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AN ESTIMATION OF WORLD FOOD PRODUCTION

BASED ON LABOUR-ORIENTED AGRICULTURE

by

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SUMMARY

A study is made of potential world grain production if labour-oriented systems of agriculture would be applied all over the world on all land that is suitable for such systems. The hypothetical situation of worldwide labour-oriented agriculture is used to estimate the extent to which present agriculture has to be improved in order to feed the world population in the coming decades without intruding upon presently still available nature. It is a theoretical study, as in some parts of the world much more modern systems of agriculture are already introduced; however, in many countries of the world agriculture production is lower than in labour-oriented agriculture, because less productive subsistence and traditional systems of farming are still practised. The results of the theoretical study of labour-oriented systems of agriculture are compared with production levels obtained in present agriculture, and with the potential production of worldwide modern agriculture. The study gives some indications of the disastrous effect of current agricultural development policies of many countries on living conditions, ecology and environment.

It is assumed that in labour-oriented systems of agriculture no chemical fertilizers and machinery are used. Almost all work is done by hand labour and animal traction. Farm management is adapted to local conditions of soils and climate. The estimation is made for 151 broad regions. Results are summarized per continent. In addition, some calculations are made of the consumable grain production and of the maximum number of people that can live in the world, if such systems were applied.

Conclusions are given in section four.

1. Introduction

Some years ago an estimate was made of the maximum photosynthetic food production of the world (Buringh, van Heemst and Staring, 1975). It has produced basic data for an economic investigation called "MOIRA", a Model Of International Relations in Agriculture (Linnemann et al., 1977), that describes the world food situation at the time the world population will have doubled (approximately the year 2010). The estimate of maximum photosynthetic food production was based on a rather detailed study of soil conditions, land and climate characteristics and the growth of a standard crop. The main result was that, from a technical point of view, agriculture can produce approximately thirty times the present food quantity under favorable conditions of optimal farm-management, applying all technology known at the present time.

In some discussions of the methods and results of this study it was proposed e.g. by some FAO-officials, to try to estimate world food production when a much less advanced system of farm-management (e.g. without the use of tractors, modern machines, pesticides and fertilizers) is applied. This is a type of agriculture without inputs external to the farm, and is denoted here with the lable "labour-oriented" agriculture. It is described in more detail in the next section.

The purpose of this study therefore is to produce basic material for other studies in the field of agriculture, economy and sociology, and to get a general idea of food production under these specific conditions.

Yields obtained when applying a system of labour-oriented agriculture are higher than yields obtained in traditional subsistence farming, which is still practised in most developing countries.

The calculations in this study are made for broad soil regions as explained in the previous study. It is not possible to combine those regions in such a way that results can be obtained per country, because boundaries of the regions are determined by landscape and climatic conditions and not by boundaries of states.

The estimation of food production based on labour-oriented agriculture is theoretical not only because of the various assumptions to be made, but particularly because such systems of agriculture hardly exist. However, much can be learned from this study, because in large areas of the world agriculture is still practised on a lower level. It is almost impossible to improve agriculture rapidly, as agricultural development depends on the economic capabilities of large numbers of farmers. This restriction applies whether efforts are made to introduce labour-oriented systems or modern systems alike.

Still, the calculations made on intensive, labour-oriented farm-management systems may be considered valuable as the estimations show that without modern agriculture in at least some regions, the food situation of the world would be worse than it is at present. The model of labour-oriented agriculture is recognized to be rather simple and therefore the results give only a general impression. The various figures should be considered as crude approximations.

This study leads to some interesting conclusions, discussed below. It is, however, necessary to point out that it is made for continents on a global scale, although based on more detailed studies of 151 broad regions.

This study is intended to make a contribution to the discussion of world food production and potentials. Often those discussions lack sound basic knowledge on factors like soil productivity, available water for crop production or agronomic potentials.

A number of relevant economic, social and political factors is not included in this estimation, and various agricultural factors are simplified. Specialists who may use the results of this study therefore are advised to introduce their own reduction factors where this seems relevant. Therefore, all basic data and assumptions are given in section three. The results and their reliability are discussed in section four.

2. Labour-oriented agriculture

This estimation of world food production is based on a system of agriculture without inputs external to the farm that is called "labour-oriented agriculture". It is assumed that all farmers have adopted crop rotation systems and crop varieties appropriate for local conditions of soils and climate. There is almost permanent cropping, except when rainfall is such that a fallow system has to be applied. There is each year one harvest. Capital inputs are very low. All work is done by farmers, members of their families and for larger farms also by some labourers. They have simple tools, and animal traction is used for preparing the land, forthreshing and for transportation of the farm products. There are no chemical fertilizers, insecticides etc. Soil fertility is on a rather low level. Legumes and foddercrops are important for crop rotation and food for animals. The farmers use stable and green manure, compost, and also ashes and other waste products from the cities. Some rich soils have a mineral supply through weathering. Nitrogen often is the limiting factor in crop production. All farmers take good care of the crops. Weeding is done by hand.
Land that is somewhat too wet is drained by ditches and if necessary there are windmills for drainage of small areas. In some alluvial plains and river delta's (e.g. Mesopotamia, the Nile delta and in plains and delta's of South East Asia, where irrigation is practised for centuries) irrigated agriculture is practised. Maybe in such areas of the tropics there is locally even double cropping promoted by the fertility of the irrigation water and nitrogen fixing algea.

Besides the cultivated land there are large areas of grazing land for the animals. The draught animals also need products of the cultivated land, as do pigs and poultry, whereas cattle mainly are fed on grazing land, which has a rather low productivity, because all stable manure and compost is given to the cropland. As there is a limited quantity of organic manure, cropland mostly is manured once in two or three years. Woodland and forests supply timber and firewood; pigs are often fed by forestproducts.

Although fish is an important food in some areas, the products of fishing are not included in the calculations, because for the total world food production fish is of minor importance.

This type of labour-oriented agriculture has existed in parts of Western Europe, in particular in Belgium and the Netherlands in the beginning of the nineteenth century. At that time it was an advanced system of agriculture in comparison to the systems of subsistence and traditional farming of earlier centuries. It is extensively studied and described by Slicher van Bath (1960).

Various examples given in this book have contributed to the method of calculation applied and permitted rather reliable assumptions.

Crop risks and some other factors of a socio-economic character are not taken into account for the time being, because first the estimations are made for favourable conditions. Later on, reduction factors for various technical, economic and sociological aspects can be introduced. Labour-oriented systems of farming are very labour intensive, there is much work to do and the farmer's family is busy the whole day. It is therefore to be expected that more than 50 percent of the population is working in agriculture.

When making the estimations of food production based on labour-oriented agriculture it is supposed that relatively advanced farm-management methods are practised everywhere in the world; otherwise the total food production would be much lower. The intention is to determine how much food can be produced if modern means of farming are not available. It is realized that this computation is based on rather optimistic assumptions as shall be explained in section four.

3. Methods of calculation

In this section all basic material, the assumptions and the formulas are given. This provides an opportunity for the reader to change the data, if this is felt necessary. In order to know how much food can be produced, data are needed on the acreage of land that can be cultivated, on the crops that are grown, and on the yields. Moreover, a calculation has to be made of that part of the yield that is available for human consumption and this leads to the number of people who can live in the world.

Symbols

Broad soil regions are indicated on the maps in figures 1-6 and in the first column in tables 1-6. A numbers indicate low land, B numbers upland, C numbers mountainous land, and D numbers desert and tundra.

A	area of broad soil regions (M ha)
CL	cultivated land (M ha)
CGP	consumable grain production (Mt)
EGP	estimated grain production (Mt)
FMAL	fraction of maximum agricultutal land area
MAL	maximum agricultural land area (M ha)
MPGE	maximum production of grain equivalents (Mt or $kg.ha^{-1}$)
PAL	potential agricultural land (M ha)
PC	production class

ha	hectare = 10^4 m^2
kg	kilogram
M	mega = 10^6 (million)
t	ton = 1000 kg

3.1. Maximum agricultural land area (MAL)

The information on land available for cultivation is based on a previous publication (Buringh, van Heemst and Staring, 1975) in which 222 broad soil regions were distinghuished. A simplification has been made by combining all units D (deserts and tundra's) in one unit for each continent. The same is done for all units C (mountains). The location of the remaining 151 broad regions in this computation is given in figure 1 through 6, the acreage (A) is given in million hectares (M ha) in tables 1 through 6.

In the previous study soils, topography, vegetation and climate have been studied in detail for each broad region in order to know how much land could be cultivated, and in addition a "development cost class" (DCC) varying from 1 to 5 was estimated. It is realized that not all land can be or is reclaimed when only hand labour is available. For various broad regions the factor FMAL, which is the share of the maximum area of agricultural land, therefore is often smaller than the equivalent factor FPAL used in the previous study. For those regions where reclamation is not too difficult (DCC = 1 or 2 or 3) the FMAL is the same as FPAL in the previous computation, whereas for broad regions that are more difficult to reclaim, (the regions with DCC = 4 and DCC = 5) the FMAL is assumed to be respectively 0,2 and 0,1. This means that in such regions respectively 20 percent and 10 percent will be cultivated; these are the easiest parts to reclaim in such regions. Some exceptions are made for regions with reallly good soils and climate with DCC = 5 and here FMAL = 0,2. Not all land that potentially can be cultivated is included when estimating FMAL, because some land (10 to 20 percent) suitable for cultivation has to be used for non-agricultural purposes.

Table 1: South America, data on broad soil regions

Reg.		A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A	1	297.8	.1	29.8	1	69.3
	2	40.9	.2	8.2	1	19.1
	3	81.8	.5	40.9	1	95.1
	4	24.9	.5	12.5	1	29.1
	5	10.7	.2	2.1	3	2.2
	6	24.9	.3	7.5	1	17.4
	7	53.4	.2	10.7	1	24.9
	8	16.0	.3	4.8	1	11.2
	9	37.4	.6	22.4	1	52.1
	10	112.2	.4	44.9	2	70.7
B	1	108.6	.1	10.9	1	25.3
	2	97.9	.1	9.8	3	10.0
	3	46.3	.2	9.3	1	21.6
	4	170.8	.5	85.4	2	134.5
	5	56.9	.2	11.4	1	26.5
	6	97.9	.3	29.4	2	46.3
	7	23.2	.5	11.6	3	11.9
	8	40.9	.2	8.2	1	19.1
	9	35.6	.2	7.1	1	16.5
	10	10.7	.2	2.1	1	4.9
	11	121.1	.1	-	-	-
C		270.1	.05	13.5	2	21.3
		1780.0		382.5		729.0

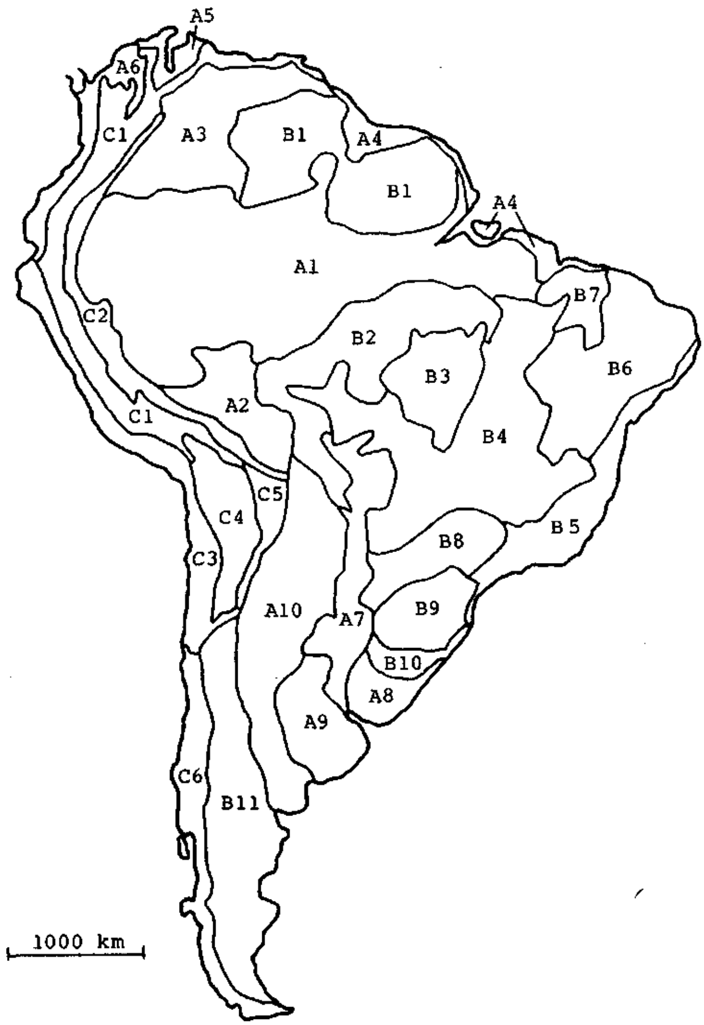


Fig. 1 Map of broad soil regions of South America

Table 2: Australia and New Zealand, data on broad soil regions

Reg.		A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A	1	41.8	-	-	-	-
	2	29.5	.2	5.9	3	6.0
	3	66.5	-	-	-	-
	4	28.8	.4	11.5	2	18.1
B	1	45.9	.2	9.2	1	21.4
	2	60.4	.2	21.1	1	49.1
	3	28.8	.1	2.8	1	6.5
	4	27.4	.2	5.5	3	5.6
	5	61.1	-	-	-	-
	6	26.7	-	-	-	-
	7	36.4	-	-	-	-
	8	48.6	.5	24.3	3	24.9
	9	23.3	-	-	-	-
	10	43.8	-	-	-	-
	11	34.3	.4	13.7	1	31.9
	12	2.8	.2	.6	1	1.4
	13	9.6	.2	1.9	1	4.4
	14	10.3	.2	2.1	1	4.9
C		85.8	-	-	-	-
D		166.6	-	-	-	-
		877.8		98.6		174.2

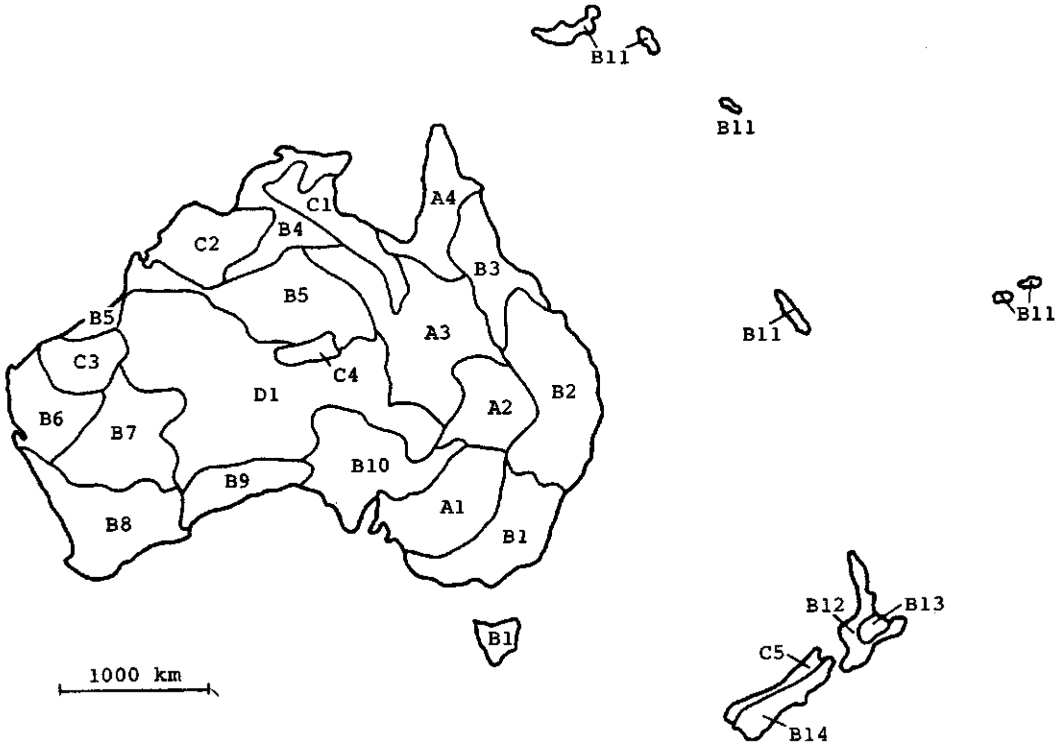


Fig. 2 Map of broad soil regions of Australia and New Zealand

Table 3: Africa, data on broad soil regions

Reg.	A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A 1	40.3	.05	2.0	4	3.4
2	8.2	.6	4.9	4	8.3
3	40.3	.4	16.1	3	16.5
4	14.2	.5	7.1	1	16.5
5	30.9	.1	3.1	1	7.2
6	62.9	.2	12.6	1	29.3
7	15.4	-	-	-	-
8	17.3	-	-	-	-
9	15.4	.5	7.7	2	12.1
10	26.0	.4	10.4	2	16.4
11	8.6	-	-	-	-
B 1	36.4	.05	1.8	4	3.1
2	99.7	-	-	-	-
3	231.9	-	-	-	-
4	212.5	.4	85.0	3	87.1
5	52.7	.5	26.4	2	41.6
6	73.1	-	-	-	-
7	164.2	.2	32.8	1	76.3
8	118.8	.2	23.8	1	55.3
9	157.1	.4	62.8	2	98.9
10	155.7	.6	93.4	3	95.7
11	119.2	.3	35.8	2	56.4
12	75.4	.4	30.2	2	47.6
13	8.5	.3	2.5	3	2.6
14	114.8	-	-	-	-
15	31.2	.4	12.5	1	29.1
16	31.8	-	-	-	-
C	133.9	.05	6.7	2	10.6
D	933.6	-	-	-	-
	3030.0		477.6		714.0

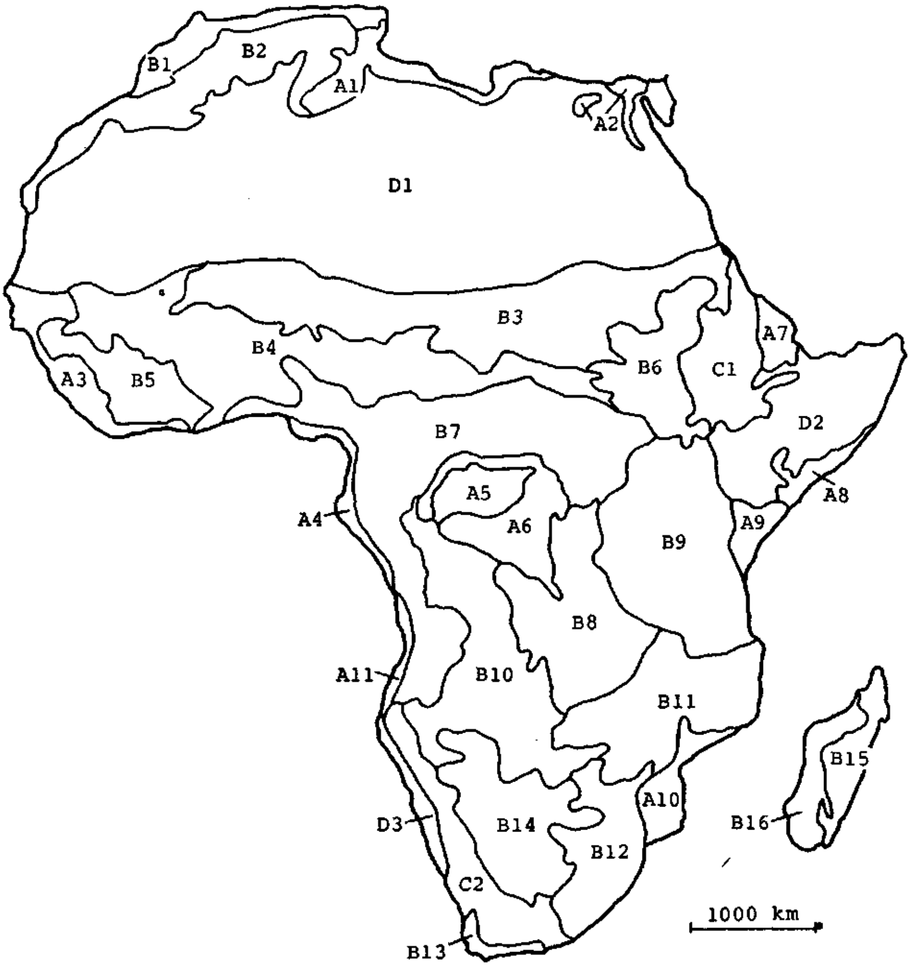


Fig. 3 Map of broad soil regions of Africa

Table 4: Asia, data on broad soil regions

Reg.		A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A	1	12.3	.2	2.5	4	4.3
	2	39.2	.2	7.8	4	13.3
	3	55.9	.5	28.0	1	65.1
	4	32.6	.1	3.3	1	7.7
	5	26.0	.6	15.6	1	36.3
	6	51.5	.6	30.9	1	71.8
	7	59.0	.3	17.7	1	41.2
	8	93.3	.6	56.0	1	130.2
	9	94.6	-	-	-	-
	10	146.5	.5	73.3	1	170.4
	11	232.3	.2	46.5	1	108.1
B	1	4.8	.2	1.0	4	1.7
	2	24.6	-	-	-	-
	3	115.3	-	-	-	-
	4	43.1	.2	8.6	2	13.5
	5	96.4	.2	19.3	3	19.8
	6	92.0	.4	36.8	2	58.0
	7	248.6	.2	49.7	1	115.6
	8	60.7	.5	30.4	2	47.9
	9	120.1	.1	12.0	1	27.9
	10	38.7	.5	19.4	1	45.1
	11	102.6	.1	10.3	1	23.9
	12	180.4	-	-	-	-
	13	78.3	.4	31.3	2	49.3
	14	123.2	.4	49.3	1	114.6
	15	51.9	.4	20.8	1	48.4
	16	139.9	.1	14.0	1	32.6
C		1261.4	.02	25.2	4	42.8
D		764.8	-	-	-	-
		4390.0		609.7		1289.5

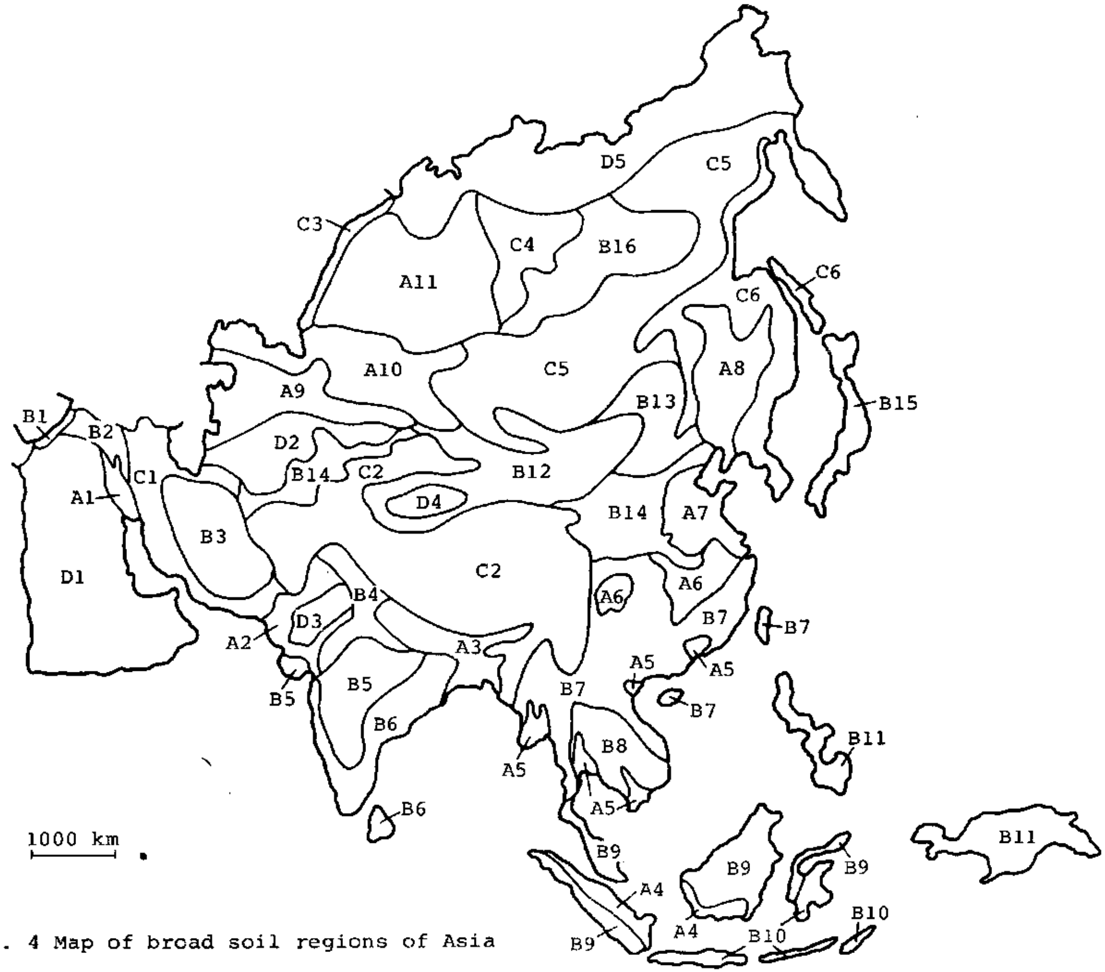


Fig. 4 Map of broad soil regions of Asia

Table 5: North and Central America, data on broad soil regions

Reg.	A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A 1	289.6	.4	115.8	1	269.2
2	72.1	.6	43.3	1	100.7
3	56.1	.7	39.3	1	91.4
4	9.0	.5	4.5	1	10.5
5	19.1	.6	11.5	1	26.7
6	19.1	.6	11.5	1	26.7
7	35.1	.6	21.1	2	33.2
8	58.1	.4	23.2	1	53.9
9	3.9	.05	.2	4	.3
10	100.2	.6	60.1	1	139.7
B 1	86.9	.5	43.5	1	101.1
2	42.8	.6	25.7	1	59.7
3	58.1	.2	11.6	1	27.0
4	42.8	.2	8.6	2	13.5
5	175.5	-	-	-	-
6	11.4	-	-	-	-
7	162.6	.3	48.8	1	113.5
8	26.1	.4	10.4	2	16.4
9	30.7	.5	15.4	1	35.8
10	44.8	.5	22.4	1	52.1
11	1.7	.5	.9	1	2.1
C	159.5	.05	8.0	2	12.6
D	914.8	-	-	-	-
	2420.0		525.8		1186.1

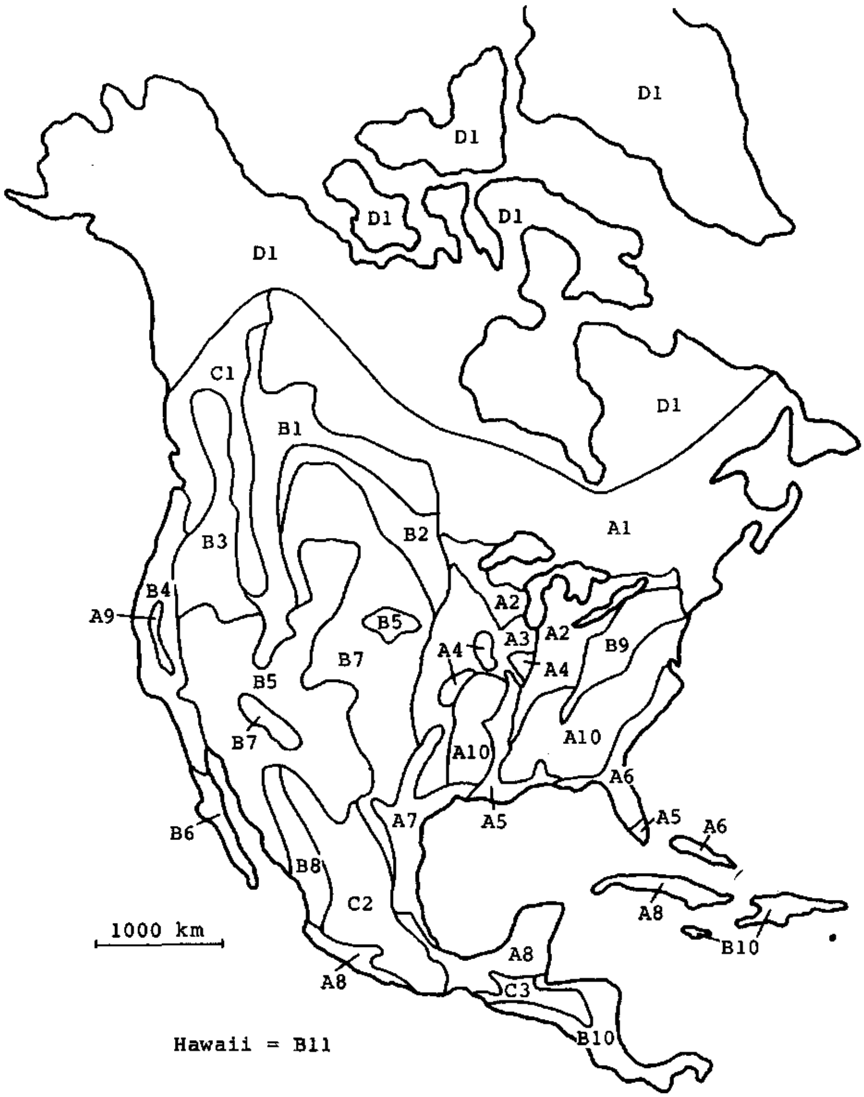


Fig. 5 Map of broad soil regions of North and Central America

Table 6: Europe, data on broad soil regions

Reg.	A (Mha)	FMAL	MAL (Mha)	PC	EGP (Mt)
A 1	78.8	.3	23.6	2	37.2
2	134.4	.4	53.8	1	125.1
3	68.1	.5	34.1	1	79.3
4	114.2	.7	79.9	1	185.8
5	20.6	.2	4.1	2	6.5
6	10.0	.6	6.0	2	9.4
7	45.0	.6	27.0	1	62.8
8	12.5	.5	6.2	1	14.4
9	4.4	.5	2.2	1	5.1
10	4.4	.2	.9	1	2.1
11	2.5	.2	.5	1	1.2
12	3.2	.6	1.9	2	3.0
B 1	79.3	.3	23.8	2	37.4
2	10.0	-	-	-	-
3	5.7	.2	1.1	1	2.6
4	49.4	.4	19.8	1	46.0
5	57.5	.6	34.5	1	80.2
6	18.2	.2	.3	2	.5
7	25.0	.2	5.0	3	5.1
8	23.1	.5	11.6	2	18.3
9	13.8	.5	6.9	2	10.9
10	18.2	.3	5.5	1	12.8
11	21.8	.1	2.2	2	3.5
12	15.0	.4	6.0	2	9.4
13	7.5	.05	.4	4	.7
14	4.4	.5	2.2	2	3.5
C	156.9	.05	7.8	2	12.3
D	46.1	-	-	-	-
	1050.0		367.3		775.0

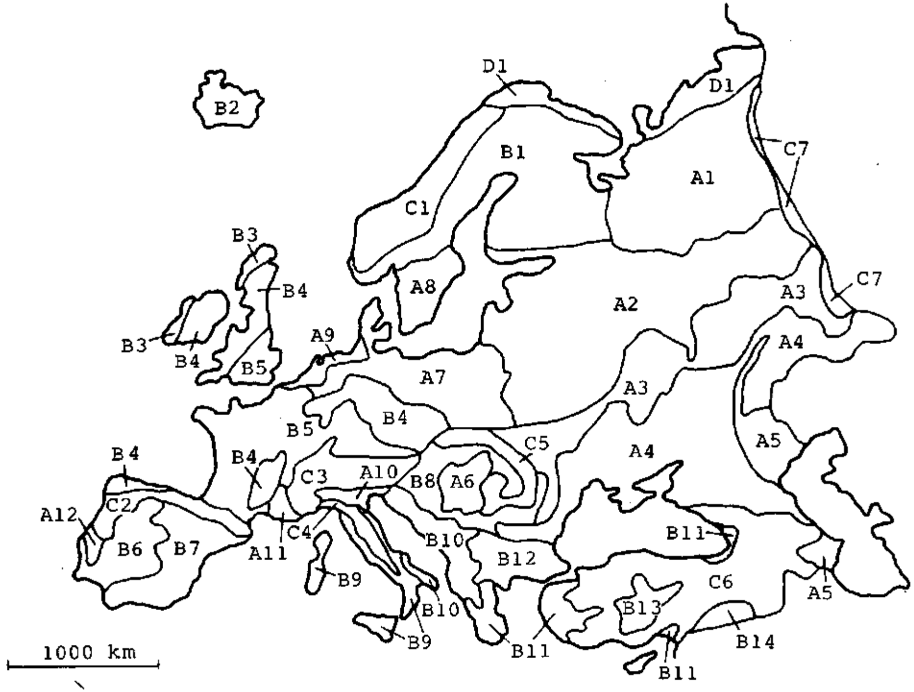


Fig. 6 Map of broad soil regions of Europe

3.2 Estimated grain production (EGP)

Yields in systems of labour-oriented agriculture are low in comparison to modern agriculture, but higher than the present national averages in some countries. From about fifty publications, including those of the FFHC-fertilizer Program, a large number of cereal yields on unfertilized demonstration fields and experimental plots in various countries are collected. In different countries different cereals are grown, and for a correct comparison the yields have to be standardized.

Without the use of the artificial manure the amount of nitrogen available for a crop is low. Under these circumstances the relation of yields to nitrogen uptake is linear, which permits to standardize yields of different cereals using this relation.

From fertilization experiments by which nitrogen uptake was determined, the yield per kg nitrogen consumed was calculated under a low level of nitrogen supply. The results were for wheat about 62.5, for maize and sorghum 65, and for rice 77.5 kg grain (with 15% moisture) per kg nitrogen consumed. Therefore, as only fertilizer returns on rice are distinct from the other cereals, a reduction factor of .8 was introduced to convert rice production into a grain equivalent base. Moreover, as rice production usually is expressed in paddy, the rice grain content is taken as 75% of paddy production. Together, those 2 reduction factors lead to an average of 60% grain equivalent of paddy production. Consequently for rice production regions a production of 165 kg paddy corresponds with 100 kg grain in the calculations.

The converted yield data per hectare of unfertilized fields are collected by broad soil region. Data are available of some seventy regions. Within several regions deviations are large. This, however, is not surprising, since physical conditions in these large regions are far from uniform. Moreover, the history of the various experiment and demonstration plots concerning fertilization, land use, crop rotation and farm management is not similar, and mostly not mentioned in the publications.

Based on the information mentioned above, the broad soil regions (fig. 1-6) are grouped into four grain production classes (PC). Reference is made to a previous study (Buringh et al., 1975) in which the factors for water deficiencies (FWD) and soil conditions (FSC) influencing crop yields are given for each region. At one end of the scale there is a production class (PC = 4) where production is only possible with irrigation, because precipitation is very low. (FWD $\geq$ .2, independent of soil conditions). At the other end there is a production class (PC = 1) without water stress, because there is a high soil water holding capacity combined with moderate rainfall (FSC $\geq$ .8 and FWD $\geq$ .3) or there is enough rain during the growing season (FWD $\geq$ .7 and FSC $\geq$ .5). The two other classes are intermediate. One class (PC = 3) refers to regions where soil conditions and precipitation are relatively poor (FSC = .5 and FWD = .3 to .6 or FSC = .6 and FWD = .3 to .4). In the other production class (PC = 2) soil and weather conditions are moderate (FSC = .7 and FWD = .3 to .6 or FSC = .6 and FWD = .5 to .6).

The cumulative relative frequency of the observed yields for each production class is grouped in intervals of 200 kilograms, and shown in figure 7. In each production class yields are normally distributed with a large standard deviation, as could be expected for reasons already mentioned. In table 7 the expected mean yield, the standard deviation and the estimated grain yield in kilograms per hectare are given.

Table 7: Production classes (PC)

Class	mean yields and standard deviation ($kg.ha^{-1}$)	estimated grain yield ($kg.ha^{-1}$)
1	1750 ± 1150	2325
2	1250 ± 650	1575
3	800 ± 450	1025
4	1250 ± 900	1700

The last figures are used in the following calculations. They represent for each production class the mean yield plus half of the standard deviation. This assumption is made because labour-oriented agriculture is not based on unfertilized soils but on soils that get some local manure, compost etc., when available, and sometimes green manure. Consequently yields somewhat higher than yields of unfertilized land, may be expected.

3.3 Acreage and area per production class

From the tables 1 to 6 the total acreage of each production class for all continents and for the world was calculated. The results are shown below in table 8.

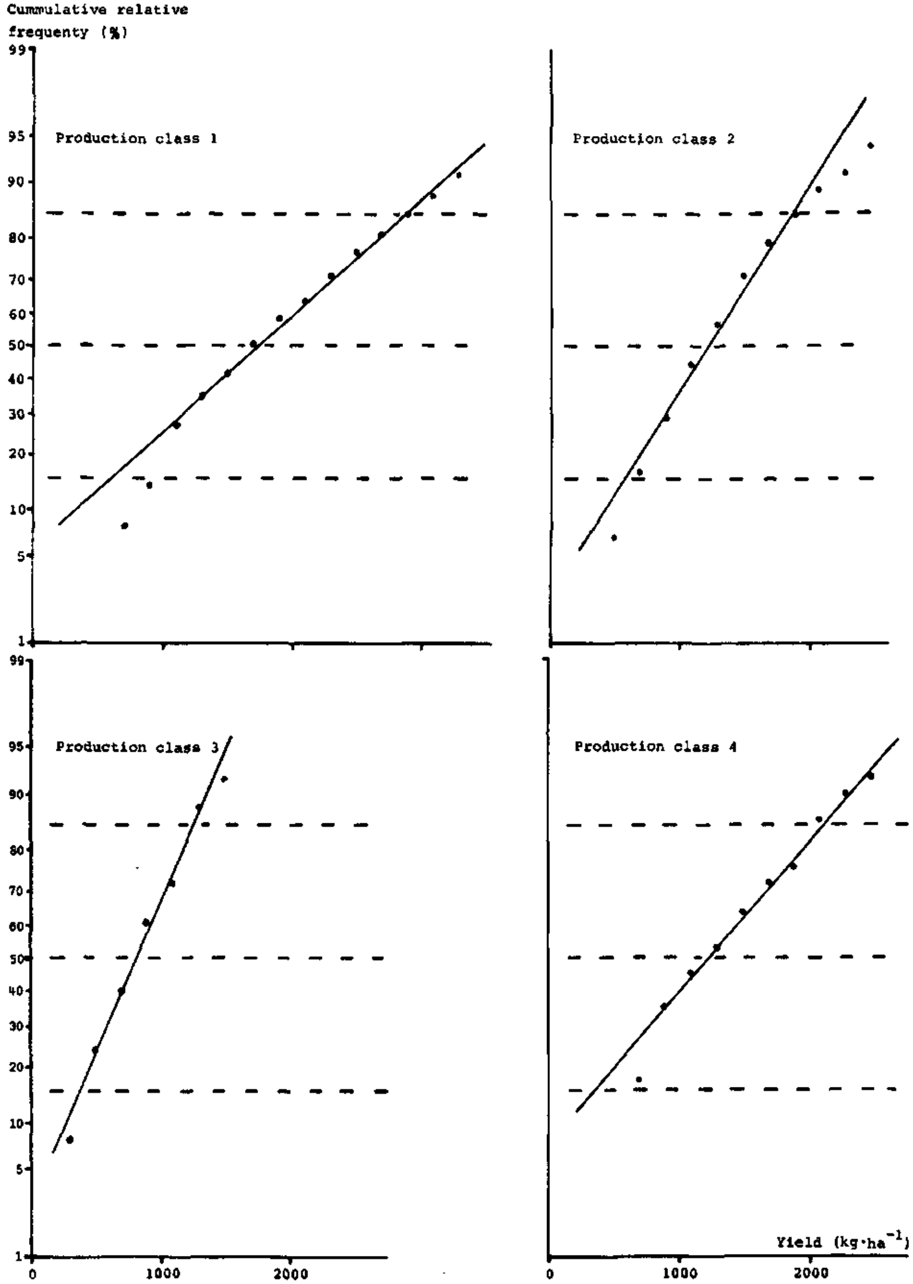


Fig. 7 The cummulative relative frequenty of the observed yield intervals plotted on normal probability paper.
The expected mean is found at 50 %, the standard deviation is half the difference in yield at 85 and 15 procent

Table 8: Maximum agricultural land (MAL in Mha) per production class and by continents[a)]

Prod. Class	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
1	185.8	51.4	91.9	446.8	477.5	265.5	1518.9
2	173.2	11.5	180.0	107.1	48.1	96.4	616.3
3	23.5	35.7	197.0	19.3	.0	5.0	280.5
4	.0	.0	8.7	36.5	.2	.4	45.8
	382.5	98.6	477.6	609.7	525.8	367.3	2461.5
(in % of each continent)							
1	49	52	19	73	91	72	62
2	45	12	38	18	9	26	25
3	6	36	41	3	0	1	11
4	0	0	2	6	0	0	2

a) Percentages may not add up to 100 because of rounding.

The numbers presented above indicate the predominance of the developing countries which contain, by rough approximation, at least 60% of the total land identified as the maximum available for agriculture. The most productive land (class 1) represents 62% of the total, whereas land which can only be made productive (class 4) by way of irrigation constitutes less than 2% of the estimated total. It should also be noted that regions are quite different in terms of the distribution by production classes, with rather favourable composition in North America, Asia and Europe, but the opposite for Africa.

In order to put these numbers into perspective, some comparisons are made with the total land area of each continent, the estimates of potential agricultural land which were presented in the earlier study of Buringh et al. (1975), and with the land areas presently cultivated. These data are presented in table 9 which also contains some of the ratio's and shares that describe agricultural land availability.

Table 9: Summary of land area data by continents (in Mha)

	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
1. Total land area (A)	1,780	878	3,030	4,390	2,420	1,050	13,548
2. Potential agr. land (PAL)	596	199	711	887	627	399	3,419
3. Maximum agr. land (MAL)	383	99	478	610	526	367	2,462
4. Cultivated land (CL)	77	32	158	689	239	211	1,406
	(as % of total area, A)						
5. Potential agr. land (PAL)	34	23	24	20	26	38	25
6. Maximum agr. land (MAL)	22	11	16	14	22	35	17
7. Cultivated land (CL)	4	4	5	16	11	20	10
COMPARISONS							
8. PAL - CL (Mha)	519	167	553	198	388	188	2,013
(% of potential, not cultivated)	26	8	27	10	19	9	100
9. MAL - CL (Mha)	306	67	320	-79	287	156	1,057
(% of maximum, not cultivated)	29	6	30	- 7	27	15	100

As was already noted in section 3.1 above, the main difference between potential (PAL) and maximum (MAL) agricultural land is caused by the fact that the availability of manual labour only, as assumed in the present study, restricts the capacity to reclaim land and thus reduces MAL in most regions well below PAL. This can readily be seen by comparing lines (5) and (6) in table 9, particularly for Australia, South America and, to a lesser extent, Asia. Comparisons with cultivated land (see lines (8) and (9) of table 9) show that the distribution of land not (yet) cultivated by continents is not significantly affected by the choice between potential or maximum agricultural land as the basis for comparison, except for Asia where it appears that the pressure of people on the land has already extended cultivation to a larger area than is assumed maximally (but not potentially) feasible.

3.4 Production by production classes

As was done, in section 3.3, for area and acreage estimates, likewise in this section the production estimates for each continent are grouped together and summarised by the four production classes. These are also taken from tables 1-6 where estimated grain production (EGP) is given for each soil region.

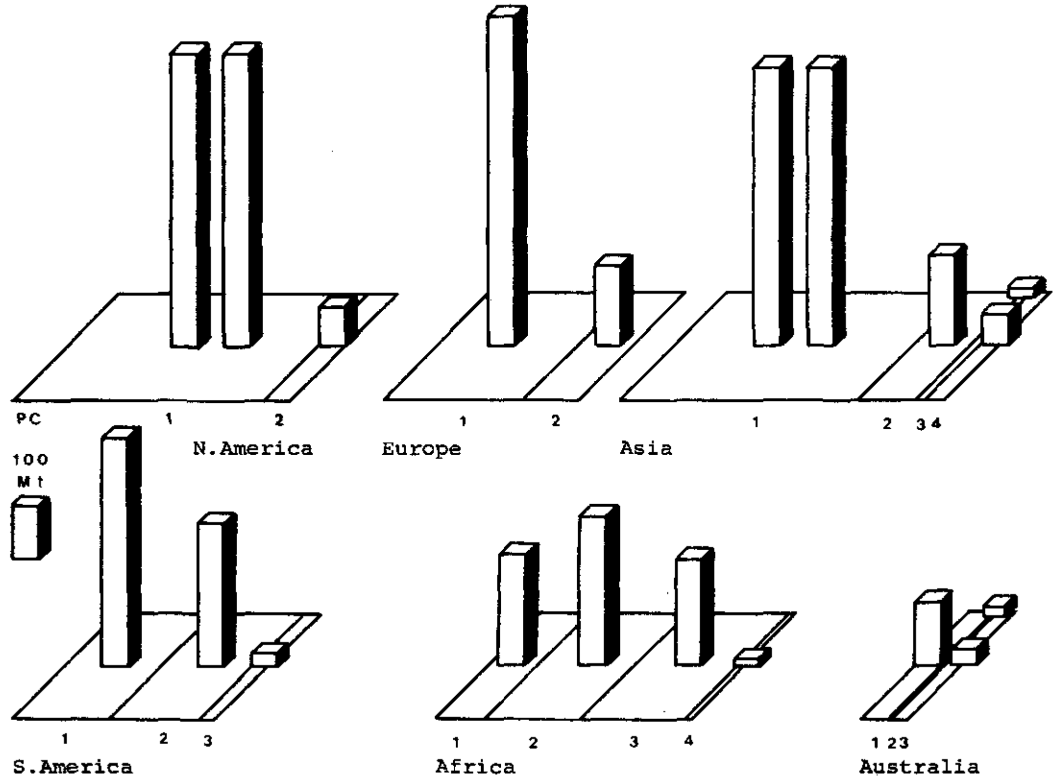
Table 10: Estimated grain production (Mt) per production class and by continents

Prod. class	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
1	432.1	119.6	213.7	1038.9	1110.1	617.4	3531.8
2	272.8	18.1	283.6	168.7	75.7	151.8	970.7
3	24.1	36.5	201.9	19.8	.0	5.1	287.4
4	.0	.0	14.8	62.1	.3	.7	77.9
	729.0	174.2	714.0	1289.5	1186.1	775.0	4867.8
(in % by	continents)						
1	59	69	30	80	94	80	72
2	37	10	40	13	6	19	20
3	3	21	28	2	0	1	6
4	0	0	2	5	0	0	2

As was to be expected on the basis of the estimated yields per hectare in each production class, combined with the distribution of land over these classes, the largest share of total output is obtained from land in production class 1. However, it is interesting to note that the less favourable composition of land in Africa leads to a largest share of production class 2 in total output; a similar, though not as significant, composition difference is noted for South America (see also figure 8).

It is also worthwhile to note, that in general only few of the soil regions distinguished in tables 1-6 contribute significantly to total grain production. In most continents except Australia only 4-7 regions contribute 1% or more to total world output; together those 30-odd regions generate almost 60% of estimated world production. Some regions have even been omitted entirely because of their very small output.

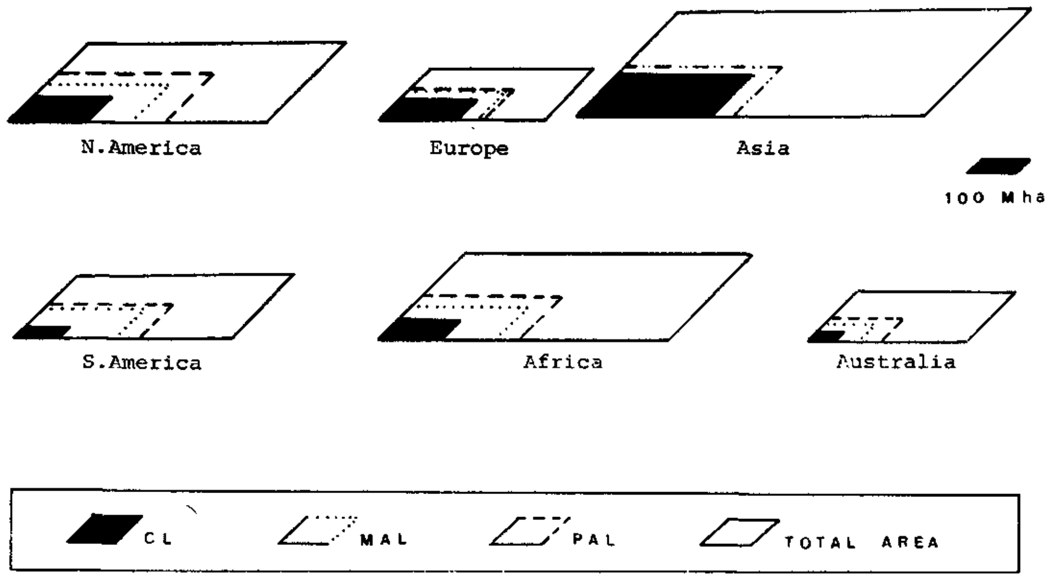
Fig. 8 Estimated grain production (EGP) by continents and production classes



PC = production class (1-4)

Surfaces of production classes proportional to maximum agricultural land (MAL) in each continent

Fig. 9 Cartogram of cultivated land (CL), maximum agricultural land (MAL), and potential agricultural land (PAL) proportional to the total area in each continent



3.5 Consumable grain production (CGP)

The calculations presented in section 3.4 boldly assume that all cultivated land is use for grain crops. In reality on presently cultivated land only 66 percent is used for grain crops and it is therefore logical to assume the same percentage to apply for labour-oriented agricultural systems. Thus, real production of grain equals 0.66 EGP.

Further reductions are necessary to account for grain uses other than human consumption. Assuming 15% for seeds, 15% for feed and 20% for storage losses, only half of grain output remains for direct human consumption. Other percentages could be used, as seed and feed uses may appear somewhat excessive, but storage losses may be conservatively estimated. Therefore an estimate of 50 percent for grains reaching human consumption may be realistic.

Consequently total consumable (by humans) grain production (CGP) amounts to 0.66 x 0.50 x EGP. It should be remembered, however, that the consumable grain yields remain at a level equal to 0.50 x the estimated yields, as the one-third reduction which applies to total availability relates to land under grain crops and not to yields.

The resulting estimates, together with earlier (1975) estimates of maximum production are presented in table 11, below.

Table 11: Summary of production data by continents

	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
(in Mt)							
1. Max. prod. of grain equivalents (MPGE)	11,106	2,358	10,845	14,281	7,072	4,168	49,830
2. Estimated grain production (EGP)	729	174	714	1,290	1,186	775	4,868
3. Consumable grain production (CGP)	241	57	236	426	391	256	1,606
(Yields in t per hectare)							
4. Max. prod. of grain equivalent (MPGE)	18,6	11,8	15,3	16,1	11,3	10,5	14,5
5. Estimated grain yield	1,9	1,8	1,5	2,1	2,3	2,1	2,0
6. Consumable grain yield	1,0	0,9	0,8	1,1	1,1	1,1	1,0
(Shares in total production)							
7. MPGE (in %)	22	5	22	29	14	8	100
8. EGP (in %)	15	4	15	26	24	16	100

3.6 Alternative fallow systems

Even the estimates of section 3.5 may be judged still rather optimistic. In a system of labour-oriented agriculture it is hardly realistic to assume that all land is permanently cropped and harvested, and that 66 percent of the potential agricultural land area could be used to grow cereal crops. There is probably not enough manure and compost and it is difficult to find relevant systems of crop rotations for all soils and climate conditions. Therefore a similar calculation of the total consumable grain production (CGP) as has been made in section 3.5 also has been made for two other situations:

a) assuming that only two-thirds of the cereal crop land is in fact harvested, whereas one-third is fallow, and

b) assuming that only half of the cereal crop land is in fact harvested, whereas the other half remains fallow.

As a consequence, the estimates of consumable grain production (CGP) are proportionately reduced. The estimates are shown below in table 12.

Table 12: Labour-oriented agriculture, consumable grain production (Mt) for three alternative crop rotation systems

	South Am.	Australia	Africa	Asia	North Am.	Europe	World
1. 66% of grain crops[a)]	241	57	236	426	391	256	1606
2. 44% harvested	160	38	157	284	261	171	1071
3. 33% harvested	120	29	118	213	196	128	803

a) Source: see table 11.

3.7 Reference comparisons with modern agriculture

In the previous study of Buringh et al. (1975), referred to before, the maximum production of grain equivalent in the world was calculated. Those estimates differ not only in terms of land use (see section 3.3 for the relevant comparison) but also in their basic assumptions concerning the system of agriculture. In fact, the earlier study assumed an agricultural system which would permit the photosynthetic maximum food production on all potential agricultural land, applying all presently known methods and technology.

To compare those estimates with the outputs of labour-oriented agricultural systems requires some additional assumptions and estimates. The photosynthetic maximum production of grain equivalent was estimated in the 1975-study at 49,830 Mt, but it would be quite unrealistic to assume that all farmers applying modern methods would be able to achieve the maximum. It seems more realistic that they will, on average, only reach half the maximum. This reduced the maximum production (MPGE) by half, so that estimated grain production (EGP) equals 0.5 MPGE, or 24,916 Mt of grain equivalent. Data by continents are presented in table 13. In practice 66% of the land is used to grow cereal crops, and if it is assumed that some 5 percent of the yield is needed as seed for sowing, and 15 percent of the yield is storage loss, the quantity of consumable grain production in modern agriculture is: CGP = 0.66 x 0.80 x EGP, and if it is expressed in kilograms per hectare: CGP = 0.80 x EGP. The yield of consumable grain in kg per hectare is .80 x the estimated grain yield. Data are given in table 14.

Consumable grain production then becomes 13,156 Mt, but it should be noted that this figure is still based on the full cultivation of all potential agricultural land. If instead of this (PAL = 3,419 Mha), one uses presently cultivated land (CL = 1,406 Mha) with otherwise the same assumptions of land use for cereals, seed uses and losses, then consumable grain production is reduced to 5,338 Mt. This, then, permits a comparison on equal terms between modern agricultural methods on the one hand and labour-oriented systems on the other.

Tabel 13: Production potentials of different systems of agriculture (Mt)

	South Am.	Australia	Africa	Asia	North Am.	Europe	World
1. Modern, agr. (MPGE) on all potential agricultural land	11,106	2,358	10,845	14,281	7,072	4,168	49,830
2. Modern agr. on all potential agr. land (EGP)[a]	5,553	1,179	5,423	7,141	3,536	2,084	24,916
3. Modern agr. on present land in agr. use (EGP)	710	188	1,193	5,492	1,335	1,091	10,009
4. Labour-oriented (66) agr. (EGP) on max. agr. land	241	57	236	426	391	256	1,606
5. Labour-oriented (44) agr. (EGP) on max. agr. land	160	38	157	284	261	171	1,071
6. Labour-oriented (33) agr. (EGP) on max. agr. land	120	29	118	213	196	128	803

a) Line (1) reduced by 50%.

Table 14 compares the quantities, by continents, of consumable grain production (CGP) under different systems. It should be remembered that the reduction factor for seed, feed and losses is much higher for labour-oriented systems (50%) than is assumed for modern agriculture (20%).

Table 14: Production potentials of different agricultural systems (Mt)

	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
1. Modern agr. on all potential agr. land; consumable grain production (CGP)	2,932	623	2,863	3,770	1,870	1,100	13,156
2. Modern. agr. on present agr. land; consumable grain production (CGP)	379	100	636	2,929	712	582	5,338
3. Labour-oriented agr. (66) on max. agr. land (CGP)	241	57	236	426	391	256	1,606

The amounts shown for labour-oriented agriculture refer only to the case in which two-thirds of the land is cropped with grains and harvested. The two alternatives (one third fallow, or one half fallow) can be derived as proportions of line (3) in table 14. The important point to be made here is that modern agriculture on presently cultivated land only produces more than 3 times the quantity of food-grains as labour-oriented agriculture on the maximum agricultural land; the comparison is valid because of consistent assumptions about land use under the two systems.

3.8 Food for how many people?

In the previous study on the photosynthetic maximum food production in the world no estimates were given of the number of people that could live on our planet, as many relevant factors involved were not taken into consideration.
It would e.g. be unrealistic to assume that all potential agricultural land could be cultivated in practice.
It is, however, possible to make a rough estimate of the population which could be fed if modern agriculture is applied on present agricultural land. This number roughly amounts to 6,678 millions, assuming a rather high standard of living expressed in terms of average grain consumption of 800 kg per caput per year.

This is significantly more than the present average of 600 kg consumed in the developed countries.
The data for different agricultural systems are summarized in table 15. The estimates of the number of people of each continent, that can be fed under different agricultural systems, are based on the production estimates of consumable grain production available for human consumption in the previous chapters.

Table 15: Estimates of sustainable population for different agricultural systems (in millions of persons)

	South Am.	Aus-tralia	Africa	Asia	North Am.	Europe	World
1. Present population 1977[a]	230	20	410	2400	390	750	4200
2. Modern agr. on present agr. land	474	235	795	3661	890	728	6673
3. Labour-oriented agr. (66) on maximum agr. land	803	190	787	1420	1303	853	5356
4. Labour-oriented agr. (44) on maximum agr. land	535	127	525	947	870	570	3574
5. Labour-oriented agr. (33) on maximum agr. land	401	95	383	710	651	427	2677

a) Based on World Bank population data (1968) and growth rates.

For labour-oriented agriculture the consumption level of 300 kg grain per year is assumed, which is equivalent to some 2000 kcalories per day. Some additional food is provided by fruits, vegetables, oil seeds, meat, etc. According to statistical data nearly one half of the present world population lives in the less-developed countries, producing only 30% of the total grain production, which means an average consumption of 210 kg per caput per year. In two of the three results for labour-oriented agriculture the population number sustained at a rather low level of food consumption, is smaller than the present population, although much more land is cultivated than at present.

There are various predictions on how many people can live on earth, depending on the different assumptions of the standard of living and food comsumption. Gifford et al. (1975) have made an estimate for Australia and conclude that, given the present standards of living, some 25 million people could live in that country, whereas this number would be 200 million if sustained at a very low consumption level. In the present study, the population of Australia under conditions of labour-oriented agriculture could be some 80 million people. (The number of 190 million in the table refers to Australia including New Zealand and Oceania).

Table 16 which summarizes the main results discussed above, also gives the numbers of agricultural population in each continent, needed to produce the agricultural production. On the base of the harvested acreage, it is possible to make a rough estimate of the agricultural population. The utilization of labour on a farm without external inputs is about .5 man per hectare of arable land (Baars, 1973). In modern agriculture this is about .067 man per hectare (De Wit e.a., 1976).

An average of 40% of the present world population is economically active, the population dependent on agriculture in the two production systems is respectively 1.25 and .17 person per hectare of arable land. For the labour-oriented variants this amounts to 37% of the total population and for modern agriculture 2.5%. At present, the agricultural population is in average almost 50% of the world population.

Table 16: Data of various systems of agriculture

Agricultural system	Cultivated land	Harvested cereal crop land	Average yield	Total cons. food	Available food	Population	Agr. population
	Mha	Mha	$kg{-}ha^{-1}$	Mt	b)	M	M
Present	1406	928	1,358	1260[a)]	300	4200	2000
Modern (on present agr.land)	1406	928	7,287	5338	800	6673	160
Labour-oriented (66)	2462	1625	1,978	1606	300	5353	2000
Labour-oriented (44)	2462	1083	1,978	1071	300	3570	1350
Labour-oriented (33)	2462	812	1,978	803	300	2677	1000

a) without post harvest losses

b) kg per caput per year

3.9 Land use

The general land use in labour-oriented agriculture is given in table 17 for all continents and the world. The maximum agricultural land is all cultivated. In order to have at least a minimum of manure, the area of grazing land should be 1.6 times the area of arable land (Slicher van Bath, 1960). The non-agricultural land is all desert and tundra land (regions D in tables 1-6) and half of the mountainous land (regions C in these tables). For urban purposes an area of ten percent of the total land area excluding non-agricultural land, is assumed.

Table 17: General land use, labour-oriented agriculture (Mha)

	South Am.	Australia	Africa	Asia	North Am.	Europe	World
Agricultural land	383	99	478	620	536	467	2462
Grazing land	612	158	764	976	841	588	3939
Forest land	490	347	584	1109	-85	-123	2323
Non-agr. land	125	209	1001	1396	995	126	3852
Urban land	165	65	203	299	143	92	968
Total land	1780	878	3030	4390	2420	1050	13544

As all land use types except forest (which also includes wildlife areas) are calculated, forest is a residual category which can become negative. Indeed, the results for North and Central America and for Europe are negative. This indicates that a system of labour-oriented agriculture would destroy all forests (except in the high mountains) in those continents. Due to introduction of modern methods and techniques of agriculture there are still large areas of forest in these continents.

The differences of land use patterns between labour-oriented systems and modern systems are very large, as is clear from table 18, which provides a summary comparison, including also the present land use pattern. The data are also presented in graphical form, in figure 10.

Table 18: General land use, three systems of agriculture (Mha)

	Modern	Present	Labour-oriented
Agricultural land	1400	1400	2500
Grazing land	2000	3000	3900
Forest, wild life	5100	4600	2300
Urban land	1100	600	900
Non-agricultural land	3900	3900	3900
Total	13500	13500	13500

The acreage of grazing land in modern agriculture is set at 2000 million ha, assuming modern management leading to a considerably higher production than is obtained at present.

To sustain the present population in a system of labour-oriented agriculture, an area of more than 1000 million hectares would be cultivated in addition to the 1400 million hectares already cultivated at present. It is clear that misuse of land (soil erosion, soil salinization and degradation and desertification) would occur over much larger areas than at present. Much land would be damaged to such an extent, that it would become useless for food production. No reduction factor for land misuse is included in these calculations.

3.10 Results and reality

In this chapter various remarks on the reliability of the results are made. The general impression is, that some main assumptions are too optimistic. For example, it is assumed that all farmers can apply a suitable crop rotation, adapted to local condition, and that each farmer has in addition to arable land an even larger area of grazing land in order to obtain enough manure. It is also assumed that technical means needed for simple reclamation works are available, and that all farmers are taking good care of their crops, using simple tools and animal traction. Moreover, it is assumed that labour-oriented agriculture can be practised in all regions. In large part of Africa, however, where tse-tse fly occurs or where riverblindness prevents occupation and cultivation of land, such a system of labour-agriculture is hardly possible or even impossible. More examples for other regions can be given.

It is already mentioned, that the computation of consumable grain production in a system of labour-oriented agriculture in which one-third of the potential agricultural land is fallowed each year is probably the most realistic. This means that the number of people that can be sustained on our planet is 3570 million, or 85% percent of the present population.

Various other factors, which may reduce the estimates even further, are not taken into accounts, e.g. risks of climate, disasters, diseases, pests etc. If these are also included in the estimation procedure, all results will probably have to be reduced.

As far as crop rotation is concerned, reference is made to the examples given by Slicher van Bath (1960) for various parts of Europe. For the subtropics and the tropics reports on experiments in some research stations indicate that similar crop rotations seem to be possible although crops are different. In the present computation the problem of crop rotation in labour-oriented agriculture probably is handled too optimistically as well. However, in computations like this, simplifications have to be made. The additional calculations for situations in which only two-thirds or one-third of the cereal grain area is harvested each year (CGE (44) and CGE (33) in table 16) are intended to handel this problem in a broad and aggregative manner. Thus, the data obtained for CGE (44) are probably most realistic, if farming risks are to be included in the computation.

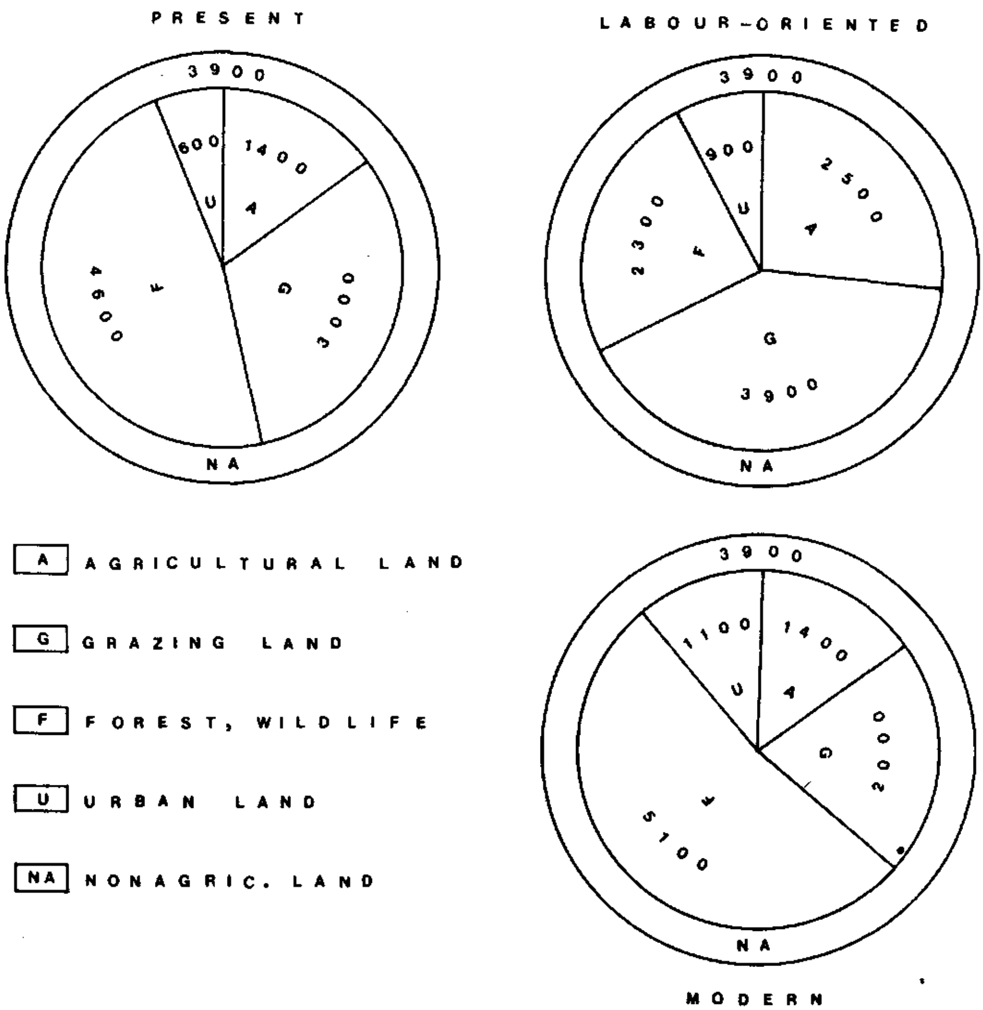
The present study is based on cereal crop and on consumable grain. The food situation would be somewhat more favourable if potatoes and other tubercrops like cassava are grown on a considerable part of the 33 percent of the potential agricultural land not used for cereals. However, risks involved in this production because of diseases are still remembered in Ireland.

The calculations may be optimistic on another count: it is likely that an important part of organic manure is given to non-cereal food crops, resulting in a lower average grain production per hectare.

Another factor is land development. In labour-oriented agriculture an additional 1056 Mha are cultivated and also more than 900 Mha of grazing land are added as compared to the present situation. These 2000 Mha are mainly developed from forest land. It is clear that soil destruction, particularly soil erosion, would be enourmous. Desertification would be widespread. Therefore, it seems to be realistic to decrease the area of land that would be cultivated in labour-oriented agriculture (MAL).

The average estimated grain production, as assumed for the various regions (EGP) (in tables 1-6) appears to be rather realistic, because they are determined after consultation of various publications of experiment stations and refer in particular to fields where little or no fertilizers are applied. Reference is also made to: Slicher van Bath (1960), De Wit (1972, 1973), Isnumadji (1973), Baars (1973), Dekkers, Lange and De Wit (1974), Schuffelen (1965), Flach (1970), Young (1976). The variation in yield (difference between

Fig. 10 General land use of the world



the lowest and highest production class) is much smaller than in modern agriculture. Therefore an assumption that is somewhat lower or higher does not influence the results significantly. In fact during our investigation we first made an estimation based on five production classes with somewhat lower average grain yields based on scarce data of agricultural systems similar to labour-oriented systems. Later on it was prefered to adapt the figures given in table 7, since it turned out that more data were available and the assumptions made are less subjective. The differences between the first calculations and the ones published here are only minor. A review of the assumed average yields by regions suggests that some may be overestimated.

The final conclusion must be, that various assumptions are rather optimistic and consequently the results are probably too optimistic as well.

4. CONCLUSIONS

4.1 Consequences of labour-oriented agriculture

If labour-oriented agriculture would be practised all over the world on land that is suitable for this system of farming, 2462 million hectares would be cultivated, that is 1056 Mha or 75 percent more than presently cultivated. The total consumable grain production would be 1606 Mt. i.e. 336 Mt or 26 percent more than present cereal grain production. As stated before, not all land can be sown each year, because once every three years or even once in two years a fallow year must be introduced. The consumable grain production is then respectively 1071 Mt and 803 Mt, which is 200 Mt (16 percent) or 467 Mt (37 percent) less than is produced at present. The conclusion therefore is, that it is impossible to feed the present world population if only labour-oriented agriculture is practised.

Some readers may have the idea that food production in labour-oriented agriculture can be increased by applying simple technology that hardly needs inputs external to the farm. This might be true for existing traditional farming, but as simple technology is already included it is not true for labour-oriented agriculture as discussed above. Moreover, the limiting factor remains the availability of nitrogen and phosphate for crop production. These nutrients have to come from farm manure, compost, legumes etc. When calculating the availability of these nutrients,for which the ratio of 1 hectare arable land against 1.6 ha grazing land is assumed, the yields per hectare as mentioned in section 3.2 may be expected.

Labour-oriented agriculture would occupy 2462 million hectares of cultivated land and 3939 million hectares of grazing land (table 17), together 6401 million hectares or almost half of the total land area of our planet to support the world population. As 4000 million hectares of land is not suitable for agriculture, (too dry, too cold, too stony) and some 900 million hectares are needed for urban use there is only 2300 million hectares left for forests, supply of fire wood and wild life. Labour-oriented agriculture, therefore, will cause serious land use problems. As very large areas have to be reclaimed and crop yields are rather low, it is not difficult to conclude that misuse of land, particular soil erosion, degradation, and desertification will be even more disastrous than already at present. Almost everywhere land will be damaged. Soil conservation would be virtually impossible, because of low incomes of the farmers. Ecological conditions would be widely disturbed. At present the annual destruction of natural forest is estimated at 8 million hectares in Asia and 5 to 10 million hectares in Latin America. With labour-oriented agriculture the distruction of forest will be much more severe, and soil erosion will be widespread.

4.2 Present agriculture

The present situation in the world, although it is not ideal, at least seems to be much better than a situation resulting from labour-oriented agriculture. But for a highly inequal distribution there is at present enough food (De Hoogh, 1976). From a technical agricultural point of view it is not difficult to increase food production. This is due to the fact that only a part of presently cultivated land (approximately 20 percent) is used for improved or modern agriculture. This part produces some 40 percent of total foodgrains (Buringh, 1977). This demonstrates the low productivity level of farming on 80 percent of the cultivated land area.

In the 35 years to come, population will about double and food production has to be tripled, as has been understood already for many years. The food crises of 1972 and 1975 have made the food problem more visible. In order to increase food production almost all countries reclaim new land. The level of productivity remains low, even in most of the newly areas. Many examples of recent reclamations can be given. In Brazil the reclamation of the virgin Amazon basin has started on a large scale; the Soviet Union is reclaiming very large areas in Central Asia. What is really going on in the world at present time is that relatively little is done to increase the productivity of the land that is already cultivated and instead large new areas are reclaimed, whereas the production of this new land is similar to the production obtained when labour-oriented agriculture is practised, even when the system of agriculture seems to be modern because of the use of modern machinery. The estimation of food production based on labour-oriented agriculture, therefore, gives an idea of what can be expected in the future, if such an agricultural policy were continued. It is clear that much land is damaged, and even much more land will be damaged in the next decades. It seems that responsible people do not realize sufficiently that productive agricultural land is an important natural resource which can be damaged or even lost entirely if not used with care and foresight.

4.3 Modern agriculture

The result of the estimates for modern agriculture is that on 66 percent of the land which is currently cultivated, 5338 Mt of grain can be produced (table 14). This is more than four times the present cereal grain production. In a study of the production obtained on a farm around 1800 in the south-western part of the Netherlands and described by Baars (1973), Dekker, Lange and De Wit (1974) derived the same conclusion.

It is also calculated that more than 6600 million people can be sustained at a high level of consumption (800 kilograms of grain per capita per year). At a consumption level as presently prevailing in the Western world (600 kilograms) even twice the present population could have enough food. Moreover, modern agriculture only needs 3400 million hectares of cultivated and grazing land for food production. This is 1000 Mha less than used at present, and it is only 25 percent of the total land area. Much more land (5100 Mha) is available for forest and wild life.

One also can conclude that a food production level four times the present output is not needed for some time and that approximately one-third of the presently cultivated and grazing land can produce enough food for the present population and consequently even more land is available for forest and wildlife.

It would, of course, be rather simplistic to list the problems associated with traditional and labour-oriented agriculture and the advantages of modern systems, without discussing the problems associated with the latter. Their omission is not because of a lack of awareness, but because there are not the subject of the present study. Modern agriculture is not without its own effects on ecology, and has implications for employment, the demand for energy and the need for water - to mention only a few - which cannot be neglected in a proper comparison.

4.4 Agricultural development policies

The conclusions of this study suggest an extension of the discussion in the area of agricultural development policies. Only a few remarks are made here.

It is evident that labour-oriented agriculture is not a solution for the world food problem. Even a step by step improvement of present agriculture is not enough, because it takes too much time. Helping poor farmers to increase crop production does not contribute much to the total world food production. This does not mean, that poor farm-families do not need help to improve their

Fig. 11 Cartogram of the potential agricultural area (Pal, indicated as total surface), the cultivated land (CL, the shaded areas), the present cereal grain production (front column), and the consumable grain production for modern agriculture (CGM in Mt) in each continent

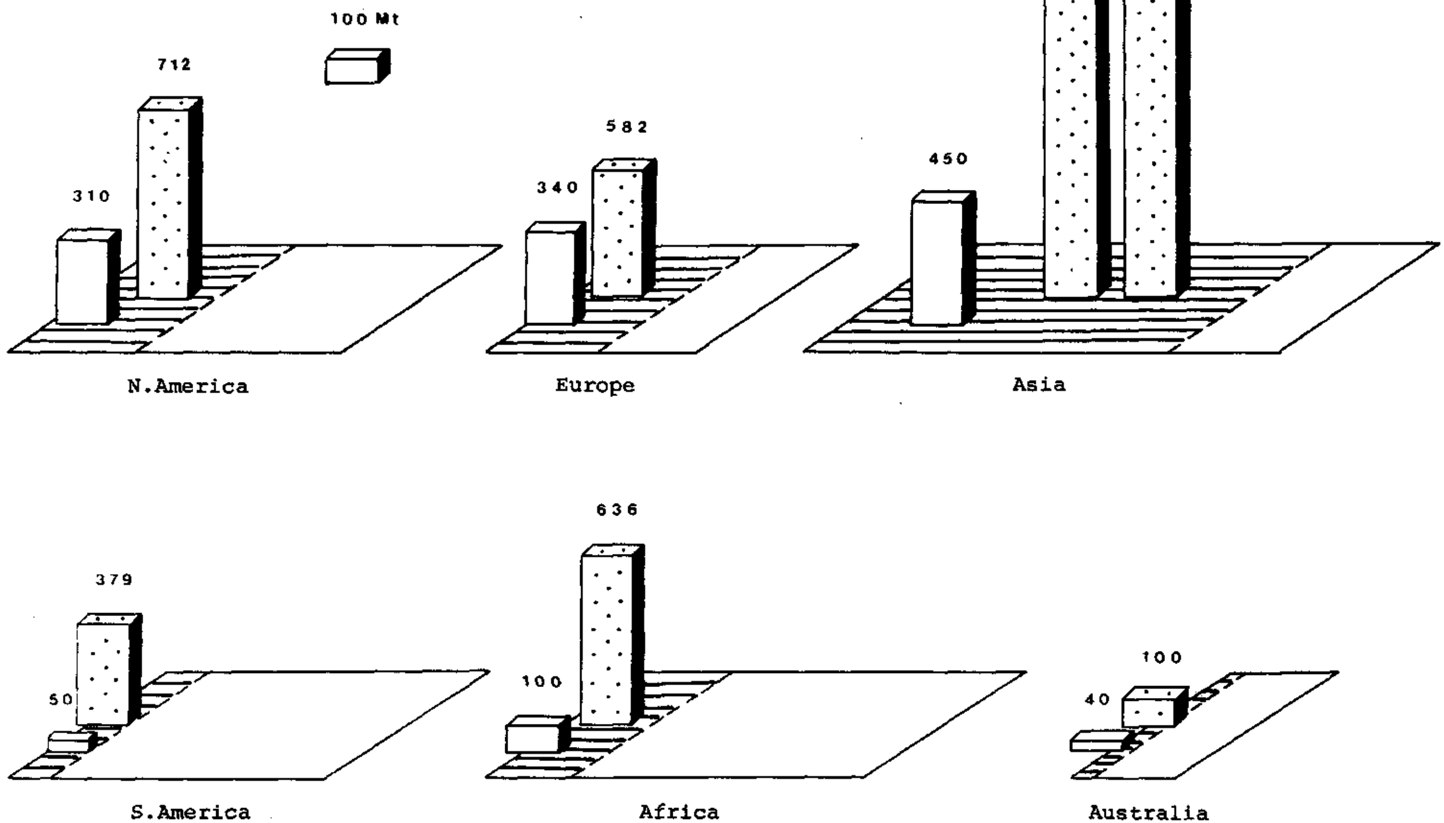
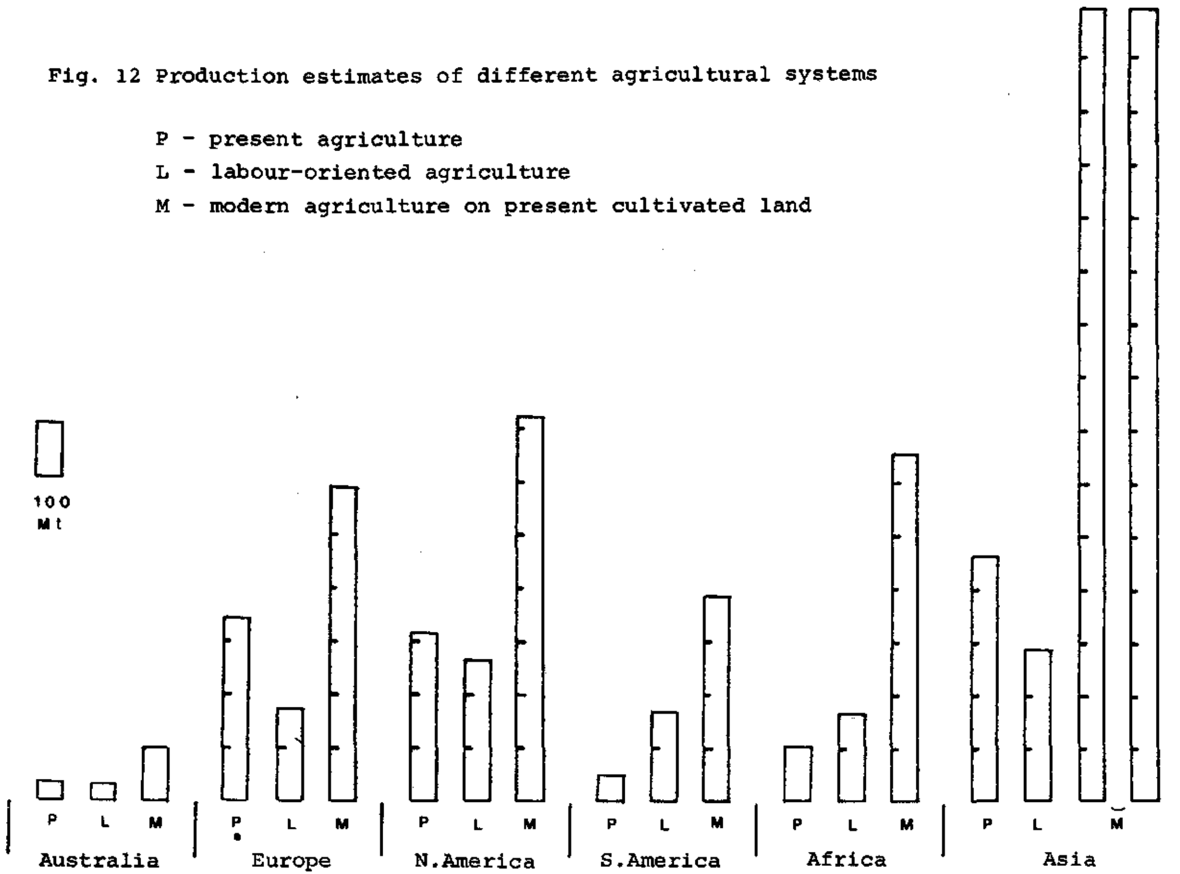


Fig. 12 Production estimates of different agricultural systems

P - present agriculture

L - labour-oriented agriculture

M - modern agriculture on present cultivated land



living conditions, but other efforts to increase food production needs to be made as well.

The present policy of reclaiming large areas of land, in order to produce more food for an increasing population, has disastrous consequences in many countries. Unfortunately, this policy is followed by many countries, particularly by powerful countries, that have discovered that food is an important political weapon.

From a point of view of living conditions, natural resources, ecology and conservation of the environment it seems to be much wiser to introduce on a large scale modern systems of farming in those parts of the various countries where productive land is already cultivated, but where productivity is still very low. Land use intensity, resulting in much higher crop yieldsper unit of land, has to be increase rapidly. Reclamation of new land has to be restricted. In the meantime much more effort needs to be made to protect and to conserve land. Misuse of land has to be avoided.

In many countries agricultural development policies are to be changed.

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