevent famine. This is what has been done in recent years by some groups of scientists. It is well known that hunger and malnutrition in the poor countries of the world is one of the most important problems of today. The food problem is caused not only by the exponential growth of the world population, but also by the simple fact that not enough food is produced in the countries where it is needed. Moreover the food problem is not a problem of the poor society alone, it is also the problem of the rich societies, and it is our problem, too, as we shall elaborate on later.

Without mentioning various authors who have tried to study the possibilities of food production for specific countries or for the whole world, attention will be given to recent studies and their results. An important report was made by the President's Science Advisory Committee (PSAC) for the President of the United States in 1967 (PSAC, 1967). Based on knowledge of soil conditions and climate, an assessment was made of land suitable for cultivation. PSAC stated that the cultivable area is 1,406 million hectares (Mha) and the potential cultivable area is 3,190 Mha (respectively 11 percent and 24 percent of the total non-ice-covered land area of the world). Part of this land can be cropped twice or three times annually. Some 400 Mha can be irrigated; 200 Mha are already irrigated. The conclusion is that much more food can be produced than is done at present. Revelle (1976), a member of the PSAC, and Meadows (1975) estimate that some 50 billion people could live on the earth.

Since the modern computer and a new scientific method—systems analysis—became new tools for dealing with a complex system and a large amount of information, world models dealing with the food problem have been developed. The first model by Meadows et al. (1972), described in the famous book *The Limits to Growth* (the first report for the Club of Rome), did not give hopeful results. With an increasing population, more land is needed for nonagricultural purposes, and on all land available more food has to be produced. It was expected that by the year 2000 no new land for reclamation would be available if trends continue as they did during the last decades. And if the productivity of the land would be quadrupled, this situation would be reached before the year 2050.

The second study for the Club of Rome by Mesarovic and Pestel (1974) was not too optimistic either. It has many mistakes on the points of land suitability and possible crop production. The third study, *A Latin American World Model: Catastrophe or New Society*? (Herrara et al., 1976), had radically different and much more optimistic results. It was argued that the major problems are not biological and physical but sociopolitical. The work was performed at the Fundation Bariloche in Buenos Aires.

The fourth world model, *Model of International Relation in Agriculture* (MOIRA), made by a Dutch team guided by Professor Linnemann, will be published shortly. The main parts are already available (de Hoogh, 1976; Linnemann, 1977). As a member of this group, I studied, together with some other specialists, the potentialities of all land, as well as the theoretical maximum food production on this land, in order to have some idea of the ultimate possibilities of the world food production (Buringh et al., 1975).

The results of this investigation indicate that the area of potential land suitable for cultivation is 3,419 Mha (26.3 percent of the land surface). This is almost the same as the result of the PSAC, although we have used much more up-to-date information on soils, as the new soil map of the world (FAO/Unesco, 1971/77) became available. Taking into account various physical limitations (soil conditions, climate, photosynthesis, and so on), we found a theoretical upper limit of food production of 40 times the present production, when this production is expressed as grain equivalent. Approximately 65 percent of the cultivated land is used for cereal crops; some 30 times the present grain production could be produced on that land.

These results, like those mentioned here, should not be used without studying in detail the original publications, because various assumptions have been made and limitations are indicated. Moreover it is necessary to introduce various reduction factors to get realistic data. The economists of the MOIRA group have used the data on available land and productivity for other model studies to find out, for various policies, if the world food problem can be solved by the time the population has doubled, approximately the year 2010. The conclusion is that this is hardly possible; food aid will still be necessary, poor countries will have to try very hard to produce food for their respective populations, and the rich countries will have to change policies drastically.

The general conclusion of the PSAC, the Bariloche, and the MOIRA studies is that economic, social, and particularly political conditions in the world are limiting the production of food and not the availability of cultivable land or the productivity of this land. It is not agriculture or the present knowledge of agricultural technology that sets the limit now and for a long time ahead. Reference is made to a series of interesting articles in *Scientific American*, September 1976, in which, for example, Wortman (1976), Revelle (1976), and Loomis (1976) state that the situation about the world food problem is hopeful.

Clark and Cole (1976) have made a comparison of the four major world models mentioned previously. From the point of view of food production, an important difference in these studies is that Meadows studied the world as one region, Mesarovic and Pestel divided the world into 10 regions, the Bariloche group into 4 regions, and the MOIRA group into 222 regions (for the economic studies in 116 regions). In the MOIRA study (Buringh et al., 1975), maps of all continents showing these 222 regions are presented, and all formulas, data, and assumptions are given.

From these investigations it is easy to see that studying the world food problem based on extensive information has just started. Much more detailed work has to be done, methods have to be improved, and more reliable information is badly needed. The reliability of global and national data, at least of most countries, is rather weak. The reasons for this have been published by Farmer in Hutchinson's *Population and Food Supply* (1969). In the meantime some of the groups already mentioned, as well as groups in Austria and Japan, are working on new and improved world models in relation to the food problem.

Food Production Compared with Food Needed

The main food is grain (wheat, rice, and corn). The world grain crop was 1,220 million metric tons in 1975 (U.S. Department of Agriculture) and 1,270 million metric tons was the average for 1972-1975. If this could be equally distributed over the world population, nobody would be hungry. But, because of the unequal production and distribution of these cereals, millions of people are undernourished or hungry, and thousands of them die each year. According to the United Nations, 400 to 500 million people of the total world population of 4 billion are hungry or undernourished. Poverty is the reason that the hungry people cannot buy food. It is a problem of 10 million villages with 2 billion inhabitants and of the people living in slums around big cities.

In 1985 some 700 or 800 million people will be hungry. In the year 2010 the world population will be double, 8 billion. Some specialists believe that, from the year 2125 on, the world population will be constant, with 12 billion persons, who will need five times the quantity of food we produce at present (Koppejan, 1976).

Although some specialists state that the number of hungry people estimated by the United Nations is too high (400 million—it should be 70 million), it is generally agreed that the world population will double in 35 years' time. This means that at least two to three times more food has to be produced by the year 2015.

In calculations, food has to be expressed in a comparable unit; for example, in kilocalories per day per person, in kilograms protein per day per person, in kilograms grain per year per person or in hectares per person, or the acreage needed to produce food for a person. In the last case a person's need for space to live and for the infrastructure has to be calculated as well. As there is no consensus on the figures for these units, the results of various calculations often are rather different, particularly when they are used on a global scale.

The production of food depends greatly on soil conditions, climate, types and varieties of crops, and, in particular, on farm management.

Consequently there are not only important differences among the various countries, but also—and even more important—regional differences in food production. This is the reason that computations are made for 222 regions in the MOIRA study, although even this study is still rather crude.

Some countries produce much more grain than they need for their own population. The United States, Canada, and Australia are the main grain-exporting countries (exporting 96, 12, and 7 million tons respectively in 1975/76). In the tropics, Thailand is the only country exporting rice and corn. The total world trade in grain averages 115 million tons a year. The main importing countries are the USSR, Western Europe, and Japan. The need of all importing countries is expected to increase annually by 30 million tons of cereal-grain (Brown, 1974). In 1968 there was a grain stock of 128 million tons. Because of several reasons to be mentioned later, this stock was only 24 million tons at the end of 1974.

For those countries where people are poor, only a small amount of food can be bought; and, if there is a shortage in the rich countries or in the centrally planned countries, cereal prices will increase rapidly and the poor countries cannot buy. According to a 1974 United Nations' report, the poor countries will need 85 million tons of grain annually during the next eight years. Wortman (1976) estimates the deficit of grain in 1985/86 at 100 million tons if trends of the last 15 years do not change. These figures indicate the problem of today as well as tomorrow.

The cultivated grain (mainly wheat, rice, and corn) provide 75 percent of the energy and protein needs of man. These cereal crops are grown on 65 percent of the cultivated land of the world. Not all land that is cultivated provides a yield every year, because part of it is fallow or is temporarily used for grazing. The cropping intensity of the cultivated land in the world therefore is approximately 60 percent (figures vary from 50 to 65 percent). The remaining part of the cultivated land (35 percent) is used for growing root and tuber crops, vegetables, fruits, and the like, and for nonfood crops.

Besides the 1,406 million hectares of cultivated land, there are currently 4,000 million hectares of grazing land. The animal production on this grazing land contributes a very low portion (2 percent) of total food production; consequently it is hardly necessary to take this into account in global models. Livestock today is mainly raised on good pasture land (part of cultivable land), or is fed with products of cultivated land. The PSAC (1967) concludes that, in addition to the 3,200 million hectares of cultivated land, some 3,600 million hectares could serve for grazing livestock. However, this grazing land can provide only a few grams of animal protein per person per day for the estimated world population in the year 2000.

Food production of the sea can also be neglected in calculation on a global scale, because it is only 1 percent of all food. Marine organisms will never produce considerable amounts of food when compared with production of food on land. Fresh water fishing is 12 percent of the total world catch, and the total protein from fish is less than 2 percent of the world protein production, even when the fish catch is considered to be very high (Korringa, 1972).

Synthetic food is no solution for the world food problem (Wortman, 1976), nor is industrial food made from nonedible farm products. So on a global scale food products from grazing land, oceans, fresh water, and synthetic food can be overlooked in calculation. These products, however, can be important for specific regions.

The conclusion is that cereal grains (65 percent of the cultivated land, 75 percent of the food energy) are most important for mankind; consequently more attention should be given to cereal crops.

Cereal-Grain Crops

The annual yield of a cereal crop may vary from 600 to over 20,000 kilograms per hectare. The low yield reflects the traditional farm technology of almost two-thirds of the world's agriculture that is characterized as subsistence farming, with simple farm management, absence of chemical fertilizers, and therefore small energy subsidy and low output.

The yields are mainly limited by the amount of nitrogen supplied by nature. Such traditional farming has existed in Western Europe since the Middle Ages, when the yield of cereals was an average 800 kilograms per hectare. From this the farmer needed 200 kilograms for seed for the next year, 300 kilograms for beer and food for animals, and the remaining 300 kilograms for food for the farmer's family (de Wit, 1973).

Later on the yields were increased by using a somewhat improved traditional farming system (crop rotation, introduction of legumes, fodder crops, and consequently production of more and better stable manure). Yields of 1,500 and sometimes 2,000 kilograms per hectare were obtained. The next step was a farming system improved still further (better tools, some machines, some fertilizers, and so on), which grdually became a rather modern and finally a modern system of farming based on scientific technology.

Now the average yield of wheat crops in a modern system of farming, as in the Netherlands, is over 5,000 kilograms per hectare, the U.S. average being 2,200 kilograms per hectare (1972). With a very modern system of farming, yields of 7,000 kilograms per hectare and more can be obtained. The biological maximum yield (the photosynthetic potential) of a wheat crop in the Netherlands is over 10,000 kilograms per hectare. This is an absolute maximum since it is assumed that there are no limitations in nutrients and water supply, no pests and disease, and no weeds; therefore, the solar radiation, and consequently the photosynthesis of the crop, is the final limiting factor (de Wit, 1973).

The biological maximum depends on climatic conditions, which are more favorable in the tropics than in more temperate zones. A rice crop, for example, may produce almost 10 tons of padi; and when three crops can be grown in one year, the yield per hectare increases to 26,000 kilograms (de Vries et al., 1976; van Ittersum, 1971). However, as the average yield of rice in the tropics is only approximately 2,000 kilograms per hectare padi, this indicates that a traditional system of farming (including some irrigation) is the general farm practice. Irrigated rice fields have a more natural supply of nitrogen, because of blue algae, than nonirrigated fields.

For corn the average yield in traditional subsistence farming in the tropics is 1,000 kilograms per hectare. When advanced farm technology is applied in the tropics, an average yield of 7,000 kilograms per hectare is obtained (Young, 1976), whereas the maximum yield on an experimental field has been 20,000 kilograms per hectare. The average corn yield in the world is approximately 2,100 kilograms per hectare, the average of the U.S. Midwest is over 6,000 kilograms per hectare, and the highest yield has been 17,000 kilograms per hectare.

Similar examples can be given for many other crops. They simply demonstrate the fact that in general most farming in the world is still done in a very simple way based on traditional technology. Farming techniques have remained almost unchanged for centuries. Farming is mainly subsistence farming on small areas; 80 percent of the world's farmers till an area smaller than 5 hectare! Modern farming is practiced on a rather small scale. Agriculture in industrialized countries has made great progress during the last decade. In the United States, where farm technology recently is changing from semimodern to modern, however, it is still of intermediate intensity (Loomis, 1976). Although agriculture in the United States is highly mechanized, much can be improved. The average yield of wheat and corn is respectively 2,200 and 4,000 kilograms per hectare. Examples of high yields on some farms indicate that much higher averages are possible. The biological maximum for a cereal crop is calculated at 11 to 18 tons per hectare for the central part of the United States (Buringh, et al., 1975).

Sometimes individual farmers may get very high yields under favorable conditions. On experimental fields yields may be one and a half or two times the average farm yields. Ittersum (1971), who has made calculations on rice yields, states that farmers who apply modern farm technology will obtain 65 to 75 percent of the photosynthetic maximum.

It is concluded, and this is not new, that most farmers in the world can produce much more food on the land that is currently cultivated if they apply better agricultural technology. It is unrealistic to compute the world cereal-grain production for all cultivated or for all potentially cultivable land on a basis of modern farm management applied by all farmers or on a basis of the photosynthetic maximum production, because the modernization of farming cannot be obtained in a few years. Improvements in farming are made step by step.

Statistical data collected by FAO give an idea of food production per hectare in the various countries. These data, however, are not very accurate, at least for most countries. To get an idea of the present performance of the world's farmers, as far as cereal-grain production is concerned, an approximation has been made of the present production classes and the acreage involved, taking care that the total production is 1,270 million tons—the average 1972-1975 cereal production of the world. This quantity is produced on 65 percent of all cultivated land (1,406 million hectares). Consequently 914 million hectares are cereal crops.

The world average maximum photosynthetic production on such an area is 13,400 kilograms per hectare (Buringh et al., 1975). If it is assumed that 0.1 percent of the harvested land is yielding 50 percent of the maximum yield (6,700 kilograms per hectare), the total production of this land would be 67 million tons of cereal grains, which is 0.5 percent of the world total. This and a similar calculation for five more groups is given in Table 7-1. If the world's agricultural technology is somewhat improved so that half of the area in each group could go one class up, the results would be a total production of 138 percent (see Table 7-2). Both tables, although they are rough approximations, indicate what the world production of cereal crops can be if agricultural technology is somewhat improved all over the world for half the area of each group.

Another possibility to increase the amount of food available in the world is better storage. Specialists estimate storage losses of 10 to 40 percent. In the United States post-harvest losses are 10 percent (Wortman, 1976), whereas in most tropical countries they are 40 percent or more. If these losses are limited to 20 percent, approximately 150 million tons more grain is made available for human consumption.

Table 7-1. Estimated Production Classes and Their Average of Cereal-Crop Production in the World (present situation)

Area			*Yield*		
Percent	*Mill. Hectare*	*Percent of Biol. Max.*	*Kg/Ha*	*Million Tons*	*Percent of Total*
0.1	1	50	6,700	6.7	0.5
.4	4	40	5,400	21.6	1.7
2.5	23	30	4,000	92.0	7.3
17.5	160	20	2,700	432.0	34.4
35.7	326	10	1,300	423.8	33.7
43.8	400	5	700	280.0	22.4
100.0	914			1,256.1	100.0

Table 7-2. Estimated Production Classes and Their Average of Cereal-Crop Production in the World (somewhat improved situation)

Area			*Yield*		
Percent	*Million Hectare*	*Percent of Biol. Max.*	*Kg/Ha*	*Million Tons*	*Percent of Total*
0.1	3	50	6,700	20.1	1.2
.4	14	40	5,400	75.6	4.4
2.5	91	30	4,000	364.0	21.0
17.5	243	20	2,700	656.1	38.0
35.7	363	10	1,300	471.9	27.3
43.8	200	5	700	140.0	8.1
100.0	914			1,727.7	100.0

The number of horses and mules in the United States was 25 million in 1916 and 3 million in 1959 (Baker, 1960). This demonstrates how much land that formerly was needed to feed these animals (in general the yield of one hectare for one horse), has become available for human food production because of mechanization. There are 350 million farmers in the world, and there are only 10 million tractors. Maybe here, too, is a key to increased food production, although not all land producing food for animals is suitable for growing cereal or other crops.

It is well known that much more fossil energy is needed for modern agriculture than for traditional or improved agriculture. During recent years various investigations have been carried out. Most traditional farmers only use human labor or human labor and animal traction, and have simple tools. From the viewpoint of fossil-energy consumption, traditional subsistence farming has a high overall efficiency because of very small energy subsidy. In highly mechanized farms much fossil energy is needed for chemical fertilizers (1 kilogram nitrogen fertilizer is produced with 1.5 kilograms fossil energy) for fuel and for manufacturing the farm machinery. In modern agriculture in industrialized countries, about 5 to 7 percent of the total fossil-energy consumption is used in agriculture. A similar percentage or more is needed for all activities outside the farm until the bread or other food reaches the consumer's table.

Solutions of the World Food Problem

Most agronomists and economists agree that more food can be produced by reclaiming more land, by intensifying farming, or by both. Various proposals are based on: applying fertilizers; introduction of high-yielding crop varieties; controlling weeds, diseases, and pests; mechanization; more efficient irrigation; improvement of credit facilities and infrastructure; education of farmers; and so on. In addition, more agricultural research and enlargement of the agricultural extension services are necessary. It is also proposed that large-scale plantation farming for food crops in poor countries be introduced. Others prefer large-scale land reform or nationalization of land.

The food problem of the world is a complicated problem of production, transportation, processing, marketing, and the like, a problem with many agronomic, economic, social, and political aspects that are difficult to solve. It would be, and sometimes is, considered a rather simple problem, because it seems not so difficult and complicated to produce more food, although conditions of climate, soils, and farm technology are not favorable in some regions.

The main point is to improve the conditions of poor farmers, who have to adapt their farm technology to make better use of the land-production potentialities. This cannot, for example, be reached simply by increasing prices of farm products, but it needs a completely new approach in the fields of economy, sociology, and, in particular, politics. It is easier to propose simple solutions than to take appropriate measures. In this connection reference is made to interesting articles by Mellor (1976), dealing with the situation in India, and by Wellhausen (1976) on agriculture in Mexico. In both countries the so-called green revolution has improved the situation of landowners and commercial farmers.

But production revolution has hardly improved the situation of the small and poor farmers; the reverse has often been true. Many of them even became landless farmers as a result of the green revolution. In the developing countries 78 percent of the farmers have less than 5 hectares. Together they cultivate only 21 percent of the land. It is more difficult to increase food production on this land than on that of the larger holdings because small farmers cannot take risks.

Until a few years ago many influential persons believed that the agronomists could not solve the food problem, because not enough food could be produced and because the exponential growth of the world population was the most important problem that had to be solved, particularly in the poor countries. Since the results of some recent studies on potential cultivable land and on their productive capacity are known, most people are convinced that the food problem is mainly a social-economic-political one.

Even if people were to agree on methods, techniques, organization, and finance to increase food production, and the work could be carried out, it would take at least 25 years or more to reach the final goal of all countries producing all the food they need. Building up larger food reserves and increasing foreign aid for agricultural development in the poor countries will be needed for many years to come.

LAND USE AND PRESERVATION OF NATURAL ENVIRONMENT

Present Land Use

The total non-ice-covered land surface of the world is 13 billion hectares, of which 1,406 million hectares (11 percent) is cultivated, 3,000 to 4,000 million hectares is grazing land, and 4,000 million hectares is forest. The remainder is desert, tundra, mountainous, or rocky. At present about 200 million (or 14 percent) of the cultivated land is irrigated. It has already been mentioned that 65 percent of the cultivated land is used to grow cereal crops that provide 75 percent of the energy and protein needs of humanity. In addition 8 percent of the energy needs is provided by root and tuber crops, 9 percent by sugar crops, and 5 percent by peas, beans, nuts and oil seeds (Loomis, 1976).

Grazing land has an average carrying capacity of one animal unit per 20 hectares (PSAC, 1967); the production is less than 5 kilogrms of meat per hectare per year. Of the forested area, some 2,500 million hectares is natural tropical forest. Less than 1 percent of the forest in the tropics is plantation forest. The overall average wood production is estimated at 4 m^3 hectares per year. It is somewhat higher in the tropical rainforest. Of all the timber cut in the world, 50 percent is used for firewood. In the tropics even 80 percent of the annual cut is firewood, because 90 percent of the population in the tropics relies on firewood for domestic needs (IDRC, 1976).

The area used for cultivating crops is increasing because grazing and forest land is being reclaimed. These reclamations contribute more to the annual growth of food production (2.5 percent) than intensification of the cropping system. An estimated 0.5 to 1.0 percent of the cultivated land is lost annually to nonagricultural land use (housing, industry, transport, recreation, mining), that is increasing rapidly. Approximately 5 percent of the former cultivated land is already occupied for nonagricultural purposes. The loss of rather good land to new housing schemes and roads is rapidly increasing in densely populated regions. One has to bear in mind that within the last 30 years the population has doubled. On West Java, whose land surface of 4.6 million hectares makes it one of the most densely populated regions of the world, already 18 percent of its once cultivated land is now used for nonagricultural purposes.

In most all countries of the world and in particular those in the tropics and subtropics, large areas of cultivated land are damaged by wind and water erosion, by salinization and sodication, and by desertification. This misuse of land is approximately 500,000 hectares annually, which is 10 hectares every minute (5 hectares erosion, 3 hectares salinization, and 2 hectares desertification and degradation). Some estimations made recently are higher and are probably exaggerated; for example, Dumont (1973) supposed that the loss of land because of misuse is 38 hectares per minute, and Kovda (1973) found 100 hectares per minute. FAO is now undertaking an assessment of soil degradation in the world.

Reference must be made to the effective loss of soil nutrients in exported agricultural products. Ferwerda (1970) mentioned, for example, a loss of 4.6 million kilograms of K_2O annually in Ecuador by export of bananas, 2 million kilograms in Hawaii by export of pineapples, and 2 to 3 million kilograms by export of tea in Sri Lanka. The conclusion is that the world in general is not taking good care of its land, which is caused partly by too low prices for agricultural products. Techniques to stop the misuse of various types of cultivated land are well known.

Land-use Potentials

Although it was already known from rough estimations that approximately as much land as is now cultivated is available for reclamation, the first more profound study was made by the PSAC (1967) and the second by the MOIRA group (Buringh et al., 1975). The studies were carried out in different ways, but the results are similar. The MOIRA group has used recent and more detailed information on soils and climate of the world, and therefore a differentiation in 222 regions has been made. It is now known, at least roughly, where the various areas of potentially cultivable land are situated and what is the potential productivity. An example of one of the continents (South America) is given in Figure 7-1; the classes are explained in Table 7-3.

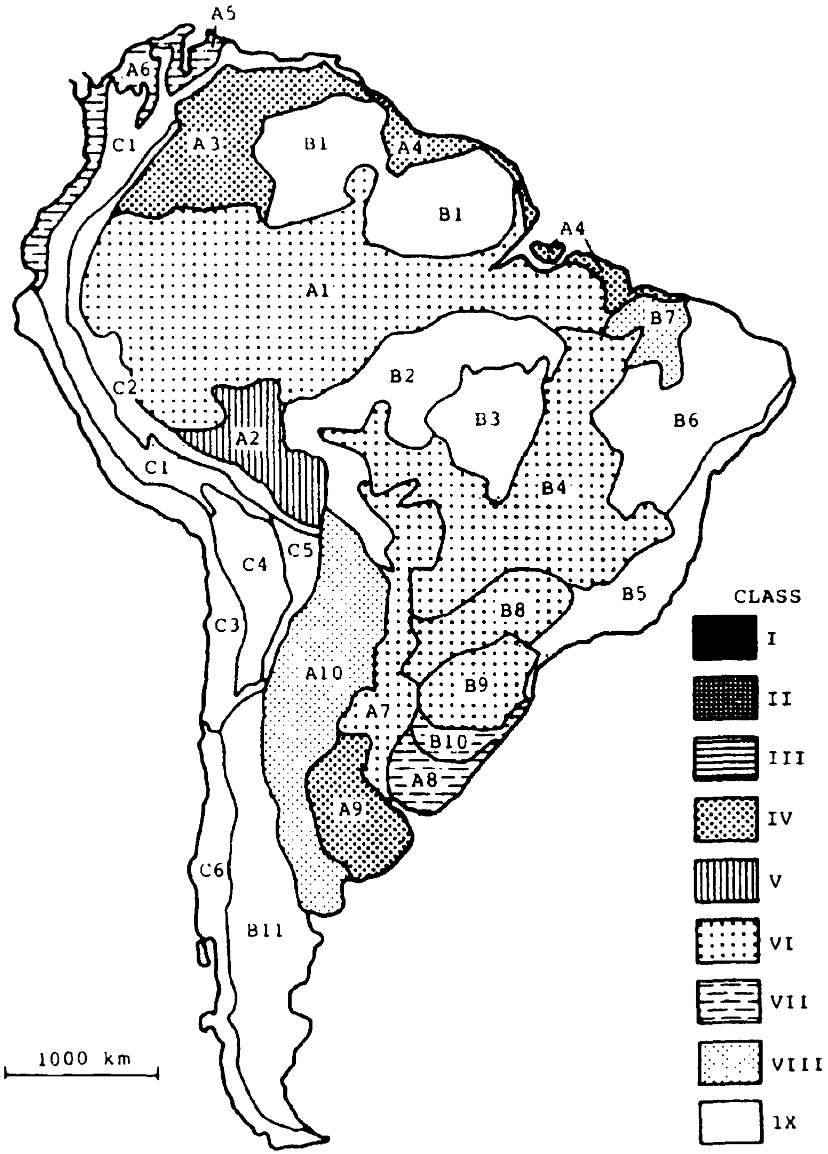

Figure 7-1.

Table 7-3. Classification of the Relative Importance of Potential Agricultural Land in the Broad Soil Regions of South America

Class	*Importance*	
I	Extremely high	> 50
II	Very high	> 45 - 50
III	High	> 40 - 45
IV	Moderately high	> 35 - 40
V	Medium	> 30 - 35
VI	Moderately low	> 25 - 30
VII	Low	> 20 - 25
VIII	Very low	> 15 - 20
IX	Extremely low	⩽ 15

Classes I up to IX indicate (in percentages of the areas concerned) the land area potentially suitable for cultivation, expressed in equivalent land with potential production, including irrigation.

The outcome of the studies is that the potential cultivable land surface is 3,200 million and 3,400 million hectares, respectively (24 or 26 percent of the total land surface), which is approximately three times the actual harvested area. Of the potentially cultivable land, some 400 million and 470 million hectares, respectively, are potentially irrigable.

The PSAC (1967) states that, in addition, there are 3,600 million hectares available for grazing livestock. In various publications summaries of the PSAC study are given; for example, Simonson (1967) Kellog and Orvedal (1969), and Revelle (1973 and 1976). In the FAO Indicative World Plan (1969), the reclamation of 97 million hectares for the period 1970-1985 was foreseen. It seems that the annual increase in food production (2.5 percent) is a bit more than the annual increase of the population (1.9 percent), and is mainly the result of cultivating land that was not cultivated before. A much smaller increase is the result of improving farm technology.

The potential for increasing the cultivated land surface are largest in Africa and Latin America and not in Australia, as suggested by Mesarovic and Pestel (1974). Recent studies also have revealed that there are still enormous potentials in Southeast Asia that contradict what was generally believed earlier. Van Liere (1977) refers to development studies of the MeKong River basin, which has a food-production potential comparable to the present food production of North America. It is my impression that more detailed regional studies, already made in some countries, will reveal that even more potentially cultivable land is available than indicated before.

Very often it is said that large areas in the tropics—in particular those characterized by old, deeply weathered soils—are not suitable for cultivation. Fortunately specialists of tropical agriculture and tropical soil science have a different opinion, which is supported by results of recent experiments and research.

There are almost 80 small countries with a population of less than 5 million people; 30 of these have even less than 1 million people. Some economists believe that it will be difficult for those countries to extend the area of cultivated land. This is not true, in general, because it depends mainly on how much land is potentially cultivable in each country. Surinam for example (350,000 people) has the potential for several million people as far as food production is concerned (Buringh, 1977).

During recent years the potentials of some countries have been studied, particularly of Australia (Gifford et al., 1975; Nix, 1976) and of Canada (Nowland, 1975a and b) in order to have a basis for immigration policies. Such studies are important from the viewpoint of results and also for the methodology used. In Australia the area of potentially cultivable land seems to be much smaller than was expected in the American and Dutch studies. It is interesting to learn that Gifford et al. (1975) conclude that, on a low level of existence, Australia can support a population of 200 million people, whereas it can support only 22 million people if Australia wants to continue to export 65 percent of its food production and the population wants a high standard of living (present population in Australia: 13 million). Such an example is instructive, because several kinds of calculations are made to get a rough indication of how many people could live on the earth. Sometimes this number is stated as 40, 50, or even 80 billion people. Such calculations are confusing and unrealistic, not only because they are based on poor information, but also, even more, because it should indicate which standard of living will be provided. There is, moreover, no need for such predictions.

Land Reclamation

It seems that in most countries reclamation projects, and therefore an increase of the cultivated area, often are preferred to improvement and intensified use of present agricultural land. Unfortunately many reclamation projects in poor countries have not had the good results that were calculated or predicted. Some projects are complete failures, although often this fact is not published. One such exception is the Dejaila project in Iraq (El Hakim, 1973). Irregular and often unofficial settlement of private farmers along newly constructed roads in tropical forest areas sometimes are a success; however, a failure is often experienced mostly because of poor soil conditions or insufficient financial means.

Large-scale projects carried out during the last decades in Central Asia by the Soviet Union (Breznev, 1974) also have failed to a great extent, because of the great climatological risks. The consequences of low wheat yields in 1972 and again in 1975 are well known, not only in the United States but also all over the world, particularly in the poor countries, which did not have enough money to pay the high wheat prices as a consequence of the Soviet Union's import of American wheat. In the United States this has led to higher food prices, followed by a sharply increased value of land, intensification of cropping, cultivation of former pasture and forest, and to large reclamation projects in the Amazon basin in Brazil, mainly by private American persons and firms (Eckholm, 1976; *Time*, 15 November 1976). Gruhl (1975) reports that in the Amazon region 36 million hectares of natural forest is to be cut down. A few years ago it became clear that food—particularly wheat and corn—might become a major political weapon considered more important than oil.

A food war has already been going on since 1972, and earth satellites of NASA and CIA are the most important tools. Food intelligence has become a new field of research. It studies actual land use, monitors all changes in land use, and provides monthly predictions of food production of all major countries in the world (MacDonald, 1976).

Protection of the Natural Environment

The natural ecosystem in many parts of the world is destroyed because of human activities. Since the population grows so rapidly, it is possible that the remaining natural regions in the world will be destroyed in the near future. This can be a catastrophe for various reasons. Some ecologists are not content with publications that indicate a large available land surface of potentially cultivable land, because they are afraid all this land will be cultivated soon. This fear, however, is no reason why people should not know facts. In the MOIRA study not all cultivable land of the regions is used in the computation; some 10 to 20 percent, sometimes even 50 percent (Amazon basin) of it not used for agriculture is assumed being used for wildlife, recreation, and so on.

The expanding agricultural and nonagricultural land use and the misuse of land are real problems. All means to prevent misuse of land are available; they only have to be put into effect. But this costs money. It would be wise to locate new housing and industrial schemes on poor or nonagricultural land. Moreover, the policy of most countries can be changed to intensifying agriculture on the currently cultivated land in order to produce more food. The possibilities for this will be discussed in more detail in the following section.

In addition, the grazing land can be considerably improved. Grass production of two to five and even more times the present production is possible. In the forests, particularly in the tropics, much more timber can be produced if wood collection and timber robbery of the natural tropical forests is stopped and if plantation forestry is practiced. In doing this, reclamation of new land can be limited, the area of grazing land can be much smaller than it is at present, and very large areas of natural forest can be reserved. If this is done, then there are regions large enough to conserve flora and fauna species. No doubt there is a real solution; however, better care must be taken of all types of land. All these activities will cost research, personnel, practical political solution, management, and investments, and therefore a greater part of the consumable income of people in the rich countries must be spent on food and nature care.

If there could be an agreement on future main types of land use, as proposed tentatively in Table 7-4, agriculture (including some 500 million hectares of plantation forest for timber and firewood production) would need only 3 billion hectares; whereas 5 billion hectares are available as nature reserve, not counting the 4 billion hectares of land with a very cold or very dry climate.

It is supposed that pollution of the environment is under control and misuse of land has stopped. If the world population will increase to some 12 billion people in about 150 years, and from then on remain almost constant, the population will be three times larger than the present population. The food requirement is estimated at five times more than at present. Psomopoulos (1976) states that 22 billion people can live on the globe in a "high quality environment."

Although it seems rather unrealistic to make this kind of far-ahead global view, we know that the situation is not hopeless. There is still

Table 7-4. A Rough Scheme of Land Use (millions of hectares)

Land-Use Type	*Present Use*	*Future Use*	*Future Reservation*
Cultivated land	1,400	1,500	–
Grazing land	3,000	1,000	2,000
Forest	4,000	500	3,000
Nonagriculture	600	1,000	–
Too cold, too dry	+ 4,000	+	+ 4,000
	13,000	4,000	9,000
		+	
		13,000	

enough land for food production, and the environment can be protected. However, on a regional basis physical limitations can be serious and pollution and stress on the environment do occur, because population is concentrated in specific areas. It therefore is necessary that ecologists join groups of specialists who study land-use problems. If intensified cropping on the existing cultivated land is given priority over reclaiming noncultivated land, the problems of nature protection probably could be solved in most countries. It is concluded that present land use can be considerably improved. Reclamation of new land must be limited, and much more attention be given to nature reserves to keep good conditions for present use.

FOOD PRODUCTION POTENTIALS

As stated before, it is possible to increase crop production by intensifying the cropping system. References have already been made to the very low level of food production in many countries, especially in the poor ones. It is not new to mention that crop production could be three, five, or even tenfold the present production, because this has been shown by many agronomists.

On a global scale a rather detailed computation has been made for the MOIRA study. For each of the 222 regions of the world indicated on small-scale maps of the continents, a computation has been made of what is called "the absolute maximum production" expressed in grain equivalents (tons of cereal grain). Maybe the term "maximum photosynthetic production of grain" is better.

In each region soil and climate conditions and possibilities for irrigation are studied in relation to land use, natural vegetation, and topography. It is supposed that shortage of nutrients is corrected by adding fertilizers. Then for each region a soil-reduction factor is determined, because most soils do not have such properties to get optimal yields. The various data on climate indicate the length of the growing season, the energy available, the quantity of water available for plant growth, and so on. If soil-water conditions are not optimal, a reduction factor for water deficiency is calculated. The various climatic data also assist in calculating the production of crop dry matter. In Figure 7-2 an example of one of the continents (Latin America) is given. The classes are explained in Table 7-5. In addition the data of the various regions are indicated in Table 7-6. Table 7-7 gives the total for seven continents.

The final result is that the maximum photosynthetic production of cereal grain (on 65 percent of the potential cultivable land) is 32.4 billion tons, or approximately 30 times the present world cereal-grain

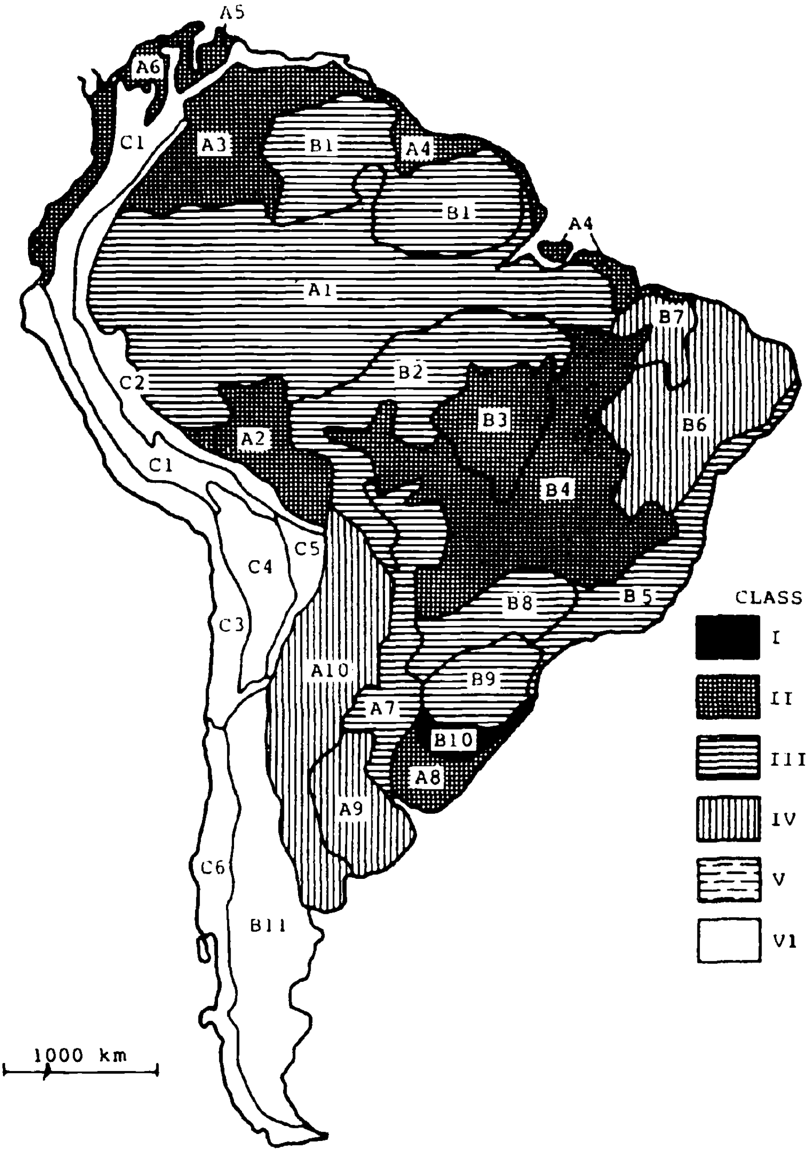

Figure 7-2.

production. The computations of the MOIRA group are made on the basis of cereal grains. If they had been made for root and tuber crops, the photosynthetic maximum production is even higher.

A possible world production of 11.4 billion tons of food grain was calculated by the PSAC study (Revelle, 1976), assuming yields as oc-

Table 7-5. Land Productivity Classes for the Potential Agricultural Land

Class	Land Productivity	
I	Extremely high	> 25
II	Very high	> 20 - 25
III	High	> 15 - 20
IV	Medium	> 10 - 15
V	Low	> 5 - 10
VI	Very low	⩽ 5

Classes I up to VI indicate the computed maximum photosynthetic production of grain equivalents in 1,000 kilograms per hectare.

cur in U.S. Midwest, and for lower quality soils, half of such a yield. This is nine times the present food production. In soil-survey and land-classification reports of parts of various countries, figures on possible crop productions are given. In those reports the present production is compared with yields obtained on experimental farms, which often are two or three times higher. The conclusion of all these studies is that almost everywhere, but in particular in countries in the tropics and subtropics, food production can be trebled or quadrupled.

In Thailand (van Liere, 1977) the average one-crop rice (padi) yield is almost 2,000 kilograms per hectare, whereas the yield on experimental farms is 6,000 kilograms per hectare. For corn it is 2,200 and 8,500 kilograms per hectare, respectively; and for soya 1,000 and 3,500 kilograms per hectare. In Indonesia (Ismunadji, 1973), where the average one-crop rice yields slightly more than 1,000 kilograms per hectare, the yield can be increased to 3,000 to 4,500 kilograms per hectare without fertilizers, and to 5,000 to 8,500 kilograms per hectare with fertilizers on the major soil types of Java. Hopper (1976) describes stages in development of farm management in Japan where average rice yields increased from 1,000 to 2,500 to 4,000 and now to 6,000 kilograms per hectare, and a yield of 8,000 kilograms per hectare is expected in the near future. Breadfield (1972) has given interesting examples on maximizing food production through multiple cropping systems in the tropics. A system of intercropping yielding 5,000 U.S. dollars per hectare was obtained on a two-hectare farm.

The yield of Cassava, actually less than 10 tons per hectare, can be increased up to 50 tons (Jennings, 1976); on modern farms 20 to 40 tons per hectare is a normal yield. In Western Europe the average wheat yield is 2,500 kilograms per hectare, whereas the production on experimental farms is 8,000 kilograms and the photosynthetic maximum is at least 10,000 kilograms per hectare.

In the USSR the average wheat yield is 1,540 kilograms per hectare, improved farming yields 4,000 to 5,000 kilograms per hectare, and the maximum on experimental fields is 10,030 kilograms per hectare. Hedrick Smith, in his *The Russians*, revealed that 27 percent of the total value of Soviet farm output comes from small private plots that occupy less than 1 percent of all agricultural land in the USSR.

In the tropics and subtropics, fields around villages produce much more than other fields, because these fields get much more organic manure and compost. In Mexico (Wellhausen, 1976) the average yield of wheat increased from 700 (1950) to 3,200 (1970) to 3,600 (1975) kilograms per hectare. Some farmers already produce 6,000 kilograms per hectare, and at experimental stations yields are as high as 10,000 kilograms per hectare. Reference is also made to the well-known achievements of the farmers in Israel, where farm output has risen some eightfold in the past 25 years (Hopper, 1976). Intensive farming also can be observed in the Nile delta in Egypt.

More examples are given on world crop productions in literature and in reports of agricultural experimental stations. It turns out that most yields obtained at a traditional level of farm management are 10 to 20 percent of yields obtained when advanced technology is applied. The best farmers can get 65 to 75 percent of the maximum photosynthetic production.

To get a better general idea of crop yields under various management practices, a crop-performance index (CPI) is introduced. It refers to the fraction of maximum photosynthetic production that is obtained under prevailing conditions and farm management. It is a fraction of the yield and is not related to cost, labor, and other economic factors. Table 7-8 indicates the crop-performance indexes. Each figure is the center of a class; for example, a 0.3 index reflects the class between 0.25 to 0.34. This index is independent from soil conditions, because each soil will have its specific photosynthetic maximum yield, when a reduction factor for soil and water deficiencies is introduced in the theoretical photosynthetic potential for a specific crop in a region with a well-defined climate. The CPI are applied in some general calculations on a global basis in order to get at least an idea of possible food production.

If 65 percent of all potentially cultivable land (3,419 million hectares) is used for cereal-crop production, with a cropping intensity of 70 percent, some 1,500 million hectares could be harvested. If half of this area has a CPI equal to 0.1 and the other half a CPI equal to 0.2, which means a low-level farming using no fertilizers and applying human labor and some animal traction, the world cereal-grain production would be 3,110 million tons, which is 2.5 times the present world production.

Table 7-6. South America

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	297.8	16.7	74	0.5	148.9	5	0.6	0.8	89.3	6611	0.0	89.3	6611	2856
A2	40.9	2.3	80	.5	20.5	4	.6	.7	12.3	982	.0	12.3	982	424
A3	81.8	4.6	80	.5	40.9	2	.7	.7	28.6	2290	.4	28.7	2294	991
A4	24.9	1.4	80	.5	12.5	3	.7	.8	8.7	697	1.2	8.8	707	305
A5	10.7	.6	80	.4	4.3	4	.6	.4	1.7	137	2.2	2.6	208	90
A6	24.9	1.4	80	.3	7.5	3	.7	.7	5.2	418	1.1	5.3	427	185
A7	53.4	3.0	78	.6	32.0	4	.5	.7	16.0	1250	.0	16.0	1250	540
A8	16.0	.9	72	.3	4.8	3	.8	.8	3.8	276	.0	3.8	276	119
A9	37.4	2.1	56	.6	22.4	2	.9	.6	13.5	754	.0	13.5	754	326
A10	112.2	6.3	64	.4	44.8	1	.8	.4	18.0	1149	1.5	18.5	1185	512
B1	108.6	6.1	78	.2	21.7	5	.5	.8	10.9	847	.4	11.1	856	370
B2	97.9	5.5	80	.3	29.4	5	.5	.6	14.7	1175	.0	14.7	1175	508
B3	46.3	2.6	78	.2	9.3	4	.7	.7	6.5	506	.0	6.5	506	218
B4	170.8	9.6	80	.5	85.4	3	.6	.6	51.2	4090	.0	51.2	4099	1771
B5	56.9	3.2	76	.3	17.1	4	.5	.8	8.5	649	.0	8.5	649	280
B6	97.9	5.5	84	.3	29.4	3	.7	.3	8.8	740	2.7	10.2	854	369
B7	23.2	1.3	82	.5	11.6	3	.4	.5	4.6	380	.0	4.6	380	164
B8	40.9	2.3	76	.5	20.5	4	.6	.7	12.3	933	.0	12.3	933	403
B9	35.6	2.0	74	.5	17.8	4	.6	1.0	10.7	790	.0	10.7	790	341
B10	10.7	.6	72	.3	3.2	4	.8	.9	2.6	185	.7	2.6	190	82
B11	121.1	6.8	48	.1	12.1	3	.7	0	0	0	2.4	1.9	92	40
C1	80.1	4.5	80	.05	4.0	3	.7	.4	1.6	128	1.4	2.2	173	75
C2	39.1	2.2	78	.05	2.0	3	.7	.7	1.4	107	.4	1.4	110	47
C3	49.6	2.8	84	.1	5.0	3	.7	0	0	0	.5	.4	34	15

C4	37.3	2.1	64	.1	3.8	3	.7	0	0	0	.2	.2	10	4
C5	16.0	.9	44	.05	.8	3	.7	.2	.2	7	.2	.3	12	5
C6	48.0	2.7	48	.1	4.8	3	.7	.5	2.4	115	2.6	3.2	153	66

Explanation of the columns:

1 Symbol of a broad soil region in a continent.
2 (A) Area of a broad soil region (10^6 ha).
3 (A%) Area (A) in percentage of the total area of the continent.
4 (PDM) Potential production of dry matter (10^3 kg × ha^{-1} × $year^{-1}$).
5 (FPAL) Fraction of potential agricultural land.
6 (PAL) Potential agricultural land (10^6 ha).
7 (DCC) Development cost class.
8 (FSC) Reduction factor caused by soil conditions.
9 (FWD) Reduction factor caused by water deficiency.
10 (IPAL) Imaginary area of PAL with potential production, without irrigation (10^6 ha).
11 (MPDM) Maximum production of dry matter without irrigation (10^6 tons × $year^{-1}$).
12 (PIAL) Potentially irrigable agricultural land (10^6 ha).
13 (IPALI) Imaginary area of PAL with potential production, including irrigation (10^6 ha).
14 (MPDMI) Maximum production of dry matter, including irrigation (10^6 tons × $year^{-1}$).
15 (MPGE) Maximum production of grain equivalents, including irrigation (10^6 tons × $year^{-1}$).

Table 7-7. Totals of the Continents and the World

	A	*PAL*	*PIAL*	*MPGE*
S. America	1,780	616.5	17.9	11,106
Australia	860	225.7	5.3	2,358
Africa	3,030	761.2	19.7	10,845
Asia	4,390	1,083.4	314.1	14,281
N. America	2,420	628.6	37.1	7,072
Europe	1,050	398.7	75.9	4,168
Antarctica	1,310	0	0	0
Total	14,840	3,714.1	470.0	49,830

A = area (million hectares).
PAL = area of potential agricultural land (million hectares).
PIAL = area of potentially irrigable land (million hectares).
MPGE = maximum production of grain equivalents (million tons per year).

Table 7-8. Crop Performance Indexes

Index	*Name*
0.1	Minimum crop performance
0.2	Very low crop performance
0.3	Low crop performance
0.4	Medium crop performance
0.5	High crop performance
0.6	Very high crop performance
0.7	Maximum crop performance
1.0	Photo synthetic maximum yield

Index 0.1 is typical for traditional farming; 0.2 and 0.3 for somewhat improved and improved farming; 0.4 and 0.5 for semimodern and modern farming; 0.6 for very modern farming; and 0.7 and more for optimal farming.

The conclusion is that enough food grains could be produced using very little fossil energy, that is, traditional subsistence farming were still applied. However, large areas of land would have been misused and damaged. The total yield would be much lower than calculated and the natural environment would have been seriously damaged.

This example demonstrates that the advances made in modern agriculture generally have not seriously disturbed the environment; on the contrary, large areas with natural vegetation still exist because of modern techniques. The natural environment can be better protected by introducing appropriate modern techniques than without them (see the section "Protecting the Natural Environment," above). Another assumed example shows that, if 65 percent of the present cultivated area (1,406 million hectares) is used for cereal crops, with a 70 percent crop intensity (640 million hectares harvested) and CPI equal to 0.4, the production then is 3,400 million tons. Here it is assumed that agriculture is on a rather (although not very) modern level, and still more than 2.5 times the present world cereal production would have been obtained.

Calculations presented here are purely theoretical. They can be made somewhat more realistic if applied to the various regions or countries of the world. In this section real figures on crop yields have been given, too. These figures clearly demonstrate the low level of farming in many countries in the world, especially in the tropics. Therefore, the conclusion is that food production in the world can be considerably increased, and there is no reason to believe that a double, triple, or quadruple production of human food is not possible. No indication has been given as to the costs; it is clear, however, that factories to manufacture fertilizers, chemicals, and machines have to be built, roads have to be constructed, and so on. Since so much money is spent for military purposes, one hardly can imagine that no money could be found to produce food for every human being in the world. People eat first to live; then they can start defending their freedom. One only can conclude that there will not be enough competent agronomists, extension workers, and soil-water and land-reclamation specialists to perform the job.

It is also stated that enough food can be produced on a rather low level of farm management. The consequence might be that various governments will decide not to change their agricultural policy, and then misuse of land will increase even on an accelerated scale, soil fertility will decrease, and soil degradation will continue. Indeed, the world can continue with robbery of the natural resources, particularly of potentially cultivable land and of natural vegetation. Such a policy would be a big mistake.

The philosophy behind all work to be carried out in the near future is that improvement of agriculture, and especially in management, in large parts of the world is necessary to produce some food. These improvements should be made step by step. This is also propagated by Papadakis (1975), Schuman (1973), and others, who indicate possibilities of low-cost techniques and intermediate technology, because the poor countries must actively encourage their agricultural development in order to become almost independent of food import.

Several economists and agronomists have already studied the food-shortage problem. It is technically not very difficult to raise low crop performance indexes by 0.1 or 0.2 points. Many regions at this moment have no direct need for introducing high-yielding varieties, applying large quantities of fertilizers, making new irrigation schemes, or the like. Maybe in some regions more advanced farm technology can be introduced. This is not the general opinion of most authors who have published information on the food problem. The main point, however, is that development of agriculture should start from the existing economic and social position of the farmers. These farmers are poor people, they are not in a hurry, and they can only be made aware of better economic possibilities after a long process of change. Therefore, it is important to strengthen local research institutes, extension services, education and rural development centers. Perhaps more attention can be given to pilot farms or to small-scale pilot schemes.

CONSTRAINTS AND BREAKTHROUGHS

Technical Constraints

It has already been proved that land for growing food crops is not a constraint. Cost of agricultural development has been discussed, and it is concluded that enough money can be made available if the governments do have the political will and take appropriate action. As far as reclamation costs are concerned, the MOIRA group has classified each of the 222 regions into one of the five reclamation cost classes. A summary is presented in Table 7-9, from which it can be concluded where land can be reclaimed at the lowest costs.

As has been mentioned, energy used for food production is approx-

Table 7-9. Potential Yield Classes and Development Costs (million hectares)

Potential Yield (metric tons/ha)	Development Cost Categories: 1 Low	2	3 Intermediate	4	5 High	Total
I. Extremely high (25)	–	–	40	37	9	86
II. Very high (20-25)	–	56	313	160	20	549
III. High (15-20)	93	35	275	271	304	978
IV. Medium (10-15)	175	297	297	125	–	894
V. Low (5-10)	26	264	218	67	13	588
VI. Very low (5)	–	163	139	49	11	362
Total	294	815	1,282	709	357	3,457

Soil regions that are either attractive because of low estimated development costs, because of high potential yields, or because more than medium yields can be obtained at not more than average cost, are located above the broken line. These regions comprise 1,536 million hectares, 41 percent of total potential agricultural land. The location of those soils, by geographic areas, is shown in Table 7-3.

imately 5 to 7 percent of the total fossil energy consumption in an industrialized country. It can be no problem. The total energy problem is not discussed. Most energy is needed for fertilizer production, in particular for nitrogen-fixing. Various estimates have already been made on the availability of phosphate (P) and potassium (K). According to Gruhl (1975), there is a reserve of both minerals for at least 400 years if the annual consumption is 30 million and 20 million tons, respectively, per year. Even longer periods are mentioned by de Wit and van Heemst (1977). Schuffelen (1965) stated that 16 kilograms NPK-fertilizers are needed to produce food for one person for one year.

FAO (Dudal, 1969) estimates fertilizers used for 1962 at 2.6 million tons and for 1985 at 31.2 million tons. Wortman (1976) mentions 80 tons of chemical fertilizers used in 1976, half of it in synthetic fixed nitrogen. Almost 160 million tons will be needed in the year 2000 (Revelle, 1976). These are just a few examples. Estimates vary widely, depending on how and where agricultural development has to be performed.

Finally, in many countries the availability of water will become a factor limiting irrigated agriculture. Therefore, the increase of irrigation efficiency should have high priority. On the other hand farmers have to learn to make as good use as possible of rainfall. Water conservation, also at present on a small scale, is extremely important in regions with a long dry season. In such regions in the tropics poverty is extreme.

Firewood will be short within a few decades. Eckhol (1976) made clear statements on the importance of firewood for populations in the tropics. Very often there are no roads to bring fossil fuel, and poor people do not have money to buy it. Foresters should pay more attention to firewood production and should also prevent people from damaging natural forests. A good example can be seen on Java, where agrosylviculture in combination with firewood production (Caleandra) has been practiced for many years. Health constraints—for example, river blindness in Africa—probably can be solved in the near future, and consequently some large river valleys, which up till now have not been used, can be cultivated.

Economic, Social, and Political Constraints

From the foregoing it is clear that economic, social, and especially political constraints are considered to be the most important aspects in discussing world food production, food shortage, malnutrition, and hunger. This conclusion is the result of various studies, particularly the PSAC, the MOIRA, and Bareloch group studies. The economic part of the MOIRA study (de Hoogh, 1976; Linnemann, ed., 1977) is interesting, but will not be dealt with here. Reference is also made to the books by Brown (1974), Eckholm (1976), Dumont (1973), and Schumacher (1973); the articles in *Scientific American* (September 1976); and various other publications on such subjects as marketing, cooperation, credit, extension, infrastructure, price politics, land value, land ownership, risk, farm management, and so on. These and other factors often limit food production. Locally, regionally, and nationally, the conditions are different; thus it hardly is possible to discuss such problems in general. Most authors therefore, give examples.

What has been said for economic constraints also fits for sociological factors, such as the attitude of the farmers, the situation of the farmer's family, education, organization, customs, religion, the contrasts between rural and city families and between the poor and rich part of the population. Some of these factors are also discussed in the literature cited in this paper and in the book by Hutchinson (1969). It seems too difficult to introduce social factors in computerized models.

Almost all constraints have political aspects and can only be solved if governments take the right measures; for this it is almost impossible to give general guidelines, although many recommendations have been formulated in various national and international conferences. Sometimes it seems almost impossible to find a solution because of the complex character of the problem. Unfortunately several people, who do not have responsibilities, think that only a few problems have to be solved to get an almost ideal situation. It is easy to blame governments of poor countries for not doing enough, or for not making the correct decisions, but it is very difficult to govern an underdeveloped poor country. In fact it probably is more difficult than to reign over a rich country, where organization is better, where large numbers of competent officers and specialists are available, where risks can be taken, and where the checking on observance of laws is better than in many poor countries.

It is no wonder that some authors refer to centrally directed and planned countries of Eastern Europe or China, where some problems are solved in a way that might be imitable by other countries. Whether the Chinese experience of transforming traditional farming is applicable in other countries is a debatable question. It is, however, clear from all studies that rich countries have an extremely high responsibility because they have to help unselfishly.

Political constraints are apparently the most important. Often it is concluded that the political will is present, but very often no political action is taken. Most political leaders generally have a short time horizon, and the food problem can only be solved in the long run. It therefore seems that an important constraint on the world food problem is the attitude that the rich countries have assumed toward the poor countries. It is everybody's responsibility to try to alter this attitude. This can be done in private discussions, meetings, conferences, and by going to the polls to vote.

Since the population is increasing so rapidly in many countries, unemployment will increase, too, because in modern advanced farms 20 to 40 man-hours are required to produce 1,000 kilograms of grain, against 1,200 man-hours in simple African farms (Allan, in Hutchinson, ed., 1969). Improving agriculture finally leads to fewer jobs.

Breakthroughs

In the various computations made, the basis has been the present known and applied technology. It has been pointed out that breakthroughs are not expected to solve the global problem of food, especially for poor countries, except where there is a possible breakthrough in political attitudes. Some scientists state that a new political will to deal with agricultural development is emerging (Wortman, 1976).

It seems possible that new technological discoveries will become available with the result that more food can be produced in the rich countries. For example, if crops could be grown that make a more efficient use of solar radiation, or that have a somewhat longer growing season, or that could fix nitrogen as do legumes, food production could be increased. Genetic and plant physiological research is being done in these fields. The number of food crops is rather small; probably some new food crops could be developed from wild species.

Soil heating in rather cold regions with a very short growing season, diversion of the course of rivers, as planned for some Siberial rivers in the USSR, improving irrigation efficiency, desalinization of sea water and of brackish drainage water, and similar technical measures also can have a great impact on future food production. Whether there will be a change in overall climate or whether local climate can be influenced by man in the future is not definitely known.

Research in many fields is going on also on the productions of unconventional foods. The results cannot be predicted. Unfortunately not enough research is carried out on the actual problem of increasing food production in countries in the tropics, although during the last decade a small number of important international research institutes are working hard on this problem and attaining much success.

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Chapter Eight

Discussion of "The Natural Environment and Food Production," by P. Buringh

Glenn W. Burton

I must enthusiastically commend Professor Buringh for his very interesting paper. We are most fortunate that Professor Buringh was a member of the Dutch team that developed the fourth world model—Model of International Relation in Agriculture (MOIRA)—and that he has shared some of its findings with us. Dividing the world's land area into 222 regions and studying each individually seems to me to be an excellent approach to studying the world food problem. I appreciate Professor Buringh's frankness in emphasizing the weakness in the reliability of the data on which their study had to be based. I agree that much work is needed, but I think they have made a good start and for that I am grateful.

I like the optimism in his report. I am pleased that both the PSAC and the MOIRA studies agree "that economic, social and in particular, political conditions in the world are limiting food production and not the availability of cultivatable land or its productivity." I suppose those of us in agricultural research could conclude from this statement that we have done our part in feeding the hungry world. We could sit back and say "Let George do it," but I don't think we should.

It is good to know that the world has twice as much cultivatable land as it now cultivates. However, I believe Professor Buringh would agree that we are already cultivating the better half. I spent a month in South America last fall looking at some of this "cultivatable land." It had a pH of 4 or less, a high level of aluminum toxicity, deficiencies in several nutrients essential for crop production, and most of it was highly erodable.

I wonder what you thought when you heard Professor Buringh state that the theoretical "upper limit of food production is 30 times the present production when the production is expressed as grain equivalent"? Did you think, "Great, we've got nothing to worry about for a long time"? I hope you kept on listening as he explained some of the assumptions on which this estimate is based. I shall not dwell on his "reduction factors in order to get realistic" data, but I will remind you that the economists in the MOIRA group concluded that solving the world food problem by 2010 is "hardly possible."

It is good to be reminded that if "the 1,270 million metric tons of grain would be equally distributed over the world, nobody would be hungry." I would like to add that if it were equally distributed, no one would eat as well as you and I eat today.

When our American Plant Studies Delegation was traveling in the People's Republic of China in September 1974, we learned that the average Chinese diet was 78 percent cereals, potatoes, and other starchy foods. About 8 percent of their diet was meat, eggs, and milk, and only 12 percent of their diet could be the other things that add zest to our eating. The diet of the average American consists of 23 percent cereals, 35 percent meat, eggs, and milk, and 37 percent other things. No wonder we eat too much. The Chinese caloric intake averages only about two-thirds that of the American, yet the thousands of Chinese that we saw showed no evidence of malnutrition. Neither did we see any fat people. The Chinese people are smaller than Americans and do not need as many calories. Many of us would enjoy better health if we ate less.

Eating is one of our greatest pleasures, and as our economic status improves, diet is modified to include more meat, milk, eggs, and other foods. It takes more land to feed a person with these foods than it does with a cereal diet. As the poor in the world improve their economic lot, they will demand more of the world's land to produce their improved diets.

In emphasizing the importance of the cereal grains, Dr. Buringh states: "The cultivated grains (mainly wheat, rice, and corn) provide 75 percent of the energy and protein needs of man." I hope we can say this one day, but I don't believe we can today. The cereals do supply about 75 percent of humanity's energy, but only about half its protein. Most of the cereals are deficient in protein content and one or more of the essential amino acids. Thus millions of people restricted to a cereal diet suffer from malnutrition associated with protein deficiencies. One major objective of the cereal breeders today is to increase the quantity and quality of the protein in the cereal with which they work. The potential of such research can be found in the Lancota variety of hard red winter wheat recently released in Nebraska. Culminating 20 years of cooperative USDA-state research, Lancota combines 10 to 20 percent more protein with the yield, disease resistance, and milling and baking qualities of leading varieties in Nebraska. Replacing other varieties grown in Nebraska with Lancota would produce 45 million kg more protein per year at no extra cost. I can think of no cheaper or better way to solve the world's protein problem.

I agree that "the modernization of farming cannot be obtained in a few years." It took 25 years to increase by 4.6 times peanut yields on 213,000 ha of land in Georgia. For years before 1950, yields had averaged 800 kg/ha. Then research learned how to control late blight *Sclerotium rolfsii* Sacc. and use herbicides to control weeds. An outstanding young county agent, J. Frank McGill, became extension specialist for peanuts in 1954 and set about to overcome the resistance to change among Georgia's peanut farmer. Using many different educational tools, including outstanding peanut production schools in each peanut county every year, and by enlisting the cooperation of research, extension, teaching, government, industry, and growers, McGill served as the catalyst for improving peanut production in Georgia. His expertise and untiring efforts earned the grower's confidence, which led to rapid adoption of constraint-removing practices coming from research. The combined effort increased average peanut yields in Georgia from 800 to 3,700 kg/ha in 25 years. Perhaps more important, it demonstrated what the world must do if it is to feed itself.

How many of you realized before today that "post-harvest losses in most tropical countries are 40 percent or more"? Even in the United States, these losses amount to 10 percent of the food produced. Surely the world can and must do something to reduce these losses.

I was glad that Dr. Buringh considered the role of muscle power in the world. At the Human Survival Seminar at North Carolina State University last month, Dr. Calvin Schwabe from the University of California at Davis told us that animals provide 98 percent of the draft power for agriculture in India, China, Korea, and Indochina. For the world as a whole, the value drops to 85 percent. He also said that if the world were to use petroleum energy in agriculture as farmers in the United States do, its known petroleum reserves would last only 13 years. In China, weeds pulled from crop fields, grass cut from every square foot of land not cropped, and crop residues supply most of the energy for draft animals. When these animals can no longer work in the fields, they are slaughtered to make food, shoes, and a host of things by the population.

Anyone who has traveled in India knows that dung from the sacred cows is the fuel used to cook the food for half the people in that country. Dr. Schwabe told us that the fuel energy supplied by the sacred cow of India exceeded the draft energy that it produces. These animals consume crop residues, weeds, and sparse vegetation from land not suited to crop production and thus compete very little with the population.

In the People's Republic of China, I took a picture of a solar cooker that could cook 3 pounds of rice in 40 minutes. Back home, I made a simpler model that could be built by almost anyone for less than $10. As I shared the plans for this simple solar cooker with H.D. Johns, our agricultural missionary in Vikarabad, India, I asked, "How much more food could India produce if she used solar cookers to cook her food on sunny days and used the dung saved to fertilize her crops?"

Professor Buringh indicated that "50 percent of the timber cut in the world is used for firewood"—and in the tropics 80 percent of the annual cut is firewood. How much forest land now producing firewood could be used for food production if humans used solar energy to cook most of their food?

I am concerned that 0.5 to 1.0 percent of the world's cultivated land is lost annually because of nonagricultural land use. It is sobering to realize that another half million ha of cropland is being misused. I wonder how much longer the world can let me do as I please with the land that I own.

The FAO Indicative World Plan caused Professor Buringh to conclude that most of the annual increase in food production in the world results from cultivating land not cultivated before, and that a much smaller increase is the result of improving farm technology. I find this hard to believe and want to share with you information in the Foreign Agriculture Economic Report Number 98, published in 1974. This report divides the world's land for grain production about equally between the developed and the developing countries. The developed countries have had no increase in land area, but have had a 63 percent increase in yield per ha over the past 20 years. During the same period the developing countries have had a 32 percent increase in land area for grain production and a 32 percent increase in yield per ha. These data suggest to me that well over half of the increase in food produced from 1950 to 1970 must be credited to the use of superior varieties, more fertilizer, and improved technology, all of which increased yields on existing cultivated land. I am pleased that Professor Buringh sees increasing yields on existing cultivated land as a means of protecting the environment.

Professor Buringh states that because the world's 4 billion ha of grazing land contribute only 2 percent to total world food production, they can be ignored in global models. The PSAC report concludes that 3.6 billion ha of the world's land could be used to graze livestock, but that this grazing land could only provide "a few grams of animal protein per person per day for the estimated world population in the year 2000." Even though this may be true, I do not believe that animals should be excluded from our plans to protect and improve the environment as we also strive to improve humanity's diet.

Converting plant foods (grains) to animal foods before they are fed to people does reduce materially the number of people that can be fed. But most of the earth's 4 billion ha of grazing land is too dry, too rough, or too cold to grow food crops. These lands can feed people only as people consume the animals that feed on the plants that grow there. Straw and other crop wastes can feed animals that, in turn, can help feed people even as they furnish draft power and fertilizer (dung and urine) to grow crops and produce meat, milk, and fuel (dung) to cook their food. Ruminants could produce substantial amounts of food for people if they were fed only crop wastes and high-quality forages bred to grow on land too rough for crop production. These forages, largely grasses and legumes, as they produce food for people through agriculture, could also control soil erosion, conserve water, greatly reduce the sedimentation of rivers, lakes, and irrigation reservoirs, and help to beautify the environment.

Replacing the native forages with well-fertilized improved cultivars can increase the yields of forage and meat many times. The native range of the southeastern United States, with an annual rainfall of 125 cm, produces about 13 kg/ha/yr of liveweight gain (LWG). Coastal Bermuda-grass planted on the same land and fertilized with 224 kg/ha of N plus adequate P and K can produce 650 kg/ha of LWG during the warm season. A clover such as crimson or arrowleaf seeded on the grass in the fall can add another 300 kg/ha of LWG during the winter and spring. Thus the total animal production from such a pasture can be 80 times the production of the native range.

In the People's Republic of China, silt washed from the hillsides and carried in rivers to lakes and reservoirs threatens to seriously damage and ultimately destroy the irrigation system so essential for her food production. The soil on most of these hills could be stabilized if the open vegetation growing there was replaced with good sod-forming grasses such as Coastal and Coastcross-1 bermudagrass. If well fertilized, these grasses could materially increase the production of scarce meat.

I was delighted to learn last year that sprigs of Coastcross-1 bermudagrass that we sent to Professor Lee in Canton, China were being increased for experimental plantings on some of these hills. Is it too much to dream that one day the hills of southeastern China will be covered with a carpet of green grass that will beautify the environment as it protects the soil from erosion, reduces silt in the streams, and feeds cattle that can supply meat, milk, cheese, butter, and ice cream to enhance the Chinese diet? I don't think so.

Professor Buringh tells us that with "so much money spent for military purposes, one can hardly imagine that no money could be found to produce food for every human being in the world." I agree. It would be a different world if the leaders of the world's governments would also agree and act accordingly.

I am glad that Professor Buringh devoted the last section of his paper to a consideration of breakthroughs. I believe they are tremendously important. Most of the world's resources used to grow food are limited because they are nonrenewable. Most cultivars used today recover less than half the fertilizer used to grow them. I believe cultivars that are more efficient in fertilizer use can and must be bred.

Professor Buringh tells us that of the land presently cultivated in the world today, only 14 percent is irrigated. Of the 3.2 billion ha of potentially cultivatable land, only 400 million (12.5 percent) are potentially irrigable. Thus water will set the ceiling for potential crop yields on most of the world's cropland. Increasing water use efficiency on these lands should be one of the major objectives of agricultural research. Breeding cultivars with greater drought tolerance that can utilize water more efficiently offers one of the best solutions to this problem. Coastal bermudagrass that yielded 6 times as much as common bermudagrass in a very dry season (twice as much in normal years) is proof that it can be done.

New cultivars and technologies may first be used in rich countries, but they can also help to solve the food problems in the poor countries. New high-yielding semidwarf wheats with a package of recommended production practices and the leadership of Norman Borlaug quadrupled wheat yields in Mexico in 20 years. I believe that significant breakthroughs can help to increase food production anywhere in the world if they can be introduced by people like Norman Borlaug and Frank McGill. It requires the cooperation and support of research, extension, industry, government, the growers, and leaders like Borlaug and McGill to get it done.

Professor Buringh said that "building up larger food reserves and increasing foreign aid for agricultural development in the poor countries will be needed for many years to come." I agree. But I also know it is difficult to help people without hurting them. I believe, therefore, that food reserves should only be used for disaster relief and that aid should be directed toward helping the poor countries increase food production on their own lands. We must remember that we help people most when we help them help themselves.

Again I must thank Professor Buringh for his stimulating and optimistic paper. I too am optimistic. Much can be done to increase food production in the world. Professor Buringh emphasized the need for both political will and political action. I believe the world need for food today and certainly tomorrow demands the will and the action of everyone who has a responsibility for feeding the world.

Chapter Nine

Discussion of "The Natural Environment and Food Production," by P. Buringh

James E. Halpin

The second discussant has been labeled as the person who is supposed to agree with the speaker or the first discussant. In that capacity, one can arbitrate the differences, and if necessary heal the wounds should they have led to fisticuffs. Or one can attempt to provide a somewhat different perspective to the material that has been brought forward, rehash it if necessary, fill up allotted time, and then sit down.

I feel very fortunate sharing the programs with the two gentlemen that have preceded me on the platform this morning. I think I'm a little more inclined to agree with Dr. Burton and his position than I am with that of Professor Buringh. Nevertheless, I am an optimist on world food and the potential for the future. There is one note of caution I would stress on this topic. Let's not make it look to be so very automatic!

I got the impression this morning, listening to the previous speakers, that things are just going to happen. For example, we are going to have more food. I would say that the automatic aspect we can assume is that we are going to have more people! I would hope that another automatic aspect is that we will have more longevity, a longer life span for the people we have. I do not feel, however, that this is quite so automatic. It is more problematical. In either case, more food will be required.

As Dr. Burton has brought out, the crops we are raising today are not the same crops that either our forefathers brought to this continent or that they found growing here. They have been altered extensively by genetics, by management, and by various economic and engineering practices, and these alterations are extremely important. The alteration process continues. While the alteration process continues, we at the same time are concerned with protecting a gene pool of wild gene sources of our economically important plants throughout the world. Gene pools are important because they are the sources of future genetic alterations which we recognize we will have to be able to make in order to cope with changes in environment, pests, and practices.

Let me give you a case in point. When the Rockefeller Foundation expanded their corn program in Guatamala, they entered into a country where corn was basically an open-pollinated crop. The Guatamalan farmer went out and picked the best ears grown, and saved those for the next harvest year. The farmers grew what was basically a wild crop under cultivation. They got quite good yields. The Rockefeller Foundation's program brought to them hybrid corn. As a result, yields increased dramatically. And as a result of this, the farmers in turn discarded native lines of corn. This is fine, except in the process of inadvertently destroying the genetic lines maintained for so long, these lines were lost for the future use of the plant breeder. And consequently there is a very real movement in the world today to search out natural lines—genetic lines of important crops—and see to it that we have them available for crop improvement. We just cannot go into a factory and manufacture them.

I refer to something like this as the General Motors Syndrome—a situation where agriculture is so very different from much of our world. I am not picking on General Motors, but it does serve as an example. General Motors can decide to make Chevrolets—a thousand different models and colors and combinations of accessories of Chevrolets at a plant in Janesville, Wisconsin; or, if they see fit, they can decide to stop making Chevrolets at the plant in Janesville, Wisconsin. They can take the dies, they can move them to another plant—say Atlanta, Georgia—and they can proceed after a startup period to turn out these same Chevrolets. There is no need for continuity. They can start and stop at will. But agriculture and our food supply is based on living systems. It is essential that we have continuity. If you break the continuity, you lose it.

I might also add, too, that we must remember that agriculture—and this refers to agricultural research—operates under certain constraints. I would like to express it this way. Engineers can have the plans for a building that would ordinarily take 21 months to build. They, however, can increase the amount of workers during construction, can go from one shift a day to two or three shifts a day, and possibly can compress the construction time so that the building is now erected and available for occupancy within 12 or 13 months. That's great! But no one has yet figured out a mechanism whereby a cow can have a calf in less than 9 months! And this holds true for much of what we are talking about. There are time restraints—biological time restraints that are imposed upon our agriculture and our food systems. These we cannot ignore.

I would say that Professor Buringh is more traveled, around the world, than I am, and is more optimistic. I do not mean to say that I'm a pessimist. I'm not that. I maintain that I think one of the points we have to face is the point of how humanity perceives this whole food issue. In this country we have basically a cheap food policy. Our readily available food supply and an absence of shortages has placed an automatic concept into the food issue here so that we do not really feel any food pressure. Looking down the road, I think we are inclined to believe that massive infusions of money and personnel can accomplish anything. If we need a satellite to orbit the earth in a short period of time, we can put a massive program together and we can place a satellite in orbit. And I don't really mean to downgrade this type of achievement. It is fantastic, and the world admires us for it. But within a biological constraint system, often it is not the quantity of the magnitude of personnel, but it is the capability of that personnel to function within the system that makes the results successful.

I would like to bring out one important point. We must protect our quality of life and try to achieve it for others elsewhere for the future. There are some major shifts that have taken place, especially in the United States, that have potential for the world, and they have occurred very recently. Dr. Buringh pointed out that the United States appeared to be at the point where there were a little over three million horses in the country. However, their population is on the increase. The 1975 figure is 6.7 million horses in this country. The unfortunate part, however, is that these horses are not working for us. We are using them as pleasure and companion animals. They are part of our pet syndrome. And so we have an increase in our companion animal population competing with our food supply for domestic human use and for potential exportation overseas.

We must also remember, too, that we have had a major increase in longevity for people in this country, and we have a potential for an even greater increase in longevity within the short life span of one, or two at the most, generations. These people will want to eat daily.

The other point is that there are areas of the world where the population pressure is very low. The country of Belize in Central America is a case study. That is a country where the average population is four people per square mile. The population is distributed basically one-third in the capital city, one-third in small outlying villages, and one-third in the rural country hacking out the jungle trying to produce food. Imagine a country with four people per square mile, and yet it imports 34 percent of its food supply! That is Belize today. Not a very productive use of apparent resources.

Why is there not greater production? Partly it is because the type of agriculture that could operate there, one that could eliminate the jungle and increase production almost instantly, is the type of agriculture that also requires a ready-made available market at a price—and a country with only 150,000 people just does not have that type of market to stimulate that type of agriculture. And so we get, in the world of agriculture, country by country, a situation where there is a need for incentives for people to produce—where they can do so at a cost that would permit them to put their results of production on the market, and have the essential resources to get the results of that production to market.

I would remind you that the majority of the people of the world continue to live near the peripheral areas of the continents because of the availability of the oceanic transports—ocean traffic and shipping. Yet, if this world is to be one with only a few areas as the sources of our surpluses, the ports for exportation may become clogged as the shipping capacity is not there to move the food that must be moved in world commerce. We have already seen this happen in the United States with the food-laden barges backed up the Mississippi River trying to get to the port of New Orleans to transfer their loads to ocean-going vessels, which are likewise stacked up trying to load. The world must expand its production locally to supply people where they are.

That's enough of the pessimistic side; I'm not a pessimist. Let us look to other aspects; the optimistic side. Our topic is natural resources. I feel there are natural resources which have not really been covered in this symposium, and I think they are worthy of mention.

The first is new plant and animal resources. The animals and plants we utilize for food production today have been domesticated by humanity because they showed promise, and in turn did actually provide a return on the investment of time, labor, and capital. The net result was favorable. Obviously, on this globe there are other plants and animals suitable for study and potential domestication. Agricultural researchers can find these others if they seek them out. We have active projects in progress right now looking for new plant and animal resources. For example, I like to joke about the alligator. My friends tell me that Halpin has the alligator syndrome. But I maintain that the alligator *might be* a very desirable animal to domesticate and utilize for a food source. It tastes like chicken. The hide is desirable for shoes and other leather products. So here we have an animal to which we could feed our garbage—garbage that in many areas we are burying or we are burning, and a resource we are losing. We could pass this garbage through an animal system and provide food in a new form for people.

The second is new innovative animal feed systems. Dr. Burton covered the area of forage crops. The figures I have for the United States is that 81 percent of the calories consumed by the red meat industry today come from grasses and not from the fattening grains. Most of the grass comes from land not suitable for row crops. Our use of grasses will increase; it already has. It has already increased because the time that beef animals are spending in the feed lot and being fed grain has been greatly reduced due to the high price of corn. It is a basic market principle: as corn goes up and people resist the increased price of red meat, then we move to more leaner and less expensive grass-fattened beef. I think this is a step in the right direction, because obviously our number one disease in this country is being overweight. We do not need the fat that excess corn will add to it.

But there are other resources to be considered in animal feeding as well. As a result of our animal production systems in this country, and the types of systems being devloped elsewhere, our animals are producing tremendous quantities of manure—animal waste. Now this is, in the eyes of some people, a dirty topic. I maintain it is a unique and valuable resource. It is a new type of resource, and one that is available in concentration as a result of current agricultural management practices. And this new resource is natural in view of its background. Most important, it has potential for increased food production.

In studies going out at the Alabama Agricultural Experiment Station and elsewhere, agricultural scientists are studying various combinations of manures with grasses, corn stalks, and other non-human-competitive food sources. Unique forms of silage are being developed. The scientists are feeding our livestock these unique rations and obtaining meat supplies that are very, very adequate. Good-quality economical beef is the result. This type of energy and nutrient cycling permits the poultry industry to feed the grain to the chickens the first time and remove a certain proportion of the diet; the chicken manure is restructured into the ration for the steer. The initial food for poultry helped create chicken meat, eggs, and later beef, as well. This may be repugnant to you, but nevertheless it is a very natural process, because animals have historically often consumed a certain amount of manure in their daily living. Particularly is this true in the wild. Consequently, we have a new resource.

We can carry this one step further. After we have obtained from this resource the food energy it contains, and has been wasted in the past on microorganisms and insects in the soil, we can pass the residue through another process and make pressboard from it. What was originally manure now is a component of the lumber trade, and as such will conserve trees, another natural resource we must not remove excessively.

Or we can utilize the same process to make lumber out of sugar baggasse, which is currently being burned. (Unfortunately, it is being burned to create an energy source for the production of sugar through the sugarcane manufacturing process.) Or we can even take the paper out of the garbage and produce another type of paneling out of that material. A wide variety of products can be developed, all useful.

Such imitation materials may not look very good when on the walls of your house. Nevertheless, it can be used in the construction trade in many places that only use lumber one time or where appearance is of no importance. Obviously it will take paint or some other type of surface coating such as the plastic types. New products can be the result of new uses of unusual resources.

The third is unique biological resources in this world of plants. Green plants represent a unique resource because of their photosynthetic capacity. I think one of the hopeful things being worked on through agricultural research is the concept of photosynthetic efficiency in important crops. Agricultural scientists are literally making food-producing plants more efficient in their use of sunlight. For example, the leaf of the corn plant is basically horizontal. As such, it is approximately seven cells thick and literally thousands of cells long and wide. The people of Illinois, through plant genetics, have restructured the corn plant so that the leaves of these experimental plants are held more perpendicular, more upright. The net result is that the rays of the sun, instead of having only five effective cells to go through to be captured from a photosynthetic standpoint, now have thousands more.

Research results show an increase in the chance for capturing the sunlight and improving its photosynthetic efficiency. Comparisons with normal lines of corn demonstrate an increase of approximately 15 percent in these experimental lines over the conventional corn lines from which they are derived. But there is a second improvement as well. Because the leaves of these experimental corn plants are now more upwardly inclined, and the plants require less space, you can move the plants closer together and increase the number of plants per acre. The real key to this was brought up in the symposium earlier. It's not how many more acres we bring in production, but how much do we produce per acre—that's what may really feed the world.

I do want to emphasize a fourth component of what both Dr. Buringh and Dr. Burton have said. Modern agriculture provides a mechanism to protect the environment. It consists of its efficient production systems. Modern agriculture requires inputs from the biological scientists, the horticulturists, agronomists, the physical scientists such as soil science, the agricultural engineers, and from the economists who work with the production and the movement to markets. I do not think there is any place on earth where the "systems approach" has been brought together quite so well as has been done in American agriculture. It is important for us, therefore, to improve our systems approach and study mechanisms whereby we can move these systems into other countries. We must provide these other countries with essential modifications, however, that will meet their needs, but which are based on what we can show to be correct for their condition and not necessarily for ours.

I might add that there are other parameters that I want to state one more time before we leave. These must be considered. One is the reluctance of many governments to properly support food and agricultural research. Unfortunately, often in the underdeveloped countries of the world the emphasis in food reseach has not been "food for the people" of that country, but has been on export items—coffee, tea, cocoa, jute, and the like. There are exceptions. (One of the pleasures of having been with the Rockefeller Foundation Program is the realization that its program philosophically gave a chance for countries to realize they have needs at home and the opportunities they can develop there.) There is a need to reduce distribution costs and improve food quality in much of the world. This is not only from the standpoint of food itself but from the energy utilized or the energy lost. Certainly there is a need to be able to maintain the continuity of food production because we are talking about people who must eat continuously throughout the year in spite of the fact that agriculture historically, at least in the temperate zone, has been a system based on planting once a year—harvesting once a year—with intervening periods of either growth and development or periods of no production. The tropics are somewhat different, but as of yet we still do not have in the tropics a good, continuous system whereby you plant every day and you harvest every day. The tropics do have potential for coming close to this, however, at least for some crops.

I think the most important question that must be raised is, How much pressure should humanity put on this globe? It is actually finite in size; we share it with other organisms, some of which are available to us. If we are to speak of averages, as has been done throughout this symposium, and seek increases on such potential averages, we must remember that brief shortages can lead to malnutrition and death.

And my final point is that a low cost food policy may reduce incentives to produce. If there is anything that agriculture needs, it's incentives. We need to develop a philosophy of food from the standpoint of its overall worth, coupled with the care of our important and available resources. I hope, through research, we may develop means to acquire such incentives.