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THE CAPACITY OF THE WORLD LAND AREA TO PRODUCE AGRICULTURAL PRODUCTS

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ABSTRACT

The capacity of the terrestrial land area of the earth to produce agricultural yield is assessed in this report. The two principle considerations are the land area capable of growing crops and the changes occurring in land use, and the capacity of farmers to achieve maximum production on these lands. The area of productive cropland, based on cereal production, soil surveys of international agencies, and evaluations of scientists, indicate that about 22 to 24 per cent of the world's land area has a potential for crop production. About 11 per cent is currently cultivated. However, projecting trends to the year 2000 indicates that the area of productive cropland and the reserve of crop land (now grassland or forest) will be somewhat reduced. Nevertheless, crop production ability measured by the crop performance index, in many countries can be substantially increased.

RESUMEN

En este informe se valora la capacidad de los suelos del planeta, aptos para la producción agrícola. Las dos consideraciones principales son, en primer lugar, la superficie del suelo capaz de ser cultivada y los cambios sufridos por el uso del suelo, y en segundo lugar, la capacidad de los agricultores para lograr la producción óptima de dicha tierra. Las áreas de cultivo productivas, en base a la producción de cereales, los estudios del suelo realizados por agencias internacionales, y las evaluaciones por parte de los científicos, indican que entre el 22 y el 24 por ciento de la superficie mundial del suelo es potencialmente cultivable, y solamente un 11 por ciento se cultiva en la actualidad. De todos modos, la proyección de tendencias para el año 2000, indica que la superficie de tierras productivas y la reserva de estas tierras (actualmente pastos o bosque), se reducirá en parte. Sin embargo, la capacidad de producción de cultivos, medida por su índice de rendimiento, podría incrementarse sustancialmente en muchos países.

INTRODUCTION

Estimations regarding the capacity of the world land area to produce agricultural products have been made for more than a century. The conclusion of the older publications was that not enough food could be produced and that the world would experience hunger. As more information, particularly on soil conditions of the world, became available the statements on the food situation became more optimistic. All recent studies confirm that enough food can be produced, not only for the present world population, but also for the next generations. Some of these studies on a global scale are examined by Meadows, Richardson and Bruckmann (1982). All such studies face the following problems:

a) Almost all land has some agricultural potential, e. g. even deserts produce some feed for sheep. It is therefore necessary to set a lower limit to what is considered to be land with potential for agricultural production. Some productivity land classes have to be introduced, because the productive capacity of some land is very high, other land has only a moderate or a low productive capacity depending mainly on soil—and climate conditions.

b) Agricultural yields on most land are rather low, because the farmers still apply a traditional system of farming. Much more could be produced if a more intensive farming system could be introduced. This means that various socio-economic and institutional problems have to be solved.

c) There is still confusion on the productive capacity of land consisting of old, outbased, tropical soils, although agronomists and soil scientists have solved this problem in recent years, showing that there are real potentials for agricultural production at least on deep soils.

d) There is a continuous transformation of land. Grazing land and forest land is transformed into arable land, some arable land becomes grazing land, sometimes even forest. Studies on the productive capacity of land therefore should include all land, independent of its present use.

e) Agricultural production highly depends on socio-economic conditions. Agriculture is only a part of the economy, consequently the whole economy should be studied, which is often a very difficult task.

f) Much more information is needed for a study of the world productive capacity. Sometimes this information is not available or it is unreliable. F. A. O. and other international agencies, as well as national governments, have collected many data during the last decades. The reliability is not similar for all countries.

g) All calculations on a global or national scale have disadvantages, mainly because there is too much aggregation and variations between regions or districts are not shown. General studies may give interesting results, but they should be followed by more detailed investigations.

The list of main problems concerning studies of the capacity of the world land area to produce agricultural products could be extended. In this article most attention will be given to the physical and technical-agricultural aspects. It is hardly possible to discuss the optimal rates of agricultural production, because optimal production for a farmer may be quite different from what it is for a government. The problem of optimal production will be discussed later.

CROP YIELDS

Crops and crop characteristics

There are various annual and perennial crops, each of them with its own biological characteristics. They provide food for human beings, feed for domestic animals and raw materials for industries, and grow in various places throughout the world, where soil- and weather conditions are favourable. The growth of crops can be manipulated by farmers, who have an important influence on the final production. The manipulation techniques, as indicated by the types of farm management, highly depends on the skill of the farmers and on socio-economic and structural conditions in the country. This short explanation indicates that agricultural production depends on many factors, that often are interrelated.

Each crop has a specific growing season in which various stages of development can be observed. The development of a crop during each stage highly depends on soil- and weather conditions, which are specific for the site where a crop is grown. Due to the seasonal and annual variability of weather conditions agricultural production is variable too, and production is risky.

Crop production is considered to be a dynamic biological system influenced by many factors, that are determined by nature. Such a system is complicated. Therefore, simplification of the system is necessary. The main simplifications made in this article are:

a) A cereal grain crop is chosen, because cereal crops provide some 75 percent of all human food and are grown on more than two thirds of the arable land area. Wheat, rice and maize are the main cereal crops. Although these crops have different biological characteristics, the production of dry matter and of consumable produce are rather similar. The biological characteristics of the cereal crops are well known from experiments both in the field and in the laboratory. Cereal grain crops are harvested and give grain and straw products that are transported to the farmstead, and stubble and roots, which remain at the site.

b) In order to overcome the variability in crop yields due to variable weather conditions five and ten year averages are used. It should be realised that such an average may include one failure year that may be fatal for farmers.

c) It is assumed that cereal crop varieties are grown that are most adapted to the prevailing conditions. Plant breeders have manipulated the genetic characteristics of these main crops in such a way that such crop varieties are available. Each crop variety, however, has an upper and a lower limit of growth considering both the weather- and soil conditions. These characteristics should be known at all sites where cereal crops are grown.

Site characteristics

Each site (this may be any place the land surface of the world) has its specific conditions as governed by weather and soil conditions. Weather conditions are known from data collected in meteorological stations and from maps indicating the various types of climate resulting from aggregation of these data.

Soil conditions are known from studies in the field and in laboratories where soil samples are analysed. Here too data are aggregated and shown on soil maps, that also show topography and hydrology. Vegetation and land use maps indicate what is grown.

The information on maps, from stations and laboratories may be collected in a detailed or a more general way. The distance between the points of observation, may be short or large depending on the type of survey.

Site characteristics have to be studied from the point of view of crop growth, when studying agricultural production. This approach differs from the approach often followed by climatologists, soil scientists and biologists, whose object of study is climate or soils or vegetation. A crop needs a soil as a standing-place that provides water, nutrients, and air (oxygen) for its development, which also depends on the soil temperature. Crop growth also depends on soil biological activity e. g. decomposition of organic material, formation of humus, etc. Soil minerals, particularly clay minerals and humus, regulate exchange of nutrients. Water in soils, particularly the part that is available for plants, depends on precipitation before and during the growing season. Soil temperature is related to air temperature. Evaporation and transpiration depend on the stage of development of the crop, wind, etc. But most important is radiation of the sun that governs photosynthesis. The main factors to be taken into account in the system crop production are the following site characteristics:

weather conditions:	radiation regime, precipitation regime, air temperature regime, wind regime.
soil conditions:	water regime, nutrient regime, air regime, soil temperature regime, biological regime, mineral regime.

Each of these regimes is governed by various factors, for example the soil water regime depends on the pore space and size, organic matter content, groundwater depth and capillary rise, etc. Pore space and size are related to soil texture, soil structure and bulk density. However, the temperature regime of a soil also depends on soil texture, soil structure, organic matter content, etc. Many more examples could be given in order to demonstrate the interrelationship of the various regimes, which makes the system of crop production rather complicated, particularly when the biological regime is taken into account, because this includes all living subjects in a soil, including crop roots. In fact, the development of roots, their distribution in various soil layers and horizons, the depth of rooting and the total rooting volume in all stages of development are important, because the roots supply water and nutrients to the aboveground part of plants where assimilation takes place and the consumable products of cereal crops are produced.

It is evident that in studies on agricultural production weather and soil conditions have to be studied at a specific site. As weather conditions

Table 1. World area harvested, production, and average yield of cereal crops (data from FAO for the year 1978).

Crop	Area harvested (10^6 ha)	Production (10^6 t)	Mean yield t. ha^{-1}
Wheat	266	450	1.9
Rice (in husk)	145	386	2.7
Maize	118	364	3.1
Barley	94	194	2.1
Sorghum	52	69	1.3
Oats	28	51	1.8
Rye	16	32	2.0
Millet	55	36	0.7
Total	774	1582	

normally do not show important variations in short distances, data from nearby weather stations can be used. Soil conditions, however, are often quite different, even at short distances. Moreover the soil profile descriptions and sample analysis have to be translated into available water and other regimes, in relation to the rooting pattern of crops.

Not all factors are continuously in an optimal condition during the growing season of a crop. There is sometimes a period with a shortage of water or nutrients or there is no optimal soil temperature during a few weeks. The effect is a non-optimal growth. In some stages of crop growth such limitations may have a much greater influence than at other stages. Similar statements can be made concerning crop diseases and plagues, which often also depend on weather conditions.

Farm management

Crop production is a part of farm management, that also includes everything a farmer is doing to stimulate the growth and yield of crops, e. g. preparation of the seed-bed, sowing, weeding, fertilizing, plant protection, harvesting, threshing, transportation and storage. Most farmers of the world follow a rather simple type of farming based on traditions of many generations. Such a traditional type of farming is characterized by much labour input and very little input from outside the farm. The level of technology is low and yields are low too. In industrialized coun-

Table 2. World area harvested, production, and average yield of root and tuber crops (data from FAO for the year 1978).

Crop	Area harvested (10^6 ha)	Production (10^6 t)	Mean yield t. ha^{-1}
Potatoes	18	55	2.9
Cassava	14	49	3.5
Sweet potatoes	13	34	2.6
Yams and others	4	7	1.8
Total	49	145	

tries most farmers use tractors, machines, combine-harvesters, etc. They apply chemical fertilizers and biocides and get high yields, however, they also have high costs of production. The level of technology is high, based on education and research, and it is rather complicated. In all types of farming there are variations depending on cropping systems and ecological and socio-economic conditions. In all cases the farmer tries to manipulate the growing process of a crop in such a way that the yield is higher than it would be when the whole process depends on nature only. Moreover the farmer wants to make a profit.

The growth of a crop can, for example, be influenced by sowing at the most favourable time, by regular weeding, by plant protection. Soil conditions can be manipulated by applying fertilizers, by drainage, by subsoiling or deep plowing. Finally climatical conditions can be manipulated by supplementary irrigation or full irrigation, by wind breaks. What a farmer is doing in practice, depends highly on the economy of farming, on the available labour or machinery, on weather conditions. Many economists believe that the farmer is optimizing crop yields. This, however, is not true because most farmers know the risks of farming, they try to minimize those risks.

In summary there are four types of inputs viz.:

1. Soil preparation inputs (plowing, seed-bed preparation).
2. Labour saving inputs (tractors, mechanization).
3. Yield increasing inputs (manure, fertilizers, irrigation).
4. Plant protection inputs (disinfection of seeds, biocides).

Crop yield in the world

From the foregoing it is clear that crops are grown in many, very different ways and that yields vary widely. Differences may be up to 600 per cent and even more. Table 1 for the main cereal crops and Table 2 for the main root and tuber crops, presents data on the world production, harvested area and mean yields.

In order to get an idea of average yields of wheat and rice in a number of countries, Figures 1 and 2 are presented. Figure 1 shows 5 and

Figure 1. Average wheat yields over 5 and 10 year periods from 1800 to the present in various countries.

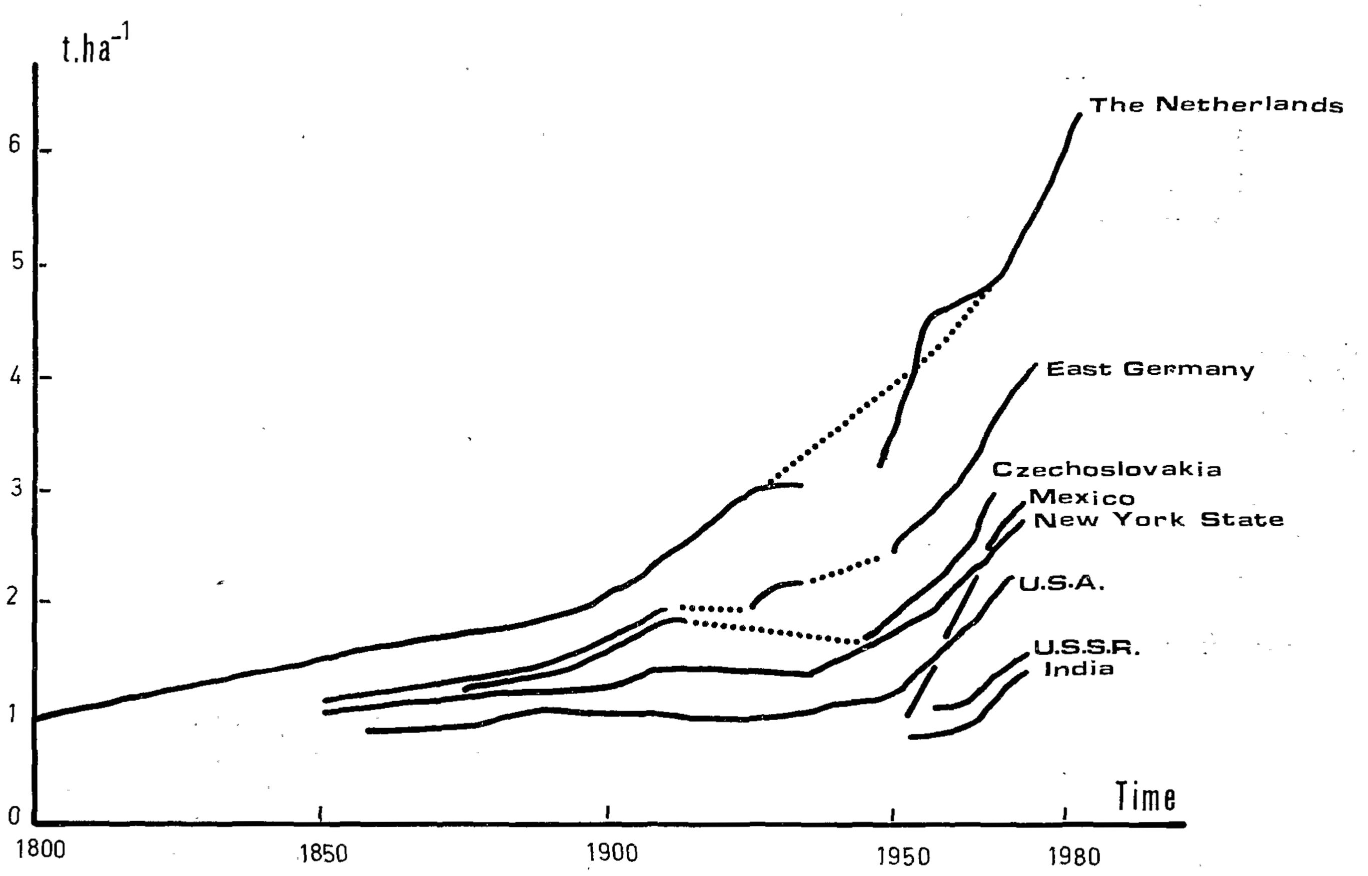
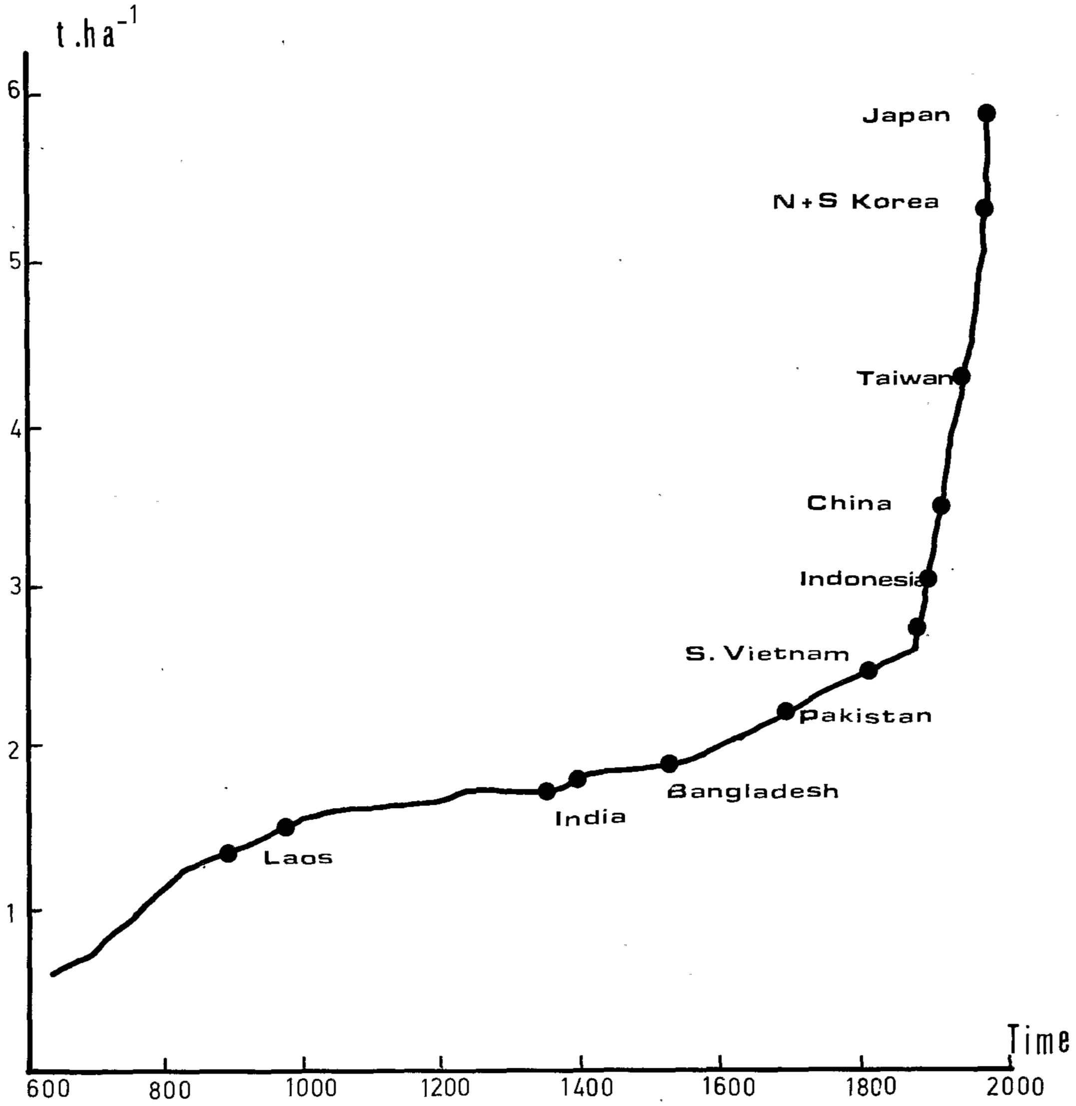


Figure 2. Average rice yield in Japan from 600 to the present. The modern average yields of other nations are located on the yield curve for Japan.



10 years averages of wheat yields over a period of more than one hundred years. During the nineteenth century wheat yields in the Netherlands have doubled. In the period 1900 till 1950 there was even a much higher increase, and during the last 30 years there has been a very high increase. The various so called "green revolutions" have been described by Buringh (1983).

At present the average yield is above 6 t.ha^{-1}. A similar graph (Figure 2) presents the average rice yields in Japan during the period 600 till 1975. Average yields obtained in other countries are here projected on the line for Japan (Hopper, 1976). I do not mean to imply that average rice yields in these countries can be as high as in Japan; however, the graph suggests that yields in many countries can be increased. In both figures various stages of farm management or levels of technology can be recognized. Low levels of technology were applied in Western Europe until approximately the end of the eighteenth century. From then on yields have increased continuously.

This may raise the question of what will be the maximum average yields to be obtained in various countries (Table 3). With reference to explanations presented in the section on agricultural production a calculation has been made for the maximum average wheat yield in the Netherlands, which probably will be 7.2 to 7.5 t.ha^{-1}. Farmers

Table 3. Maximum yields of some crops.
(figures in $t. ha^{-1}. yr^{-1}$).

Wheat	14.5
Rice	26.0 (in 3 crops)
Maize	21.2
Sorghum	21.5 (in 3 crops)
Sweet potatoes	65.2
Cassava	100
Soybeans	7.4
Sugar cane	15.7 (sugar)
Grass	80 (dry matter)
Alfalfa	22.2 (hay)

Data from literature, most maximum yields are from productive soils of experiment stations.

with some very productive land have obtained yields of 10 $t.ha^{-1}$. However, there are also farmers having less productive land with much lower yields. If only the most productive land would be used or if new wheat varieties are bred the maximum average yield in the Netherlands may even be higher than 7.5 $t.ha^{-1}$. Yields obtained on experimental fields are mostly some 10 to 25 perçent higher than farmer's yields.

There is only a small area of highly productive land in the world. Most land has production limitations. Land with a rather low productivity that still is cultivated, although it is hardly profitable to do so, is often called marginal productive land. It can be quite different land from one location to another because what is profitable is not standardized. Land that is marginal land in one farming system may be productive in another system or in a period when prices are high.

LAND USE AND AGRICULTURAL PRODUCTION

Intensity of land use and modes of agricultural production

Since the beginning of agriculture some 10,000 years ago a part of the world land area has been used for growing food crops. The ever increasing human population has been one of the main reasons that continuously more land was cultivated or used more intensively, mainly depending on the availability of suitable land and population density. There were several stages of agricultural development, which still can be observed in various parts of the world. From a technical point of view at lest seven general modes of agricultural production can be recognized, viz:

1. land rotation mode of production or shifting cultivation or bush-fallow (three years of cultivation followed by 10 to 20 years of regrowth of forest),
2. low traditional mode of production (mainly one crop year and one fallow year),
3. moderate traditional mode of production (mainly two crop years and one fallow year),
4. improved traditional mode of production (continuous cropping of cereals in rotation with legumes, root crops or grass),
5. moderate technological mode of production (continuous cropping with application of some chemical fertilizers, and simple mechanization),
6. high technological mode of production (similar to 5, but more fertilizers and mechanization).
7. specialized technological mode of production (similar to 6, but a high amount of fertilizers, application of biocides and full mechanization).

Each one has more characteristics. In general the traditional modes of production are characterized by no or very little inputs from outside the farm, whereas the technological modes do have considerable inputs from outside the farm, including machinery. These types of inputs are called, respectively, internal and external inputs.

The land rotation mode of production or shifting cultivation is at present of minor importance from the point of view of world production levels, although some 200 million people depend on it, mainly in the tropics. Production in the traditional modes of agriculture gives rather low yields, because it is mainly limited by the natural supply of nitrogen and/or phosphorus.

In the low type very little manure is available, in the moderate type some more manure can be given because of somewhat improved animal husbandry. In the improved mode of production which represents a transitional stage of development to the technological types, much more manure is available, because fallow years are replaced by growing feed for farm animals. Giving up the fallow means that much more land became available for crop growing. Since technological modes of production were put into practice even more external inputs have been used. When tractors were replacing draught animals again much more land became available for food production, because approximately one hectare of land was needed to produce feed for one horse. Each higher mode of production is characterized by more input of labour and / or capital, which means higher costs of production and consequently higher yields were needed and this means that more people can have food grown on the same land area. In most countries some of these modes of production do occur at the same time in various areas, moreover there are several transitional stages.

World land use and its limitations

At present land is used as indicated in a general way in Table 4.

In this table "non-agricultural land" refers to land used for housing, industry, services, recreation, traffic, etc., and "other land" is mainly tundra, desert and rough mountainous land. The main food crops with their area, production and average yield were listed in Tables 1 and 2.

Changes in land use have taken place throughout history and they will continue, because transformation of land use is a dynamic process. Richards. Olson and Rotty (1983) have calculated the expansion of arable land which was 432 Mha in the period 1860-1920, and 419 Mha in the period 1920-1976. The expansion of the grassland area even may have been more. There are, however, limitations, particularly for the area of arable land. The main constraints for crop production are listed in Table 5.

The areas of potential arable land are indicated in Table 6 according to soil orders of the U.S. Soil Taxonomy, and in Table 7 according to the major soil units of the world (FAO). The total land area of the earth differs in these estimates because of different bases of calculation.

Table 4. General categories of land use in the world in million hectares.

Land use	**Area**
Arable land	1,500 Mha
Grassland	3,000 Mha
Forest land	4,100 Mha
Non-agr. land	400 Mha
Other land	4,400 Mha
Subtotal	13,400 Mha
Ice covered land	1,500 Mha
Total	14,900 Mha

Table 5. Crop production constraints of the land area of the world (million hectares).

Constraints	Area	Percentage
Ice covered	1,490	10
Too cold	2,235	15
Too dry	2,533	17
Too steep	2,682	18
Too shallow	1,341	9
Too wet	596	4
Too poor	745	5
Subtotal	11,622	78
Low productive	1,500	10
Medium productive	1,100	7
Highly productive	678	5
Subtotal	3,278	22
Total	14,900	100

Table 6. World land area in different soil orders (millions of hectares, Mha).

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

Source: Soil Geography Unit, Soil Conservation Service, U. S. Dept. of Agr., Washington, 1973.

Table 7. Major soil units of the world.

Major soil unit	Total		Potential cropland	
	area (million ha)	proportion (%)	area (million ha)	proportion (%)
Acrisols, Nitosols	1050	8.0	300	9
Andosols	101	0.8	80	2
Cambisols	925	7.0	500	15
Chernozems, Greyzems, Phacozems	408	3.1	200	6
Ferralsols	1068	8.1	450	14
Fluvisols	316	2.4	250	8
Gleysols	623	4.7	250	8
Histosols	240	1.8	10	0
Lithosols, Rendzinas, Rankers	2264	17.2	0	0
Luvisols	922	7.0	650	20
Planosols	120	0.9	20	1
Podzols	478	3.6	130	4
Podzoluvisols	264	2.0	100	3
Regosols, Arenosols	1330	10.1	30	1
Solonchaks, Solonetz	268	2.0	50	2
Vertisols	311	2.4	150	5
Xerosols, Kastanozems	896	6.8	100	3
Yermosols	1176	8.9	0	0
Miscellaneous land units	420	3.2	0	0
Total	13180		3270	

The limit between low productive land and unproductive land is somewhat arbitrary because it depends on the level of technology applied by farmers. Here the present stage of knowledge and technology of agricultural production is used, and it is assumed that land reclamation projects are subsidized by governments. At a much lower level of technology a part of the non-productive arable land would be classified as productive. For example, moderately deep, very stony and rocky soils on hill slopes can be cultivated when soil management is done by hand labour; however, if tractors and machines are being used such land is often unsuitable for cultivation. Moreover, the boundary of marginal land is also determined by economic conditions.

The evaluation of land in this article is based on cereal grain crops because these are the main food crops. This land is generally also suitable for many other crops. There are however also some crops that can be grown on land classified as unproductive, e. g., olives, grapes, whereas land without potential for food crops can be used for grazing and forestry. Such land is generally not given much attention by farmers and production highly depends on what nature permits. Here too, is a gradual degradation of productivity and land and its vegetation is often not taken care of. Production on most of this land could be increased if it was given the appropriate management.

The productive capacity of land

All land has specific capacity to produce agricultural products. On land with a very high productive capacity three crops with high yields may be grown each year. Other land may have a very low productive capacity. Sometimes 20 or 50 ha are needed to feed one cow.

The productive capacity of land is an intrinsic characteristic and depends highly on the mode of agricultural production. Very often the productive capacity of land is much higher than the present production indicates. The productive capacity of land can often be increased by speci-

Table 8. Area of arable land needed in various modes of agricultural production.

mode of production	area of arable land (ha per capita)
1. Land rotation	2.65
2. Low traditional	1.20
3. Moderate traditional	0.60
4. Improved traditional	0.17
5. Moderate technological	0.11
6. High technological	0.08
7. Specialized technological	0.05

Remark. The area of arable land is based on production of cereal grains (wheat, rice, maize) on land with a medium productive capacity. The areas are smaller when more than one crop can be grown annually.

fic measures e. g. by irrigation, drainage, terracing, subsoiling, land leveling. On the other hand the productive capacity of land can decrease too, e. g. when land is gradually eroded or when it becomes saline.

When farming is carried out at a low level of technology, e. g. in the system of traditional farming, differences in soil conditions are less important than when a high level of technology is applied. In the first case the natural nutrient content determines the productive capacity, which is always low and almost equal for most land. In the case of a high level of technology, when nutrient supply is sufficient for a high yield, other soil characteristics may limit production, for example bad soil structure, a less permeable layer in the subsoil, low soil porosity. This implies that differences in soil conditions are much more important for the evaluation of the productive capacity of land at a high level of technology than for the evaluation at a low level.

Figures in Table 8 indicate how much land is needed to produce food for one person at various modes of agricultural production.

The area of productive crop land

The assessments made below are mainly based on the following conditions:

1. farming on a high level of technology (using all present knowledge),
2. soil evaluation based on the FAO / Unesco (1974-1982) Soil Map of the World,
3. all non-ice covered land of the world is included.

Table 9. Area of Potential productive cropland on various continents (Mha).

Continent	Total land area	PSAC potential area	CWFS potential area
S. America	1750	681	596
Australia	820	153	199
Africa	3010	734	711
Asia	4420	894	887
N. America	2110	465	627
Europe	1040	263	399
Total	13150	3190	3419

Results of such evaluations are given below. They are made by:

a) The President's Science Advisory Committee in the USA, (PSAC, 1967) to be indicated as: (PSAC).

b) The Centre for World Food Studies (Amsterdam-Wageningen, the Netherlands), Buringh, Van Heemst and Staring, 1975, and 1977, and Linnemann *et al.*, 1979, chapter 2) to be indicated as: (CWFS).

c) The Food and Agricultural Organization of the United Nations, (FAO, 1978 and 1979), Rome, Italy, to be indicated as: (FAO).

The PSAC has based its study on a world soil map scale 1 : 1·5 M, prepared by the US Soil Conservation Service. Soils are shown in 13 broad geographical groups and boundaries of a climatic map are superimposed on the soil map. The CWFS-study is based on the new FAO / Unesco Soil Map of the World. 1 : 5 M scale and investigations are made for 222 soil regions. Assessments are made for each continent (Table 9).

The FAO-study is also based on the FAO / Unesco Soil Map of the World, climatic conditions are superimposed on this map, and investigations are made per country.

All three studies have been made to supply basic data for studies on potentialities for food production in connection with the world food problems. That of the FAO in particular has been used to investigate the carrying capacity of the land in the various countries. The CWFS-study was a part of an economic study made for possibilities of agricultural development.

It is not surprising that these studies have given almost similar results concerning the area of potential productive crop land, because all are made by soil scientists with a background in agronomy using almost the same basic data. It can be accepted that approximately 22 to 24 percent of the world land area has a potential for crop production. Some 11 percent of the world land area is cultivated at this moment. There is a need for more detailed studies to be made per country. Investigations for some countries are being made.

All studies have pointed out that the production capacity of the potential arable land is quite different, and that production on the currently cultivated land should be increased, which is better than to continue to reclaim ever more land, as reserves will rapidly decrease. Every year much land is lost for agricultural production, mainly because of increasing non-agricultural land use, soil erosion, soil salinization and degradation.

Losses and degradation of land

There are many publications on losses and degradation of agricultural land, mainly dealing with a country or region. Some of them may be somewhat exaggerated for policy reasons. It is not always clear if degraded land can be used as grazing land or forest, and losses of land to non-agricultural land use aren often not mentioned. The last subject has been given much more attention during the last decade e. g. in Canada, the USA, Egypt and some Western European countries. Most recent results on a global scale are published by Buringh (1981 and 1982) on the occasion of a workshop organized by FAO, Unesco and UNDP. It is based on all land of

Table 10. Land use (1975) per land class (x 10^6 ha).

Land use	land class: high	medium	low	zero	total
Cropland	400	500	600	0	1,500
Grassland	200	300	500	2,000	3,000
Forest land	100	300	400	3,300	4,100
Non-agricultural land	0	0	0	400	400
Other land	0	0	0	4,400	4,400
Total all land	700	1,100	1,500	10,100	13,400

Table 11. Data used for the calculations in millions of hectares.

	land class, cropland			land class, grassland				land class, forest land				non-agr.	other
	high	medium	low	high	medium	low	zero	high	medium	low	zero	land	land
Land use in 1975	400	500	600	200	300	500	2 000	100	300	400	3 300	400	4 400
Loss by erosion		40	10			15			10				
land converted into					5	30			10	30			
Loss by toxification	25	15			5	5							
land converted into													50
Loss by desertification			10			30				10			
land converted into													50
Loss by non-agr. use	75	25	20	30	10	10			20	10			
land converted into												200	
Loss by shifting cultivation								25	25				
land converted into									25	25			
Land reclamation:													
For increasing population	25	175	100										
reclaimed from								30	100	100	70		
For replacing lost cropland	20	150	50										
reclaimed from								10	60	80	70		
For replacing lost grassland					30	40							
reclaimed from								5	20	25	20		
Land use in 2000	345	745	710	170	320	510	2 000	30	100	230	3 140	600	4 500

Table 12. Land use (2000) per land class (x 10^6 ha).

Land use	Land				
	high	medium	low	zero	total
Cropland	345	745	710	0	1 800
Grassland	170	320	510	2 000	3 000
Forest land	30	100	230	3 140	3 500
Non-agr. land	0	0	0	600	600
Other land	0	0	0	4 500	4 500
Total all land	545	1 165	1 450	10 240	13 400

the world that has been classified in four land classes concerning its productivity and on conversion of degraded land to a lower productivity or to another category of land use. It is a statistical approach, and a first approach, that surely has to be improved, particularly when similar calculations are made per country. The basic year in the study is 1975 (Table 10).

Losses and conversion of land to another productivity class and / or other land use categories have been assessed for erosion, toxification (mainly salinization), desertification, shifting cultivation and non-agricultural use. Moreover, reclamation of new land has been assessed for food production of the increasing world population and replacement of lost crop land and grazing land. This is done for a period of 25 years, ending in the year 2000. Table 11 presents the data used for the calculations.

They are used to determine the possible situation of general land use in the year 2000 (Table 12).

There are five main conclusions for the 25-years period, viz.

1. The area of potential productive agricultural land will be reduced by 4 % (this is less than generally is expected), however, the loss of highly productive land will be 22 %.

2. The reserve of crop land (now being grassland or forest) will be reduced by 24 %, however, the reserve of highly productive crop land will be reduced by 33 %.

3. The total area of forest land will be reduced by 15 % or 0.6 % per annum, which is less than is expected by foresters.

4. The area of forest on potential productive agricultural land will be reduced by 55 %. The forest area on high productive land will be reduced by 70 %.

5. The land area needed for the increasing world population (80 M per annum), the non-agriculture land area, will be increased by 50 %.

This simple, global model has been checked by comparing the results with those of other studies, which always gave higher figures for losses.

Land has been used for agricultural production for 10,000 years; however, within a period of one hundred years no reserve of land will be left. Although this study has all disadvantages of global studies and of a too simple model, the results seem to be rather realistic. There are no subdivisions in regions or countries and, therefore, it is not shown that, for example, Egypt has no land reserves, whereas Brazil has large reserves. Another fact is that rather large areas of tropical forest occur in some countries where reserves are large, whereas in other countries the reserves will soon be used up.

AGRICULTURAL PRODUCTION AND NATURAL PRODUCTION

Agricultural production

The production of organic material under natural conditions without inputs (the natural production) on land is induced by conditions of the environment, particularly weather- and soil conditions.

Crop production is induced by the conditions of the natural environment and by internal and / or external inputs, minus losses by plant diseases, pests, etc. The following equation is valid:

$$CP = NP + II + EI - L$$

in which CP = crop production, NP = natural production, II = internal inputs (available on the farm), EI = external inputs (from outside the farm) and L = the various losses.

The general modes of crop production as mentioned previously can be indicated as follows:

low traditional crop production =
NP + low II + O - L

moderate traditional crop production =
NP + moderate II + low EI - L

improved traditional crop production =
NP + high II + low EI - L

moderate technological crop production =
NP + high II + mod. EI - L

high technological crop production =
NP + mod. II + high EI - L

specialized technological crop production =
NP + low II + very high EI - L

These equations have to be presented in figures for each crop. An example for wheat is given in Table 13.

This table refers to densely populated land areas, where labour is relatively cheap, because in scarcely populated regions with shortage of labour the technological modes of crop production are much more mechanized, yields are lower and external inputs are higher than indicated in Table 13.

Natural production (NP) in Table 13 (being 500 $kg.ha^{-1}$) only can be obtained when sowing and harvesting is done; consequently, it includes some internal inputs. Moreover the example is given for a site with specific characteristics; for other sites the figures are different.

The example demonstrates that the rate of organic production of the natural vegetation cannot be predicted from the rate of agricultural production, except maybe from that obtained with a low traditional mode of production.

Crop production ability (CPA)

The Wageningen-group of agricultural specialists of the Centre for World Food Studies has developed a detailed model of agricultural production (De Wit *et al.*, 1984) based on physical and agronomic factors. These factors are dealt with in an hierarchic, dynamic simulation model with several submodels.

The first part of this model concentrates on the calculation of the maximum biological production of a specific crop, taking in account its phenological characteristics, and growth at a specific site, having its specific site characteristics, assuming an optimum supply of water and nutrients and absence of weeds, plant diseases and plagues. This is followed by the calculation of the maximum biological crop yield, using a submodel in which all factors, influencing the quantity of available water in the soil, are taken into account, and assuming optimum nutrient supply and absence of weeds and plant diseases. There are several feedbacks in the model as

Table 13. Estimated subdivision of wheat yields (kg.ha) to be obtained in the Netherlands on moderately productive soils with various modes of crop production. Symbols are explained in the text.

Mode of crop production	CP	= NP	+ II	+ EI	— L[3]
2. Low traditional[1]	750	500	250	0	—
3. Moderate traditional[2]	1 000	500	400	100	—
4. Improved traditional	2 000	500	1 200	300	—
5. Moderate technological	3 000	500	1 000	1 500	—
6. High technological	4 000	500	800	2 700	—
7. Specialized technological	6 000	500	200	5 300	—

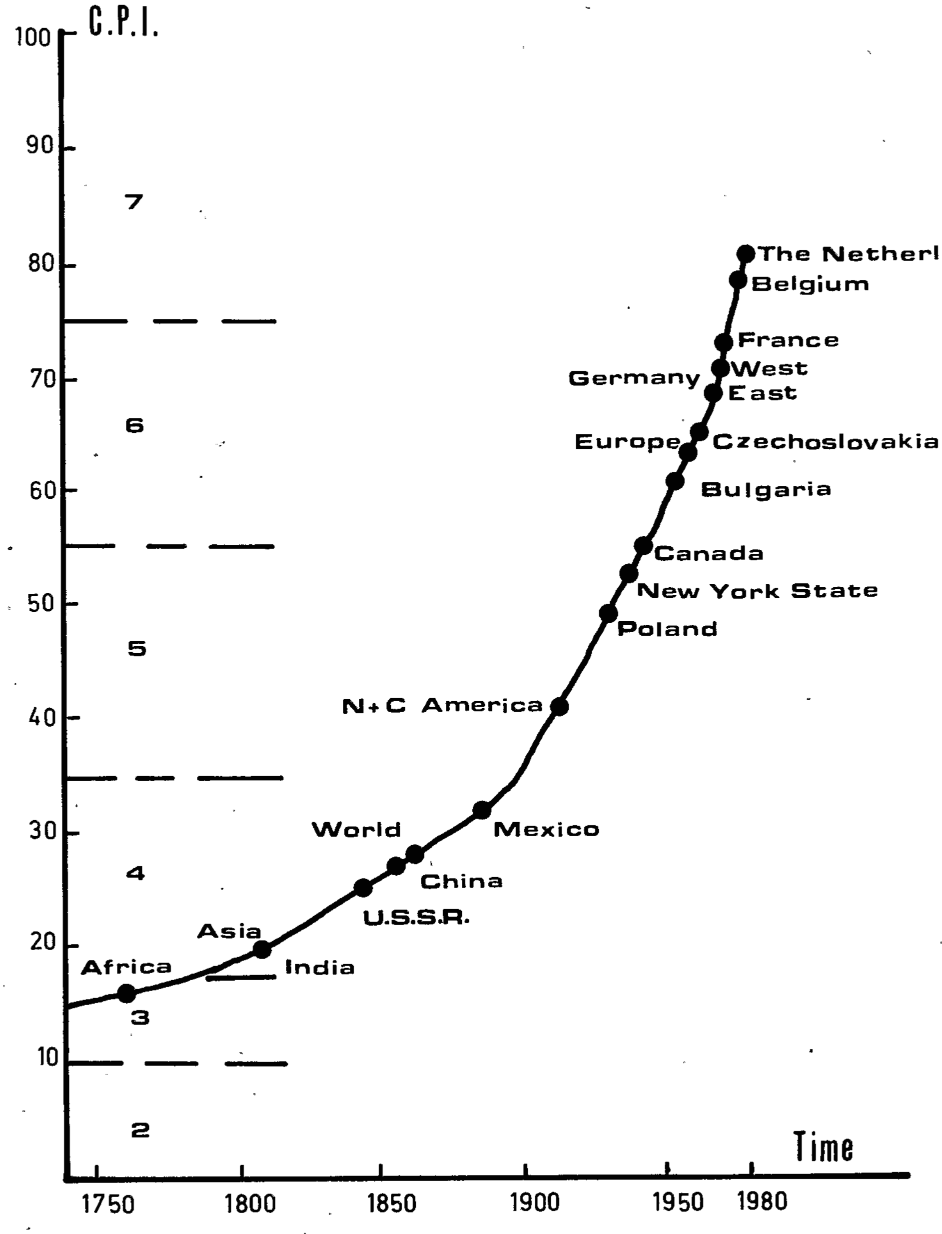
[1] Two field system, one crop in two years.
[2] Three field system, two crops in three years.
[3] Losses are not quantifed.

various factors are interrelated. The next submodel deals with available nutrients, mainly N, P, and K. It enables calculations of crop yields if different amounts of nutrients are available during the growing season. Other submodels further deal with weeding, plant protection etc. The verification of the model is done by using it for calculations of results of already executed field experiments. Part of this model and some submodels (sometimes simplified) are also published by De Wit and Goudriaan (1978), CWFS (1980) and Penning de Vries and Djitèye (1982).

The first part of this model of agricultural production, up to the introduction of the submodel concerning the nutrient status of soils is important for the subject under discussion, because it provides the possibility to calculate the *biological maximum yield* (BMY) of a crop growing at a specific site. As it is still assumed that nutrient supply is optimal and weeds and plant diseases are absent, such yields never can be obtained in practice.

Even yields on the best experimental fields are somewhat lower. In order to simplify the calcu-

Figure 3. The wheat crop production index (C. P. I.) trend for the Netherlands from 1750 to the present. The wheat C. P. I. for other countries in about 1970-75 is also shown for comparison.



lation it is assumed that the best, well-educated farmers can obtain a maximum average yield of 70 percent of the biological maximum yield.

This yield is called the *crop production ability* (CPA). Therefore

$$CPA = 0.70 \times BMY.$$

The crop production ability of a land area can be defined as the maximum average yield a farmer may expect from a crop in an average year. As the biological maximum yield (BMY) is different for different crops the CPA has to be determined for each crop.

The ratio of the *average actual crop yield* (AAY) and the crop production ability (CPA) multiplied by 100 is called the crop *performance index* (CPI)

$$CPI = AAY \times CPA^{-1} \times 100$$

$$\text{or } CPI = AAY \times BMY^{-1} \times 100 \times 0.70^{-1}$$

The crop performance index (CPI) is lower than 100, because a farmer often cannot carry out sowing, weeding, plant protection measures, harvesting, etc., at the most favourable time; moreover, there are always some spots where plant development is retarded or some plants are missing, and there are some losses. As there are always yield variations in a number of years, the average actual crop yield (AAY) should be a 5 or 100 year average. The advantage of determining the CPI is the possibility to compare average actual crop yields of land of various farmers within a region or of groups of farmers in different regions or countries. It has to be realized that all calculations are based on physical and technical-agronomic factors and that no economic factors have been taken into account; consequently, a high crop performance index does not mean that profit is high too.

The crop performance index (CPI)

The crop performance index was introduced for the first time in 1978 (Buringh, 1978) although it was somewhat differently defined. It was also used in a publication in Germany (Buringh, 1982). With the data of an earlier publication (Buringh, Van Heemst and Staring, 1975), some unpublished data and the average actual wheat yields published by the FAO in the Production Yearbooks, the crop performance indices of a number of countries have been calculated and indicated in Figure 3.

The line in this figure represents the average yields of wheat in the Netherlands for 10 and 5 year periods. Theoretically all average CPI values for wheat could reach the top at which CPI = 100.

The position of the various countries on the line indicates their relative position. Even if the somewhat arbitrary figure of 70 percent, as used to determine the crop production ability (CPA), is somewhat lower or higher, this hardly changes the relative position of the various countries on the line in Figure 3.

The various modes of crop production can be defined by an upper and lower limit of the crop performance index. For wheat and most other cereal grain crops they are as indicated in Table 14.

The examples given above refer to grain yields. It is however also possible, and even easier, to calculate the total or the aboveground level of dry matter production of a crop for various conditions and situations. In a similar way a dry matter performance index can be established.

Table 14. Lower and upper limits of the crop production index (CPI) of wheat for various modes of crop production.

Mode of wheat production	Limits of CPI lower	Limits of CPI upper
2. Low traditional	5	10
3. Moderate traditional	10	17.5
4. Improved traditional	17.5	35
5. Moderate technological	35	55
6. High technological	55	75
7. Specialized technological	75	?

Production capacities of land

The model and calculations described above open the possibility of determining the production capacity of land areas or of all land in the world for various modes of agricultural production. Up to now this has not been done because of the limited time available. Almost all information needed to carry out these investigations is available.

BIBLIOGRAPHY

BURINGH, P. (1978). The natural environment and food production. In McMains, H. and L. Wilcox (1978), Alternatives for growth, Cambridge (Mass), Chapter seven, 99-129.

BURINGH, P. (1981). An assessment of losses and degradation of productive agricultural land in the world. Workgroup on Soils Policy (FAO/Unesco/UNEP), Rome, Febr., 1981.

BURINGH, P. (1982). Potentials of world soils for agricultural production. Proc 12^{th} Int. Congr. Soil Sc., New Delhi, 1982, Vol. I, Plenary Session Papers, 33-41.

BURINGH, P. (1983). Die bisherigen Erfolge und die technischen und betriebswirtschaftlichen Voraussetzungen der "Grünen Revolution", bzw. der intensiven Landwirtschaft in verschiedenen Ländern. Tagung "Aktuelle Probleme der Welternähungslage". Hohenheim, November 1983 (in press.).

BURINGH, P., H. D. J. VAN HEEMST and G. J. STARING (1975), Computation of the absolute maximum food production of the world. Agr. Univ., Wageningen.

BURINGH, P. and H. D. J. VAN HEEMST (1977). An estimation of world food production based on labour-oriented agriculture. Agr. Univ., Wageningen.

CWFS (1980). Centre for World Food Studies: The model of physical crop production. Res. Rep. SOW-80-5, Amsterdam-Wageningen.

DUDAL, R. et al (1982). Land resources for world's food production. Proc. 12^{th} Int. Congr. Soil Sc., New Delhi. Vol. I.

FAO/UNESCO (1974-1981), Soil Map of the World, 1:5 M, Paris.

FAO (1978). Report on the agro-ecological zones project. Vol. I. Methodology and results for Africa, FAO, World Resources, Rep. 48, Rome.

FAO (1979). Agriculture: Forward 2000 (AT 2000), Rome.

HOPPER, W. D. (1976). The development of agriculture in developing countries. Scient. American, 235, (3), 197-205.

LINNEMANN, H. et al (1979). Food for a doubling population. Nth. Holland Publ., Amsterdam.

MEADOWS, D., J. R. RICHARDSON and G. BRUCKMANN (1982). Gropping in the dark, the first decade of global modelling, Wiley & Sons, New York.

PENNING DE VRIES, F. W. T. et M. A. DJITEYE (1982). La productivité des pâturages sahéliens, Pudoc, Wageningen.

PSAC (1967). Presidents Science Advisory Committee: The world food problem, Vol. II, Washington.

RICHARDS, J. F., J. S. OLSON and R. M. ROTY (1983). Development of a data base for carbon dioxide releases resulting from conversion of land to agricultural uses, Oak Ridge Univ.

WIT, C. T. de and J. GOUDRIAAN (1978). Simulation of ecological processes. Simulation Monograph Series, Pudoc, Wageningen.

WIT, C. T. de et al (1984), Modelling of agricultural production: weather, soils and crops, Wageningen, Simulation Monograph, to be published by Pudoc, Wageningen.