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Computation of the absolute maximum food production of the world

by

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SUMMARY

1 We have tried to compute the absolute maximum food production of the separate continents and the whole world. The results, expressed in grain equivalents, have only a theoretical and scientific value. They may be important as basic material for specialists who study the world food problem. These specialists can introduce various reduction factors in order to get realistic information, as our study is based only on a limited number of environmental factors. The results should not be misunderstood, because the world food problem is very complex and many other factors, in particular economic, social and political aspects, have to be taken into account.

2 The whole world is classified into 222 broad soil regions, based on soil conditions and topography. For each region, soils, climate, vegetation and topography are studied.

3 The total potential agricultural land of the world is 3419 million hectares, being 25% of the land area of the world, of which 470 million hectares could be irrigated. At present 1406 million hectares of land are cultivated, of which 201 million hectares are irrigated. The results of our computation are slightly higher than those determined in the USA in 1967, and which are used by Meadows (1972). They are quite different from those given by Mesarovic and Pestel (1974).

4 We have also classified the 222 regions into nine classes, expressing according to its availability the relative importance of the land in those regions. The regional distribution of these classes is shown on the maps (figures 1-6).

5 Taking into account the possibilities of irrigation and the limitations in crop production caused by local soil and climatic conditions, the absolute maximum production expressed in grain equivalents of a standard cereal crop is computed as 49,830 million tons per year, that is almost 40 times the present cereal crop production. As at present approximately 65% of the cultivated land is used for cereal crop production, the maximum production on that area could be 32,390 million tons of grain equivalents or 30 times the present production.

6 South America and Africa south of the Sahara are the most promising continents. Australia is the least promising.

7 Although some appraisals and assumptions have been made, we believe that the results give a rather reliable idea of the absolute maximum food production of the world and the location of the regions where most productive land is available.

8 All regions have been classified according to the absolute maximum productivity per hectare of the potential agricultural land (fig. 7-12), this gives a new idea about the regional distribution of possible land productivity, which is highest in tropical regions, in particular if double or triple cropping can be practised.

1 PURPOSE OF THIS STUDY

The purpose of this study is to try to compute the absolute maximum food production of the world, the upper limit of what can be grown on all suitable agricultural land. Moreover we have made an assessment of land resources and productivity of more than 200 regions of the world, introducing at the same time the regional aspects of food production and land productivity. We expect that such a study may be of interest to other specialists, in particular economists and sociologists who are working on the world food problem. Our study is made in connection with the project: "Problems on population doubling", initiated by the Club of Rome, and guided by Prof.Dr. H.L. Linnemann, Amsterdam. The results are used as basic data in that study. Our study is a theoretical approach to the above mentioned specific aspects of the complex food problem. It is based on measurements, appraisals and assumptions which are given separately. We have worked on a rather high level of generalization because we were dealing with the whole world, and consequently the result is an approximation. The very high potentials of food production that are computed are realistic as such, but never can be obtained in practice because of economic, social or political limitations. Specialists in other disciplines have to introduce various reduction factors in order to get realistic data.

2 METHODS

2.1 Introduction

The authors studied the land resources and the suitability and quality of the soils (Buringh and Staring), the climatic conditions and potential dry matter production (Van Heemst). In addition the quantity of water available for irrigation was collected from a recent study by Moen and Beek (1974). Up to recently it was generally accepted that 1406.10^6 hectares of land are cultivated at present and that a similar area would be suitable for cultivation in the future, making a total area of potential agricultural land of approximately 2800.10^6 ha, which is about 21% of the land surface of the world. A recent study made by some American specialists (American report, 1967; Simonson, 1967) reveals that there should be approximately 3190.10^6 ha of potential agricultural land, whereas some Russian soil scientists (Kovda, 1974) believe that approximately 5000.10^6 ha of land could be cultivated. This means respectively about 25% and 39% of the land surface. It is never computed what could be the maximum food production on these areas. Various specialists, however, have claimed that the present food production could be multiplied by ten, in particular that this should not be very difficult in (sub)tropical regions. Until recently calculations could not be made because of the absence of reliable soil maps of the various continents. Since the FAO/ UNESCO soil map of the world is available a much better basis for assessing the land resources is available. Our calculations are based on present knowledge of soils and of modern measures to bring these soils to the best possible conditions by adding manure, fertilizers and other amendments, and by improving the soils as for example by drainage, subsoiling, deep ploughing. This does not mean that all land could be given a specific set of complicated measures for amelioration to get the highest growing conditions and a maximum yield. In many soils there still are specific internal properties that shall always limit the growing conditions and therefore the crop production. We therefore introduce a reduction factor if soil conditions are limiting the food production.

Data on climate were collected from all over the world. They include precipitation, temperature, sunshine, relative humidity and wind. With these data the maximum photosynthesis and consequently the maximum dry matter production per hectare could be calculated. This is done on the basis of a standard crop, which has the properties of a cereal crop, for example wheat or rice, the main food crops, and the final result is expressed in grain equivalents. Here we assume that crop production takes place by applying modern farm management practices that are best suited for the prevailing local environmental conditions. Under the assumed optimal management practices there shall not be soil degradation, accelerated soil erosion, salinization, sodication, etc. and there shall be flood protection. Plant diseases do not occur.

The available information on irrigation (per country) is distributed over the regions as if irrigation reaches the most suitable soils. Desalinized sea-water is not considered to be a source of irrigation water, moreover we have nowhere supposed that new, still unknown techniques of farm management were introduced. The heating of soils in the cold zones is not taken into account. We did not calculate the costs of food production, which is an economic subject.

Because much potential agricultural land has to be reclaimed in the future we have only given an indication of the land development cost, in particular as far as this depends on topography, present vegetation and the hydrological conditions.

It should be clear that our approach to the problem of food production treats only a few of the many aspects.

2.2 Land resources

Soil conditions vary all over the world, often even over short distances. There are many thousands of soils with quite different characteristics and properties. Some soils are highly productive, others are too bad for crop production. There are no detailed soil maps, showing all soils in the world. The best map that shows soil conditions of the continents is the new Soil Map of the World (1:5,000,000), compiled by a large number of competent soil scientists and published by FAO/UNESCO (1974). For the continents for which these maps are not yet available we used other recent maps: Australia (Stace, 1968), Asia (Kovda and Lobova) and Europe (Dudal, Tavernier and Osmond, 1966). Each continent has been classified in 30 to 50 broad soil regions. For South America (see figure 1) the broad soil region map of FAO (fig. 7 in Vol. IV of the Soil Map of the World) was used. For the other continents we made similar maps, based on the soil maps of the continents. In total 222 broad soil-units have been distinguished. A broad soil region is a physiographic unit (see figues 1-6) indicated with a symbol on our maps. Each region covers a very large area with quite different soil conditions. The area of each broad soil region was measured by the planimetric method on map scale 1:15,000,000. The scale of the maps in figures 1-7 is much smaller and these maps are somewhat simplified. The symbols on the maps (figures 1-6) correspond with those in the tables (tables 1-6) in which the results of our measurements and calculations are given. The character A refers to lowlands, B to uplands, C to high mountain lands and D to dry deserts and tundras. The area of each broad soil region (A) is given in column 2 in the tables. The total land area of the continents is taken from data given in the Winkler-Prins atlas (Elsevier, Amsterdam, 1954). The percentage of each broad soil region (A%) of the continent concerned is given in column 3.

The soils occurring in each broad soil region were studied. Not all soils of a region can be used for crop production, some are very poor, too stony, too steep or too shallow, others are already used for urban or other non-agricultural purposes (10-30%). Poor land used for extensive grazing, a part of the forested areas, lakes and swamps that cannot be reclaimed are also excluded. This means that the potential agricultural land (PAL) that could be used for crop production is a fraction of the area of a broad soil region. The appraisal of this fraction (FPAL) is given in column 5 of the tables and the area of potential agricultural land (PAL) is calculated with the formula:

$$PAL = A \times FPAL \qquad (1)$$

The result is given in column 6. Although extensive grazing, cultivation of some specific crops and some commercial forestry may be feasible on land that is excluded, this production is ignored in this study.

Even if climate and farm management were ideal not all soils can produce the maximum production because of internal soil properties that are not optimal, and that can hardly be improved. In many regions soil conditions may prove to be a limiting factor in crop production. Therefore a reduction factor is introduced as FSC (reduction factor soil condition). For each region this factor is appraised and given in column 8. Now we can calculate (IPAL), the imaginary area of potential agricultural land with potential production:

$$IPAL = PAL \times FSC \qquad (2)$$

This imaginary area is given in column 10. For reasons to be explained in the next paragraph this formula is applied only if FSC (in column 8) < FWD (in column 9).

A part of the area of potential agricultural land (PAL) is already cultivated, there is, however, also much land that can be reclaimed or improved in the future. This requires capital inputs. In column 7 we have given an appraisal in five classes of the development costs. Class 1 represents very low costs of reclamation or improvement and class 5 very high costs, because clearing of dense forest vegetation, soil conservation, terracing, levelling and/or drainage, etc. may be needed. The classes 2, 3 and 4 are intermediate. It is expected that the costs of class 1 shall be less than $ 200 and of class 5 approximately $ 3,000 per hectare. The development cost classes (DCC) are given in column 7. These data are not used in our calculations given below. For agronomists and economists they may be an indication of the capital inputs required.

Finally it should be kept in mind that the potential land (column 6) is an assessment independent of the climate, a factor that shall be introduced in the next paragraph. An exception has been made for real desert soils without possibilities of irrigation and/or tundras (group D at the lower part of the tables).

2.3 Water deficiency and irrigation

In many regions, where precipitation in particular during the growing season of crops is low, water deficiency becomes the limiting factor for crop production. The factor for water deficiency (FWD) can be calculated as shall be explained in paragraph 2.4. It is given in column 9 in the tables.
For regions having FWD < FSC, which means that water deficiency is the limiting factor, the following formula is used to calculate the imaginary area of potential agricultural land (IPAL) in column 10:

$$IPAL = PAL \times FWD \tag{3}$$

In such regions irrigation may provide the required additional water to reach the maximum crop production. Water resources, however, are limited and therefore only a low percentage of the land can be irrigated.
In a study by Moen and Beek (1974) the potential irrigable area for a great many countries was determined. These data are mainly based on: International Commission on Irrigation and Drainage (ICID), 1969: "Irrigation and drainage in the world, a global review", and on some more recent publications by FAO and individual countries. This information was converted to the broad soil regions used in this study. In column 12 the potential irrigable agricultural land (PIAL) is given for each region, where water is available and irrigation is needed. It is supposed that the best soils in those regions are irrigated first, and if enough water is available soils with some limitations can also be irrigated. If no definite information was available (USSR, China) the irrigation projects have been located in the drier zones. We did not take into account the quality of the irrigation water, the possibilities of desalinization of sea-water, the availability of ground-water and the possibility of diverting rivers in a completely different direction.

2.4 Climatic conditions and photosynthesis

The crop production also depends on climate, which varies widely. We tried to compute the theoretical potential production, that is the production of a healthy, green, closed, standard crop, well supplied with nutrients, oxygen, water and foothold and therefore only limited by the daily photosynthetic rate, that depends on the state of the sky, the latitude and the date. In order to calculate the potential production in each broad soil region many climatic data of many locations have been collected. These data include the monthly air temperature, precipitation, solar energy, etc.. De Wit (1965) gives for a standard crop a table indicating for the middle of every month of the year the daily totals of photosynthesis on every clear (PC) and overcast (PO) day at various latitudes. PC and PO can be derived from this table for any location by linear interpolation. The mean monthly gross photosynthesis (GP) can be computed by the following formula:

$$GP = ID\ (F \times PO + (1 - F) \times PC) \qquad (4)$$

GP is expressed in kg carbohydrate . ha^{-1} . $month^{-1}$, and

ID = the number of days in the month

F = the fraction of the time when the sky is overcast:

$$F = 1 - h \times H^{-1} \qquad (5)$$

h = mean monthly sum of hours of sunshine, local data

H = the monthly sum of maximum hours of sunshine, derived from meteorological tables or computed.

To convert carbohydrates of the gross photosynthesis (GP) into plant dry matter (DM) with a standard chemical composition the following formula is applied (Penning de Vries, 1973):

$$DM = 0.65 \times GP \quad \text{or,}$$
$$DM = 0.65 \times ID\ (F \times PO + (1 - F) \times PC) \qquad (6)$$

Summing up the monthly totals for the months with an average temperature of $10^{o}C$ and higher during three months or more gives the potential dry matter production (PDM) of the specific location in kg per hectare per year in roots, stem, leaves, flowers and fruits. In column 4 the PDM as calculated for each broad soil region is given in 1,000 kg per hectare per year. If the number of months with an average temperature of $10^{o}C$ or higher is less than three the production is considered to be zero, because the growing season becomes too short for arable farming.

The standard crop that is presumed to grow has the properties of a cereal, belonging to the group of C_3-plants. At average temperatures between 25 and 35°C a C_4-plant is able to maintain higher growth rates than a C_3-plant can.

The potential evapotranspiration depends only on the climate and is defined as the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times. The potential evapotranspiration (Eo) is calculated according to Penman. In the calculation of Eo mean monthly weather data are used.
The actual evapotranspiration is also based on rain data and calculated by evaluation of a monthly water-balance, assuming an average of 150 mm water-storage in all soils. To obtain the initial value of the soil water-storage the water-balance programme is run for two years, and only the values of the second year are considered. A complete description is given by Arbab (1972).
Adding the monthly totals for the months with an average temperature of 10°C and higher during three months or more gives the potential and actual evapotranspiration of the specific location during the growing season. The difference between potential and actual evapotranspiration is the moisture deficit during the growing season. This is often one of the limiting factors for potential production. Actual transpiration is actual evapotranspiration minus potential evaporation. Potential transpiration is potential evapotranspiration minus potential evaporation. Actual transpiration is set at zero if the actual evapotranspiration is less than the potential evaporation. It is assumed that the potential evaporation is 15% of the potential evapotranspiration.

Finally the reduction factor caused by water deficiency (FWD) as used in formula 3 (see par. 2.3) is the ratio between the actual transpiration and the potential transpiration. It is determined for all broad soil regions according to local climatic data (column 9).

2.5 Maximum production of dry matter

In the paragraphs 2.2 and 2.3 we have calculated the imaginary area of potential agricultural land with potential production (IPAL) for soil conditions being the limiting factor (formula 2) and for water deficiency being the limiting factor (formula 3). Moreover we determined the area of potential irrigable agricultural land (PIAL) if irrigation water is available. In paragraph 2.4 we calculated the potential production of dry matter per hectare per year (PDM, see column 4). This gives us the possibility to calculate for each broad soil region the maximum production of dry matter (MPDM).

For regions without irrigation practices we used the following formula:

MPDM = IPAL x PDM

Substituting formulas 2 and 3 we get:
for regions where the soil condition is the limiting factor (FWD $\geq$ FSC):

MPDM = PAL x FSC x PDM (7)

and for regions where water deficiency is the limiting factor (FWD < FSC):

MPDM = PAL x FWD x PDM (8)

The result (MPDM) is given in column 11.

For regions where part of the land can be irrigated other formulas have to be applied, because for the non-irrigated land (PAL - PIAL) formula 7 or 8 has to be used, whereas for the irrigated part (PIAL) only the soil conditions can be the limiting factor. This factor (FSC) cannot be applied for the irrigated land, because the irrigation water shall be applied to the best land of the region concerned. Such land has a higher FSC than the average FSC of all the potential agricultural land of the region. Consequently we have set the FSC for the irrigated part (FSCI) on 0.8, being an acceptable factor for such land.

The imaginary area of potential agricultural land with potential production including irrigation (IPALI) therefore is:
for regions where the soil condition is the limiting factor of the non-irrigated land (FWD $\geq$ FSC):

IPALI = PIAL x FSCI + (PAL - PIAL) x FSC (9)

and for regions where water deficiency is the limiting factor of the non-irrigated land (FWD < FSC):

IPALI = PIAL x FSCI + (PAL - PIAL) x FWD (10)

The result of this calculation (IPALI) is given in column 13 in the tables.

For regions where part of the land is irrigated the maximum production of dry matter (MPDMI) can be calculated with the formula:

MPDMI = IPALI x PDM

Substituting formulas 9 and 10 we get:
for regions where the soil condition is the limiting factor of the non-irrigated land (FWD $\geq$ FSC):

MPDMI = (PIAL x FSCI + (PAL - PIAL) x FSC) x PDM (11) and for regions where water deficiency is the limiting factor of the non-irrigated land (FWD < FSC):

$$MPDMI = (PIAL \times FSCI + (PAL - PIAL) \times FWD) \times PDM \quad (12)$$

The result (MPDMI) is given in column 14, in which we have repeated the number in column 11 when no land is irrigated (zero in column 12).

For almost all broad soil regions the formulas 7, 8, 11 and 12 have been used to calculate MPDM or MPDMI, the maximum dry matter production without or with irrigation, taking into account the limiting factor being soil condition or water deficiency for the non-irrigated land. For some regions where irrigation is or can be practised over a large part of that region we have introduced a somewhat different FSCI, as follows

a) For the broad soil regions: Asia, A6; South America, B10 and Europe, B5 where FSC = 0.8 we have set FSCI at 0.9, because the best soils of these regions shall be irrigated and those soils have a higher FSC than the average of column 8.

b) For two broad soil regions (Asia, B5 and B7) the FSCI = FSC + 0.1 for the same reason.

c) The broad soil regions where FSC = 0.9 (Africa, A2; Asia, A3, A5, A7, A10; North America, A9, B7 and Europe, A4, A10 and A11) we have used FSCI = 0.9.

2.6 Maximum production of grain equivalents

The maximum production of dry matter per year (MPDMI) as calculated in column 14 can be added for each continent and for the whole world (see Table 7). It can be converted into a maximum cereal (grain) production, because the calculations made are based on the assumption that a standard crop (see paragraph 2.4) is grown. This could be for example rice or wheat. This production is called the grain equivalent production.

In order to calculate the maximum production of grain equivalents (MPGE) for each region, for each continent and for the whole world the following assumptions have been made:

the dry matter production consists of:

a roots and stuble: 25% of the dry matter;

b straw and grain: 75% of the dry matter, ratio 1:1;

c harvest losses: 2% of the grains;

d moisture content of the grains: 15%.

Therefore:

MPGE = 0.75 x 0.50 x 0.98 x 100 x 85^{-1} x MPDMI or

MPGE = 0.432 x MPDMI (13)

The maximum production of grain equivalents (MPGE) for each region is given in column 15 in the tables.

Besides the MPGE as given in our tables it is also possible to convert the MPGE into the maximum harvestable protein production from the grains (MHPPG), when the following assumptions are made:

a the protein content in a standard grain crop is 15% in regions with a temperate climate and 10% in regions with a tropical climate (on dry matte basis);

b the moisture content of the grains is 15%.

This gives:

MHPPG = 0.15 (or 0.10) x 0.85 x MPGE

or for regions with a temperate climate:

MHPPG = 0.1275 x MPGE (14)

and for regions with a tropical climate:

MHPPG = 0.085 x MPGE (15)

The maximum harvestable protein production of the roughage (MHPPR) can be computed if it is assumed that:

a 60% of the dry matter consists of vegetative above ground biomass;

b the harvest loss is 20%;

c the protein content in the biomass is 20%.

This gives:

MHPPR = 0.60 x 0.80 x 0.20 x MPDMI or

MHPPR = 0.096 x MPDMI (16)

Such calculations have been made for the project: "Problems of population doubling" (see par. 1), these results are not given in this report.

3 RESULTS AND THEIR RELIABILITY

3.1 The maps (figures 1-6)

These maps are simplified maps on a reduced scale. We used the original soil maps of the continents (see par. 2.2), which give information on the soils occurring in each broad soil region. Sometimes we have also used some more detailed soil maps of specific countries. In addition we have studied maps on topography, land use and natural vegetation in some modern world atlases. As soon as the sheets of the Soil Map of the World (FAO/UNESCO) on Asia, Australia and Europe are published the corresponding maps (figures 4, 2 and 6) can be improved. If more time had been available it would have been possible to distinguish on this FAO/UNESCO Soil Map of the World some soil regions for each country (depending on the size and the ecological conditions of the country) in order to get specific data for the various countries. However, it probably would be better to study the original soil maps of the countries.

The Soil Map of the World does not have an equal reliability for all parts of the world. Therefore the reliability of our maps is different too and not higher than the reliability of the soil maps. Our maps (fig. 1-6) are simplified for this publication, some regions (groups of islands) are not shown.

3.2 The calculations

All calculations according to the formulas mentioned before are made with non-rounded numbers. Therefore some slight differences may occur if calculations are made with the rounded numbers as given in the tables.

3.3 The data on land resources

There are two important appraisals:

a FPAL, the fraction of potential agricultural land, and

b FSC, the reduction factor caused by soil conditions.

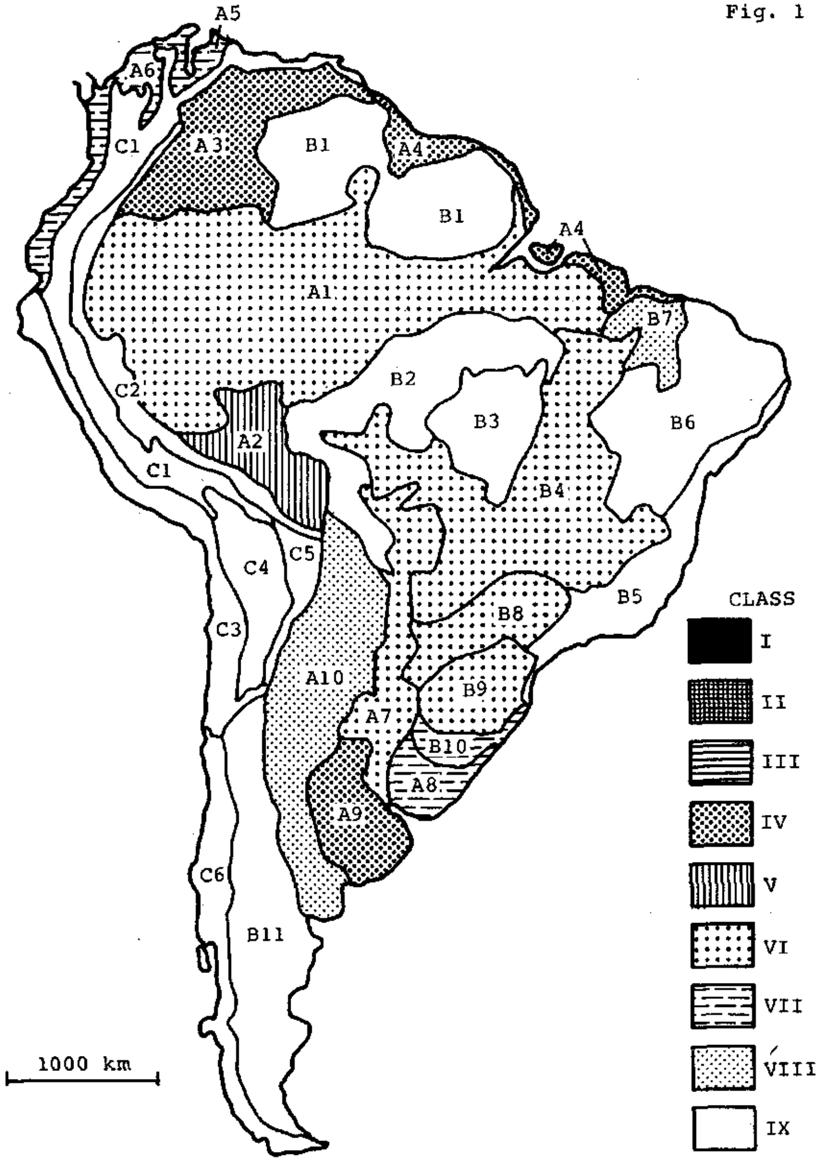
Both are based on an evaluation of soil conditions in each region. FPAL is also based on topography, elevation, land use and natural vegetation. FPAL is mostly less than 0.5 and it is never higher than 0.7, because at least 30% of the land will be needed for non-agricultural purposes. The appraisal of FSC is based on knowledge of soil conditions and soil productivity.

If the appraisals are studied in detail it should be clear that the climatic conditions are not taken into account in this stage of the calculation. It is

Explanation of the columns in the tables 1-7

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

Fig. 1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A6
C1
A3
B1
A4
B1
A4
B7
A1
B2
C2
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B6
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B4
C5
C4
B5
B8
C3
A10
B9
A7
B10
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B11
1000 km
CLASS
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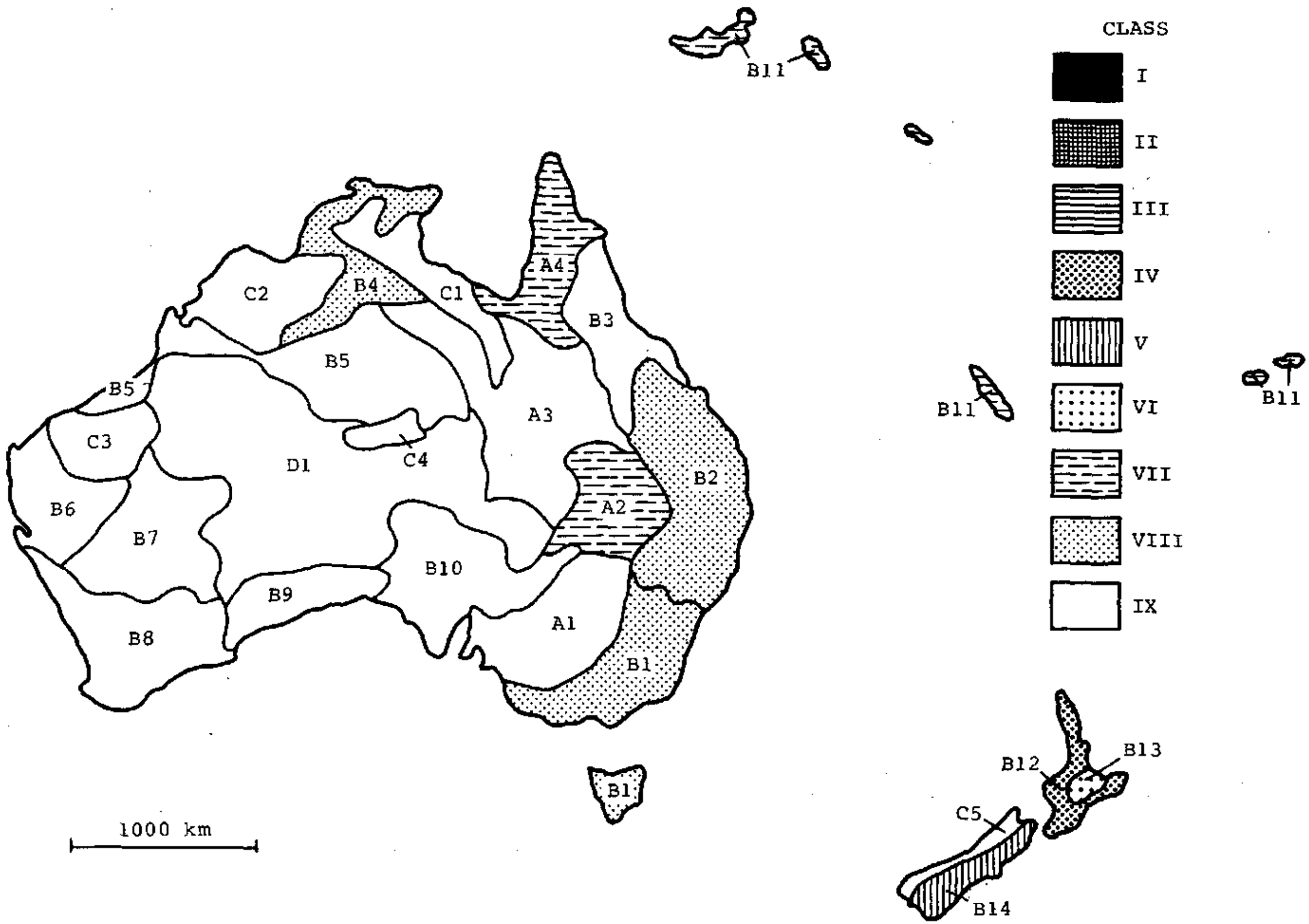
IX

Fig. 2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D1
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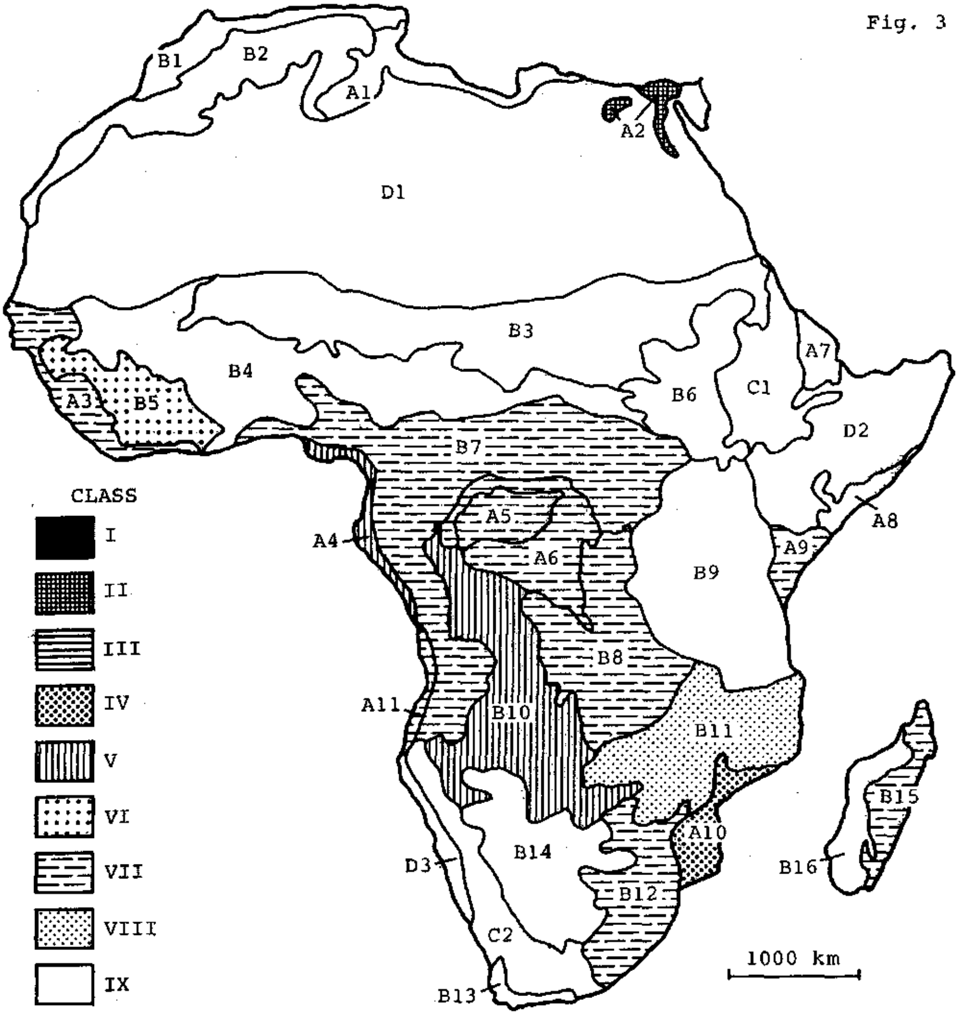
Fig. 3



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C1
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Fig. 4

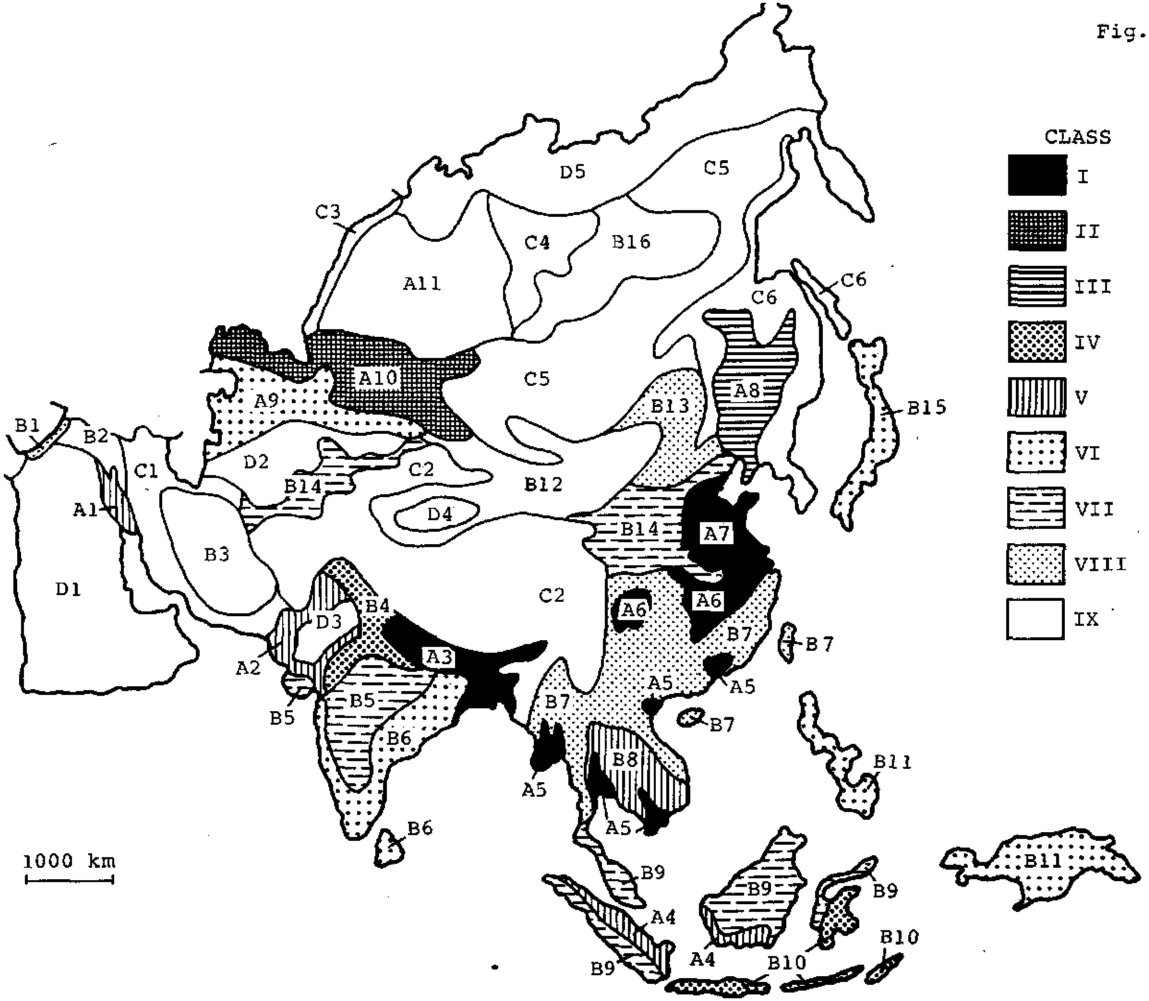

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Fig. 5

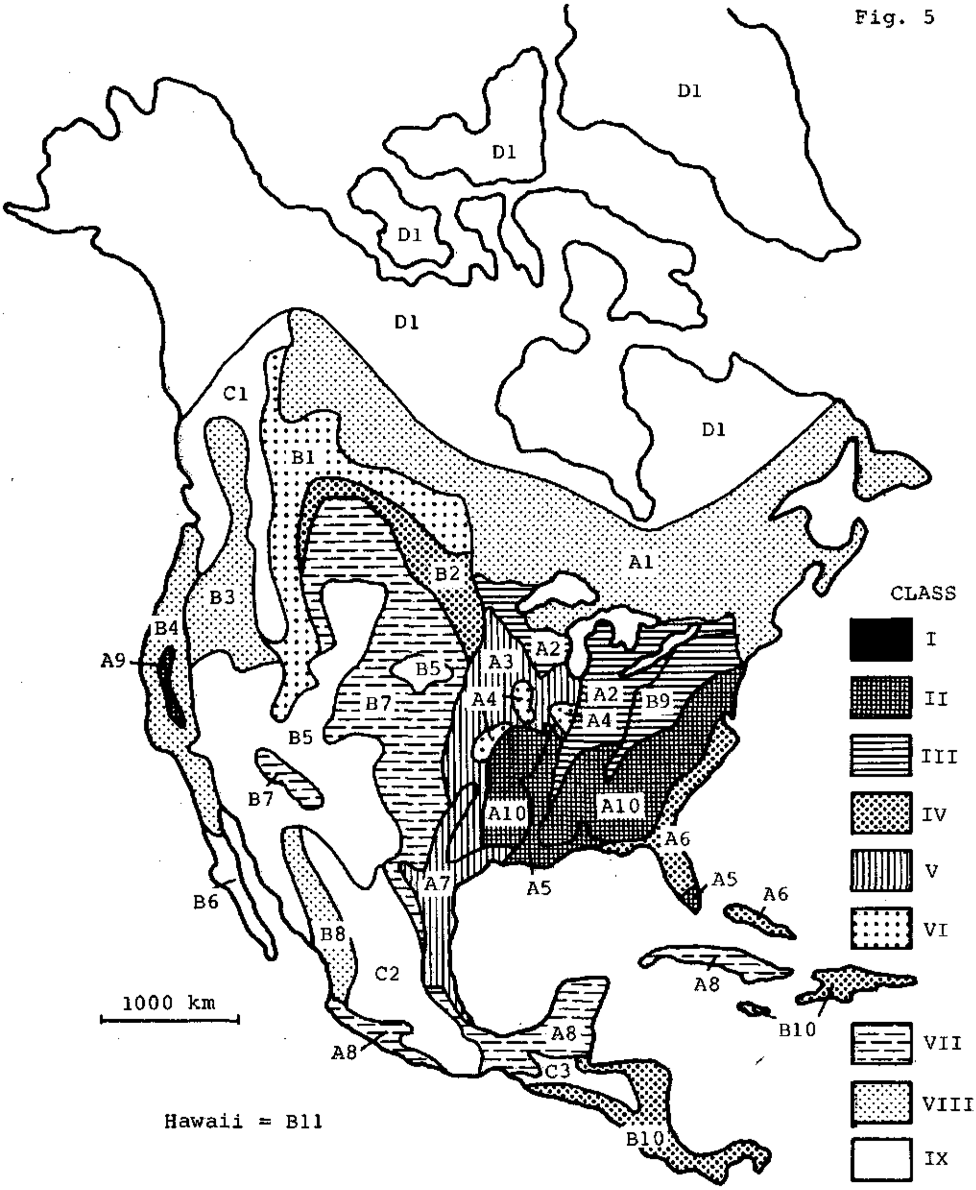
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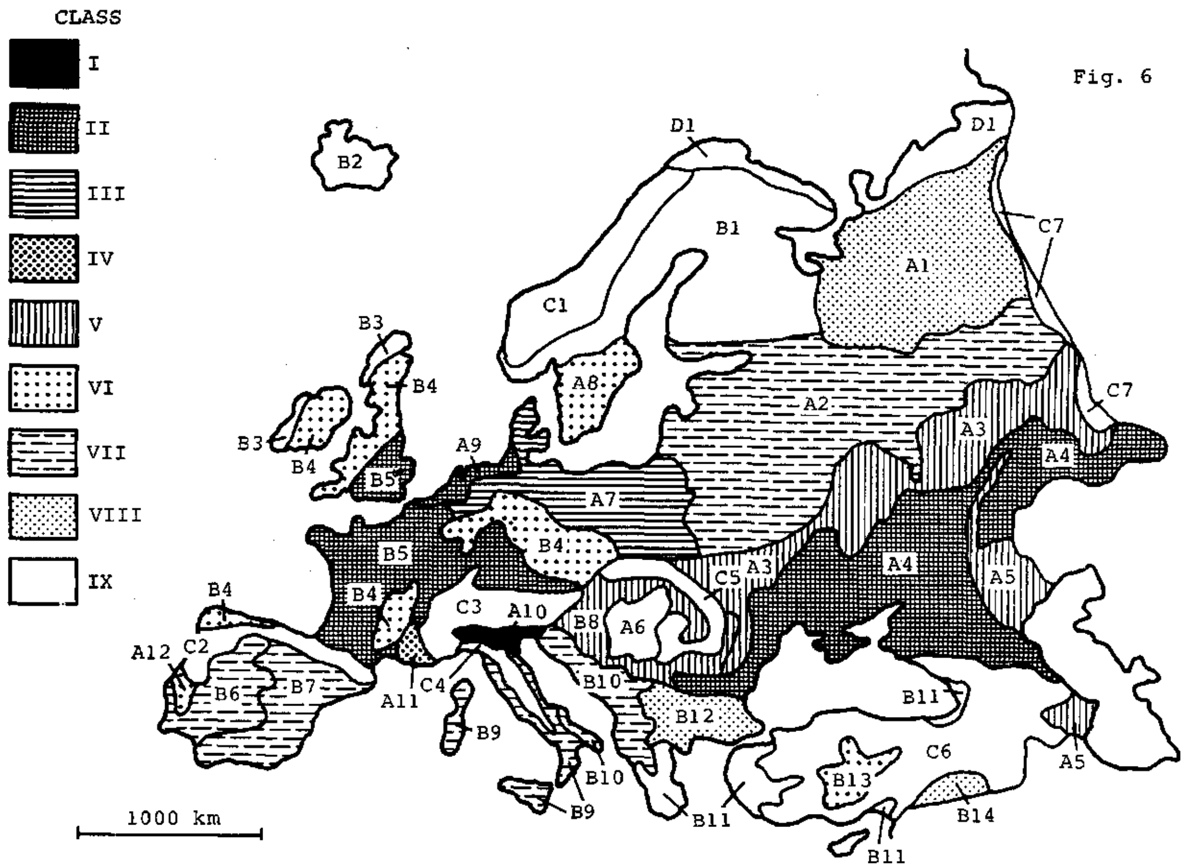
Fig. 6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A10
A11
A12
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
C1
C2
C3
C4
C5
C6
C7
D1

Table 1: South America

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	297.8	16.7	74	.5	148.9	5	.6	.8	89.3	6611	.0	89.3	6611	2856
A2	40.9	2.3	80	.5	20.5	4	.6	.7	12.3	982	.0	12.3	982	424
A3	81.8	4.6	80	.5	40.9	2	.7	.7	28.6	2290	.4	28.7	2294	991
A4	24.9	1.4	80	.5	12.5	3	.7	.8	8.7	697	1.2	8.8	707	305
A5	10.7	.6	80	.4	4.3	4	.6	.4	1.7	137	2.2	2.6	208	90
A6	24.9	1.4	80	.3	7.5	3	.7	.7	5.2	418	1.1	5.3	427	185
A7	53.4	3.0	78	.6	32.0	4	.5	.7	16.0	1250	.0	16.0	1250	540
A8	16.0	.9	72	.3	4.8	3	.8	.8	3.8	276	.0	3.8	276	119
A9	37.4	2.1	56	.6	22.4	2	.9	.6	13.5	754	.0	13.5	754	326
A10	112.2	6.3	64	.4	44.8	1	.8	.4	18.0	1149	1.5	18.5	1185	512
B1	108.6	6.1	78	.2	21.7	5	.5	.8	10.9	847	.4	11.1	856	370
B2	97.9	5.5	80	.3	29.4	5	.5	.6	14.7	1175	.0	14.7	1175	508
B3	46.3	2.6	78	.2	9.3	4	.7	.7	6.5	506	.0	6.5	506	218
B4	170.8	9.6	80	.5	85.4	3	.6	.6	51.2	4090	.0	51.2	4099	1771
B5	56.9	3.2	76	.3	17.1	4	.5	.8	8.5	649	.0	8.5	649	280
B6	97.9	5.5	84	.3	29.4	3	.7	.3	8.8	740	2.7	10.2	854	369
B7	23.2	1.3	82	.5	11.6	3	.4	.5	4.6	380	.0	4.6	380	164
B8	40.9	2.3	76	.5	20.5	4	.6	.7	12.3	933	.0	12.3	933	403
B9	35.6	2.0	74	.5	17.8	4	.6	1.0	10.7	790	.0	10.7	790	341
B10	10.7	.6	72	.3	3.2	4	.8	.9	2.6	185	.7	2.6	190	82
B11	121.1	6.8	48	.1	12.1	3	.7	0	0	0	2.4	1.9	92	40
C1	80.1	4.5	80	.05	4.0	3	.7	.4	1.6	128	1.4	2.2	173	75
C2	39.1	2.2	78	.05	2.0	3	.7	.7	1.4	107	.4	1.4	110	47
C3	49.6	2.8	84	.1	5.0	3	.7	0	0	0	.5	.4	34	15
C4	37.3	2.1	64	.1	3.8	3	.7	0	0	0	.2	.2	10	4
C5	16.0	.9	44	.05	.8	3	.7	.2	.2	7	.2	.3	12	5
C6	48.0	2.7	48	.1	4.8	3	.7	.5	2.4	115	2.6	3.2	153	66

Table 2: Australia and New Zealand

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	41.8	4.86	72	.6	25.1	4	.6	.2	5.0	361	.5	5.3	383	165
A2	29.5	3.43	78	.5	14.7	4	.6	.4	5.9	460	.4	6.0	471	203
A3	66.5	7.74	80	.4	26.6	4	.5	.1	2.7	213	1.0	3.4	269	116
A4	28.8	3.35	80	.4	11.5	3	.6	.6	6.9	553	1.0	7.1	568	245
B1	45.9	5.34	60	.3	13.8	4	.6	.7	8.3	496	.4	8.4	502	217
B2	60.4	7.02	78	.3	18.1	4	.6	.7	10.9	848	.3	10.9	853	368
B3	28.8	3.35	78	.2	5.8	4	.6	.8	3.5	270	.2	3.5	273	118
B4	27.4	3.19	80	.4	11.0	3	.6	.4	4.4	351	.5	4.6	367	158
B5	61.1	7.10	84	.2	12.2	4	.4	0	0	0	.0	.0	0	0
B6	26.7	3.11	78	.3	8.0	4	.5	.1	.8	62	.0	.8	62	27
B7	36.4	4.23	84	.3	10.9	5	.4	0	0	0	.0	.0	0	0
B8	48.6	5.66	68	.5	24.3	3	.5	.3	7.3	496	.1	7.3	499	216
B9	23.3	2.71	72	.1	2.3	4	.5	0	0	0	.0	.0	0	0
B10	43.8	5.10	64	.3	13.1	5	.5	.2	2.6	168	.1	2.7	172	74
B11	34.3	3.99	78	.4	13.7	3	.6	.7	8.2	642	.0	8.2	642	277
B12	2.8	.32	54	.5	1.4	4	.7	.9	1.0	53	.0	1.0	53	23
B13	9.6	1.12	54	.4	3.8	4	.7	.9	2.7	145	.1	2.7	146	63
B14	10.3	1.20	36	.5	5.2	4	.6	.7	3.1	111	.3	3.2	113	49
C1	24.0	2.79	82	.05	1.2	3	.6	.2	.2	20	.1	.3	25	11
C2	30.9	3.59	82	.05	1.5	3	.6	.3	.5	38	.1	.5	42	18
C3	18.5	2.15	80	.05	.9	3	.6	0	0	0	.1	.0	6	3
C4	6.2	.72	82	.05	.3	3	.6	0	0	0	.1	.0	6	3
C5	6.2	.72	54	.05	.3	3	.6	.9	.2	10	.0	.2	10	4
D1	166.6	19.38	-	0	0	-	0	0	0	0	.0	.0	0	0

Table 3: Africa

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	40.3	1.33	74	.3	12.1	2	.7	.2	2.4	179	.4	2.7	197	85
A2	8.2	.27	84	.6	4.9	3	.9	0	0	0	4.2	3.8	318	137
A3	40.3	1.33	76	.4	16.1	2	.5	.6	8.1	613	.6	8.2	626	271
A4	14.2	.47	68	.5	7.1	2	.6	.8	4.3	290	.0	4.3	290	125
A5	30.9	1.02	74	.3	9.3	5	.8	.9	7.4	549	.0	7.4	549	237
A6	62.9	2.07	76	.5	31.4	4	.5	.8	15.7	1195	.0	15.7	1195	516
A7	15.4	.51	84	.1	1.5	4	.4	.1	.2	13	.1	.2	19	8
A8	17.3	.57	84	.6	10.4	3	.6	.2	2.1	174	.0	2.1	174	75
A9	15.4	.51	84	.5	7.7	2	.7	.4	3.1	259	.1	3.1	262	113
A10	26.0	.86	80	.6	15.6	2	.7	.6	9.4	749	.0	9.4	749	323
A11	8.6	.28	76	.4	3.4	2	.5	.1	.3	26	.0	.3	26	11
B1	36.4	1.20	74	.3	10.9	2	.7	.2	2.2	162	1.9	3.3	249	106
B2	99.7	3.29	74	.2	19.9	3	.4	.1	2.0	148	.1	2.1	153	66
B3	231.9	7.65	88	.2	46.4	2	.5	0	0	0	.6	.0	42	18
B4	212.5	7.02	82	.4	85.0	2	.6	.3	25.5	2091	1.8	26.4	2165	935
B5	52.7	1.74	76	.5	26.4	3	.6	.6	15.8	1202	.0	15.8	1202	519
B6	73.1	2.41	86	.6	43.9	2	.5	.1	4.4	377	3.1	6.6	564	244
B7	164.2	5.42	76	.5	82.1	4	.5	.7	41.1	3120	.0	41.1	3120	1348
B8	118.8	3.92	80	.4	47.5	4	.6	.7	28.5	2281	.0	28.5	2281	985
B9	157.1	5.18	82	.4	62.8	3	.6	.6	37.7	3092	2.0	38.1	3125	1350
B10	155.7	5.14	80	.6	93.4	1	.5	.5	46.7	3737	.3	46.8	3744	1617
B11	119.2	3.94	80	.3	35.8	3	.6	.5	17.9	1430	1.3	18.3	1462	631
B12	75.4	2.49	76	.4	30.2	3	.6	.6	18.1	1375	.5	18.2	1385	598
B13	8.5	.28	76	.3	2.5	2	.6	.4	1.0	78	.3	1.1	87	37
B14	114.8	3.79	80	.2	23.0	2	.5	.1	2.3	184	.4	2.6	206	89
B15	31.2	1.03	80	.4	12.5	3	.5	.7	6.2	499	.5	6.4	511	221
B16	31.8	1.05	84	.4	12.7	2	.8	.2	2.5	214	1.0	3.1	264	114
C1	63.9	2.11	78	.05	3.2	3	.7	.5	1.6	125	.1	1.6	127	55
C2	70.0	2.31	80	.05	3.5	3	.7	0	0	0	.4	.3	26	11
D1	803.7	26.52	82	0	-	-	-	-	-	-	-	-	-	-
D2	114.8	3.79	76	0	-	-	-	-	-	-	-	-	-	-
D3	15.1	.50	80	0	-	-	-	-	-	-	-	-	-	-

Table 4: Asia

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	12.3	.28	78	.5	6.2	4	.8	0	0	0	4.8	3.8	300	129
A2	39.2	.89	80	.5	19.6	4	.7	0	0	0	19.6	13.7	1098	474
A3	55.9	1.27	78	.6	33.5	4	.9	.7	23.5	1831	31.7	29.8	2324	1004
A4	32.6	.74	80	.5	16.3	5	.6	.9	9.8	782	1.2	10.0	802	346
A5	26.0	.59	78	.6	15.6	3	.9	.8	12.5	973	7.9	13.3	1035	447
A6	51.5	1.17	54	.6	30.9	3	.8	.9	24.7	1335	15.0	26.2	1415	612
A7	59.0	1.34	50	.6	35.4	4	.9	.5	17.7	885	35.4	31.9	1593	688
A8	93.3	2.12	38	.6	56.0	1	.9	.7	39.2	1489	.0	39.2	1489	643
A9	94.6	2.15	56	.5	47.3	3	.6	0	0	0	31.0	24.8	1389	600
A10	146.5	3.33	76	.7	102.6	2	.9	.6	61.5	2215	20.0	67.6	2432	1051
A11	232.3	5.28	12	.2	46.5	3	.5	.9	23.2	279	.0	23.2	279	120
B1	4.8	.11	76	.4	1.9	3	.8	.2	.4	29	.8	.9	66	28
B2	24.6	.56	76	.5	12.3	2	.7	.1	1.2	93	1.9	2.6	195	84
B3	115.3	2.62	80	.4	46.1	3	.6	0	0	0	7.2	5.8	460	199
B4	43.1	.98	78	.6	25.9	4	.7	.3	7.8	605	18.4	17.2	1343	580
B5	96.4	2.19	82	.5	48.2	4	.5	.3	14.5	1186	31.0	23.8	1948	842
B6	92.0	2.09	78	.4	36.8	3	.6	.6	22.1	1702	9.6	24.0	1872	809
B7	248.6	5.65	64	.3	74.6	4	.5	.9	37.3	2387	26.6	40.0	2557	1105
B8	60.7	1.38	80	.5	30.4	3	.7	.6	18.2	1457	1.2	18.5	1478	639
B9	120.1	2.73	78	.4	48.0	5	.5	.9	24.0	1874	2.2	24.7	1923	831
B10	38.7	.88	82	.5	19.4	3	.7	.8	13.5	1111	1.2	13.8	1130	488
B11	102.6	2.56	74	.5	51.3	5	.5	.8	25.7	1898	4.6	27.0	2000	864
B12	180.4	4.10	48	.5	90.2	2	.6	0	0	0	10.6	8.5	407	176
B13	78.3	1.78	38	.5	39.1	2	.7	.3	11.7	446	4.1	13.8	524	226
B14	123.2	2.80	44	.4	49.3	3	.8	.5	24.6	1084	13.4	28.7	1261	545
B15	51.9	1.18	46	.4	20.8	3	.7	1.0	14.5	668	4.4	15.0	689	298
B16	139.9	3.18	8	.1	14.0	3	.4	.9	5.6	45	.0	5.6	45	19
C1	104.3	2.37	72	.05	5.2	4	.6	.1	.5	38	1.8	1.8	128	55
C2	461.9	10.50	52	.05	23.1	3	.6	.1	2.3	120	4.4	5.4	280	121
C3	22.0	.50	12	.05	1.1	3	.6	.9	.7	8	.0	.7	8	3
C4	74.4	1.69	0	.05	3.7	3	.6	.0	.0	0	.0	.0	0	0
C5	433.8	9.86	16	.05	21.7	3	.6	.9	13.0	208	.0	13.0	208	90
C6	165.0	3.75	40	.05	8.3	3	.6	.9	5.0	198	1.0	5.2	206	89

Continuation of Table 4

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
D1	313.3	7.12	80	0	0	-	-	-	-	-	.2	.2	13	6
D2	84.5	1.92	84	0	0	-	-	-	-	-	2.4	1.9	161	70
D3	27.7	.63	80	0	0	-	-	-	-	-	-	-	-	-
D4	23.8	.54	44	0	0	-	-	-	-	-	-	-	-	-
D5	315.5	7.17	0	0	0	-	-	-	-	-	-	-	-	-

Table 5: North and Central America

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	289.6	11.97	30	.4	115.8	3	.5	.9	57.9	1738	.0	57.9	1738	751
A2	72.1	2.98	38	.6	43.3	2	.7	.9	30.3	1151	.0	30.3	1151	497
A3	56.1	2.32	56	.7	39.3	1	.9	.5	19.6	1100	.0	19.6	1100	475
A4	9.0	.37	44	.5	4.5	2	.6	.9	2.7	119	.0	2.7	119	51
A5	19.1	.79	54	.6	11.5	2	.8	.9	9.2	495	.0	9.2	495	214
A6	19.1	.79	70	.6	11.5	3	.6	1.0	6.9	481	.0	6.9	481	208
A7	35.1	1.45	76	.6	21.1	2	.6	.5	10.5	800	1.2	10.9	828	358
A8	58.1	2.40	80	.4	23.2	3	.6	.7	13.9	1116	1.5	14.2	1140	492
A9	3.9	.16	64	.6	2.3	4	.9	.3	.7	45	2.0	1.0	121	52
A10	100.2	4.14	54	.6	60.1	3	.8	.9	48.1	2597	.0	48.1	2597	1122
B1	86.9	3.59	32	.5	43.5	2	.8	.5	21.7	695	2.0	22.4	715	309
B2	42.8	1.77	34	.6	25.7	1	.9	.6	15.4	524	.0	15.4	524	226
B3	58.1	2.40	40	.4	23.2	3	.8	.3	7.0	279	4.0	9.0	358	155
B4	42.8	1.77	60	.3	12.8	3	.7	.5	6.4	305	5.0	7.9	474	205
B5	175.5	7.25	60	.2	35.1	4	.6	.1	3.5	211	5.0	7.0	421	182
B6	11.4	.47	82	.1	1.1	3	.4	0	0	0	.2	.2	13	6
B7	162.6	6.72	44	.6	97.6	3	.9	.3	29.3	1288	10.5	35.6	1565	676
B8	26.1	1.08	80	.4	10.4	3	.7	.4	4.2	374	2.0	5.0	397	171
B9	30.7	1.27	44	.5	15.4	3	.8	.8	12.3	540	.0	12.3	540	233
B10	44.8	1.85	80	.5	22.4	3	.8	.7	15.7	1254	2.7	16.4	1276	551
B11	1.7	.07	78	.5	.9	3	.8	.6	.5	40	.0	.5	40	17
C1	70.7	2.92	44	.05	3.5	3	.6	.6	2.1	93	.0	2.1	93	40
C2	72.8	3.01	78	.05	3.6	3	.6	.4	1.5	114	1.0	1.8	144	62
C3	16.0	.66	78	.05	.8	3	.7	.7	.6	44	.0	.6	44	19
D1	914.8	37.80	20	0	0	-	0	.9	-	-	-	-	-	-

Table 6: Europe

1	2 A	3 A%	4 PDM	5 FPAL	6 PAL	7 DCC	8 FSC	9 FWD	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
A1	78.8	7.50	24	.3	23.6	3	.5	.9	11.8	284	.1	11.9	284	123
A2	134.4	12.80	28	.4	53.8	2	.6	.9	32.3	903	.0	32.3	903	390
A3	68.1	6.49	30	.5	34.1	2	.8	.6	20.4	613	6.5	21.7	652	282
A4	114.2	10.88	44	.7	79.9	3	.9	.5	40.0	1759	32.1	52.8	2324	1004
A5	20.6	1.96	44	.5	10.3	4	.7	.6	6.2	272	5.0	7.2	316	136
A6	10.0	.95	48	.6	6.0	3	.7	.6	3.6	173	2.2	4.0	194	84
A7	45.0	4.29	34	.6	27.0	2	.7	.8	18.9	643	3.1	19.2	653	282
A8	12.5	1.19	30	.5	6.2	3	.6	.9	3.8	113	.1	3.7	114	49
A9	4.4	.42	36	.5	2.2	2	.9	1.0	2.0	71	.0	2.0	71	31
A10	4.4	.42	54	.6	2.6	5	.9	.3	.8	43	2.6	2.4	127	55
A11	2.5	.24	60	.4	1.0	5	.9	.4	.4	24	1.0	.9	54	23
A12	3.2	.30	72	.6	1.9	3	.7	.4	.8	55	.4	.9	67	29
B1	79.3	7.56	24	.3	23.8	3	.5	1.0	11.9	285	.1	11.9	286	124
B2	10.0	.95	0	.1	1.0	3	.5	0	.0	0	.0	.0	0	0
B3	5.7	.54	28	.2	1.1	2	.6	1.0	.7	19	.0	.7	19	8
B4	49.4	4.70	36	.4	19.8	3	.7	.9	13.8	498	.3	13.9	499	216
B5	57.5	5.48	40	.6	34.5	1	.8	.9	27.6	1104	.3	27.7	1109	479
B6	18.2	1.73	60	.5	9.1	4	.7	.4	3.6	218	.4	3.8	228	98
B7	25.0	2.38	68	.5	12.5	4	.6	.3	3.8	255	4.6	6.1	411	177
B8	23.1	2.20	44	.5	11.6	3	.7	.6	6.9	305	4.2	7.8	343	148
B9	13.8	1.31	54	.5	6.9	3	.7	.3	2.1	112	1.9	3.0	163	70
B10	18.2	1.73	50	.3	5.5	3	.7	.7	3.8	191	1.1	3.9	197	85
B11	21.8	2.08	64	.2	4.4	5	.7	.3	1.3	84	3.6	3.1	199	86
B12	15.0	1.43	48	.4	6.0	3	.7	.3	1.8	86	1.7	2.7	127	55
B13	7.5	.71	54	.5	3.8	4	.6	.1	.4	20	2.1	2.2	117	51
B14	4.4	.42	54	.5	2.2	3	.7	.3	.7	36	.0	.7	36	15
C1	30.0	2.86	22	.05	1.5	3	.7	1.0	1.1	23	.0	1.1	23	10
C2	11.2	1.07	46	.05	.6	3	.7	.7	.4	18	.1	.4	19	8
C3	19.4	1.85	32	.05	1.0	3	.7	.9	.7	22	.2	.7	22	10
C4	5.7	.54	48	.05	.3	4	.7	.2	.1	3	.1	.1	6	2
C5	11.2	1.07	36	.05	.6	3	.7	.9	.4	14	.1	.4	14	6
C6	70.7	6.73	54	.05	3.5	4	.7	.2	.7	38	1.0	1.3	71	30
C7	8.7	.83	16	.05	.4	3	.7	.9	.3	5	.0	.3	5	2
D1	46.1	4.39	0	0	0	-	0	-	-	-	-	-	-	-

Table 7: Totals of the continents and the world

	2 A	6 PAL	10 IPAL	11 MPDM	12 PIAL	13 IPALI	14 MPDMI	15 MPGE
S. America	1780	616.5	333.6	25224	17.9	340.7	25710	11106
Australia	860	225.7	74.2	5297	5.3	76.1	5462	2358
Africa	3030	761.2	306.5	24162	19.7	317.5	25115	10845
Asia	4390	1083.4	433.5	24966	314.1	581.6	33058	14281
N. America	2420	628.6	320.0	15443	37.1	337.5	16374	7072
Europe	1050	398.7	233.1	8289	75.9	247.1	9653	4168
Antarctica	1310	0	0	0	0	0	0	0
Total	14840	3714.1	1700.9	103381	470.0	1900.5	115372	49830

supposed that the climate is optimal. The climatic conditions are considered separately in par. 3.5 in order to give every specialist the opportunity to introduce his specific appraisals or assumptions into the calculation. A disadvantage is that in some dry regions the area of potential agricultural land (PAL) may be rather large, however, FWD = 0. Examples are the regions B5 and B7 in Australia. If there is no water for irrigation, we could have set PAL = 0 as has been done for real desert areas. The consequence is that the total potential agricultural land (PAL) of some continents and of the whole world is somewhat too high. Therefore we have introduced for these totals a corrected PAL (PAL, corr), see Table 10.

The potential agricultural land that can produce two or even three crops per year is not counted two or three times to get a potential gross agricultural land area, because the double and triple cropping is taken care of in the calculation of the production of dry matter (PDM) in column 4.

The two imaginary areas with potential production, IPAL (without irrigation) and IPALI (including irrigation) have a theoretical meaning only, they facilitate the calculation procedure.

In order to know the relative importance of the availibility of potential agricultural land in all broad soil regions independent of the size of the area we have calculated the imaginary area of potential agricultural land including irrigation (IPALI) as a percentage of the total area A. The data for all regions are given in Table 8. With these data a classification of the relative importance of the availability of potential agricultural land was set up. The nine classes are defined in Table 9, and for each region the class has been indicated on the maps (fig. 1-6). These maps give an idea about the regional distribution of the potential agricultural land on the continents.

It is also possible to calculate the absolute maximum production in grain equivalents per hectare potential agricultural land by dividing MPGE by PAL for each region. This is done for all regions (see Table 10), except for the mountains, dry deserts and tundras, because in those regions the area of potential agricultural land is very limited or zero. Land productivity classes for the potential agricultural land, based on grain equivalents, are set up (see Table 11). In a special set of maps (fig. 7-12) the regions of all continents are classified according to this system. This is a type of land capability classification, indicating the absolute maximum productivity. It is based on soil and climatic characteristics, and the irrigation possibilities. Here it becomes clear that good tropical and subtropical land with irrigation

Table 8: IPALI in % of A for all broad soil regions

	S. Am.	Aus.	Afr.	Asia	N. Am.	Eur.
A1	30.0	12.7	6.7	30.9	20.0	15.1
A2	31.1	20.3	46.3	34.9	42.0	24.0
A3	35.1	5.1	20.3	53.3	34.9	31.9
A4	35.3	24.7	30.2	30.7	30.0	46.3
A5	24.3	-	23.9	51.2	48.2	35.0
A6	21.3	-	25.0	50.9	36.1	40.0
A7	30.0	-	1.3	54.1	31.1	42.7
A8	23.8	-	12.1	42.0	24.4	29.6
A9	36.1	-	20.1	26.2	48.7	45.5
A10	16.5	-	36.2	46.1	48.0	54.5
A11	-	-	3.5	10.0	-	36.0
A12	-	-	-	-	-	28.1
B1	10.1	18.3	9.1	18.8	25.7	15.0
B2	15.0	18.0	2.1	10.6	36.0	0.0
B3	14.0	12.2	0.0	5.0	15.5	12.3
B4	30.0	16.8	12.4	39.9	18.5	28.1
B5	14.9	0.0	30.0	24.7	4.0	48.1
B6	10.4	3.0	9.0	26.1	1.8	20.9
B7	19.8	0.0	25.0	16.1	21.9	24.4
B8	30.0	15.0	24.0	30.5	19.2	33.8
B9	30.0	0.0	24.3	20.6	40.1	21.7
B10	24.3	6.2	30.1	35.7	35.7	21.4
B11	1.6	23.9	15.4	26.3	29.4	14.2
B12	-	35.7	24.1	4.7	-	18.0
B13	-	28.1	12.9	17.6	-	29.3
B14	-	31.1	2.3	23.3	-	15.9
B15	-	-	20.5	28.9	-	-
B16	-	-	9.7	4.0	-	-
C1	2.7	1.3	2.5	1.7	3.0	3.7
C2	3.6	1.6	0.4	1.2	2.5	3.6
C3	0.8	0.0	-	3.2	3.8	3.6
C4	0.5	0.0	-	0.0	-	1.8
C5	1.8	3.2	-	3.0	-	3.8
C6	6.7	-	-	3.2	-	1.8
C7	-	-	-	-	-	3.4
D1	-	0.0	0.0	0.1	0.0	0.0
D2	-	-	0.0	2.2	-	-
D3	-	-	0.0	0.0	-	-
D4	-	-	-	0.0	-	-
D5	-	-	-	0.0	-	-

Table 9: Classification of the relative importance of potential agricultural land in the broad soil regions

Class	Importance	IPALI in % of A
I	extremely high	> 50
II	very high	> 45-50
III	high	> 40-45
IV	moderately high	> 35-40
V	medium	> 30-35
VI	moderately low	> 25-30
VII	low	> 20-25
VIII	very low	> 15-20
IX	extremely low	≤ 15

possibilities is suitable for double or triple cropping. Therefore it is classified in a higher class than land in temperate regions on which only one crop per year can be grown. The classification involves only the potential agricultural land, which is mostly not more than 50% of a region.

3.4 The data on irrigation

The International Commission on Drainage and Irrigation (and some other publications) indicate an area of 201 millions of hectares that are irrigated at present, and it can be expanded to 458 millions of hectares for 103 countries. Moen and Beek (1974) have introduced some new information and have found a potential irrigable agricultural land area (PIAL) for the whole world of 470 millions of hectares (see Table 7). They also indicate that an overall irrigation efficiency of 50% could be assessed, which is approximately 10 to 30% higher than the present overall irrigation efficiency. However, an additional 10 to 30% of the water supplied to the farms shall be needed for washing and leaching in order to avoid salinization and sodication. The increased irrigation efficiency provides water for washing and leaching and consequently no special correction factor had to be introduced. For more details reference is made to Moen and Beek (1974), who worked for the same project on "Problems of population doubling".

The data on potential irrigable land for more than a hundred countries as determined by Moen and Beek (1974) have been converted to the data for our broad soil regions. For some large countries with a large area of potential irrigable land (e.g. USSR, China) it was often difficult to decide which part of the total potential irrigable land should be given to the various broad soil units. There will be mistakes; for the totals for continents however, these mistakes are not important. Our numbers in column 12 (PIAL) are not accurate, in particular for the USSR and China. Moreover, the reliability of the data used could be improved if more information in particular on the potential irrigable land per catchment area would be available.

There are some regions where rice is grown with very large quantities of irrigation water (e.g. Bangladesh), for such regions we did not make corrections.

3.5 The data on climate and crop production

The assumptions and calculations are based on similar studies made for other purposes and published some years ago or recently (see par. 2.4 - 2.6). The climatic data used are often covering a long, sometimes only a short period,

Table 10: MPGE per hectare potential agricultural land (1,000 kg)

	S. Am.	Aus.	Afr.	Asia	N. Am.	Eur.
A1	19.2	6.6	7.0	20.8	6.5	5.2
A2	20.7	13.8	28.0	24.2	11.5	7.2
A3	24.2	4.4	16.9	29.9	12.1	8.3
A4	24.4	21.3	17.6	21.2	11.3	12.6
A5	20.9	-	25.5	28.7	18.6	13.2
A6	24.7	-	16.4	19.8	18.1	14.0
A7	16.9	-	5.3	19.4	17.0	10.4
A8	24.8	-	7.2	11.5	21.2	7.9
A9	14.6	-	14.7	12.7	22.6	14.1
A10	11.4	-	20.7	10.2	18.7	21.2
A11	-	-	3.2	2.6	-	23.0
A12	-	-	-	-	-	15.3
B1	17.1	15.7	9.7	14.7	7.1	5.2
B2	17.3	20.3	3.3	6.8	8.8	-
B3	23.4	20.3	.4	4.3	6.7	7.3
B4	20.7	14.4	11.0	22.4	16.0	10.9
B5	16.4	.0	19.7	17.5	5.2	13.9
B6	12.6	3.4	5.6	22.0	5.5	10.8
B7	14.1	.0	16.4	14.8	6.9	14.2
B8	19.7	8.9	20.7	21.0	16.4	12.8
B9	19.2	.0	21.5	17.3	15.1	10.1
B10	25.6	5.6	17.3	25.2	24.6	15.5
B11	3.3	20.2	17.6	16.8	18.9	19.5
B12	-	16.4	19.8	2.0	-	9.2
B13	-	16.6	14.8	5.8	-	13.4
B14	-	9.4	3.9	11.1	-	6.8
B15	-	-	17.7	14.3	-	-
B16	-	-	9.0	1.4	-	-

Table 11: Land productivity classes for the potential agricultural land

Class	Land productivity	MPGE x PAL^{-1}
I	extremely high	> 25
II	very high	> 20-25
III	high	> 15-20
IV	medium	> 10-15
V	low	> 5-10
VI	very low	≤ 5

(The numbers are in 1,000 kg per hectare) whereas in some cases an interpolation of data of some weather-stations has been made. In the case of a total absence of climatic data in some regions, data were used from locations of similar climates. The climate classification of Papadakis was used to find the similar climates. In areas with relatively good soils weather-stations are often present, which increases the reliability.

The assumption that the water-storage of all soils suitable for cultivation is 150 mm had to be introduced in order to avoid very complicated calculations. It is known that some soils have a water-storage of less than 50 mm, others of more than 200 mm. However, for the time being we could not make a useful differentiation. If similar calculations are made in more detail e.g. for some specific countries, this aspect surely needs more attention. The same applies to the standard crop and some other assumptions. On a world-wide scale, however, it is hardly possible to introduce more and variable parameters because of various complications.

There are some regions where climatic conditions are favourable for growing two or even three crops per annum, in particular when irrigation water is available. In such regions the PDM is much higher than in regions where only one crop can be grown.

It seems ridiculous to assume a high level of modern farm management and a potential production of dry matter (or grain equivalents) all over the world on all land that could be cultivated. Our purpose, however, is to calculate the absolute upper boundary of the food production (in grain equivalents) for the whole world. And here we repeat again: other specialists should introduce specific reduction factors in order to get data that could have some meaning in practice. For example, we know that much food is lost by diseases and during transport and storage, for this reason a specific reduction factor could be chosen, which could vary for the various regions.

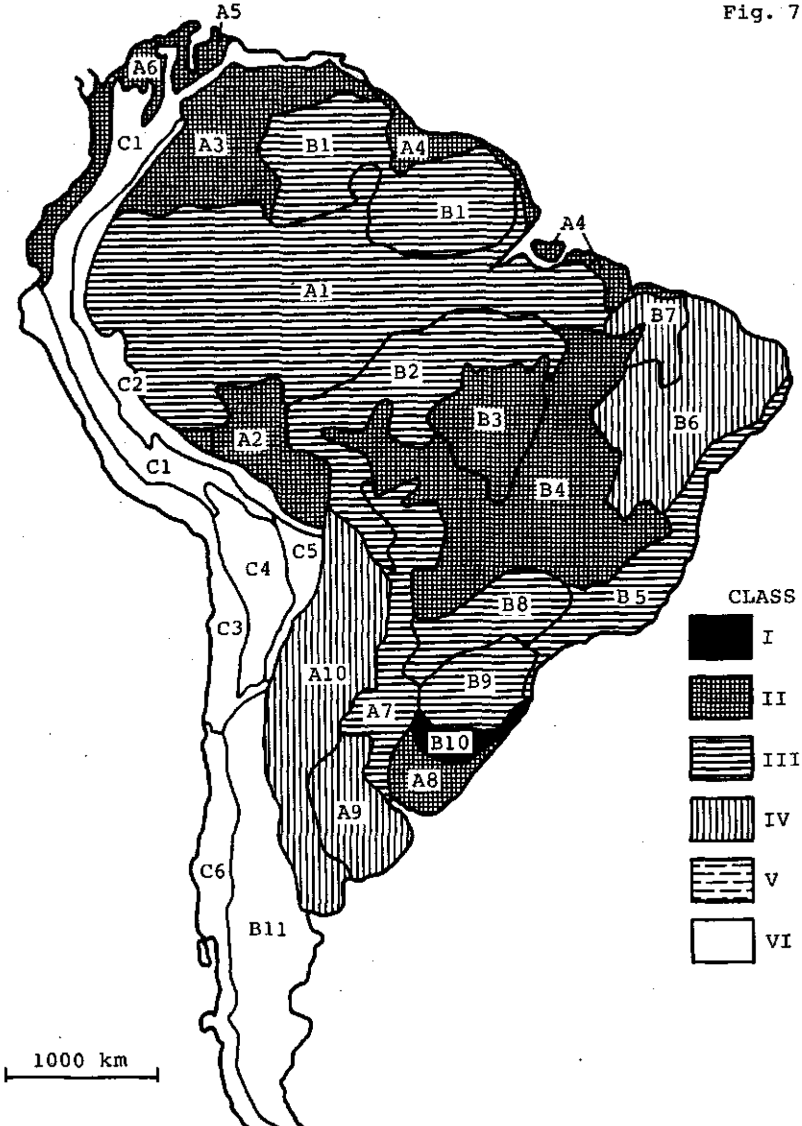
The land that is not included in our calculations because of topography, elevation, poor soil conditions or poor climatic conditions, etc. can be used and often is used by farmers, e.g. for extensive grazing. The yield is low. We have neglected this, because the total production of this land is small in comparison with the total potential production. In more detailed calculations for specific countries it probably cannot be neglected.

In various regions the productive season is somewhat longer than the growing season of one crop, it is, however, too short to grow two crops. As our calculations are based on all months suitable for crop production they are sometimes higher than could be expected in practice.

Final remark

The remarks on the reliability of the results of our calculations as given above could be followed by some more. We are convinced that some parts of our work can be improved, in particular when better basic information shall become available and when we should have had a better knowledge of the local conditions of all regions.

Fig. 7



A5
A6
C1
A3
B1
A4
B1
A4
A1
B7
B2
C2
A2
B3
B6
C1
B4
C4
C5
B8
B5
CLASS
I
C3
A10
II
B9
A7
B10
III
A8
A9
IV
V
C6
VI
B11
1000 km

Fig. 8

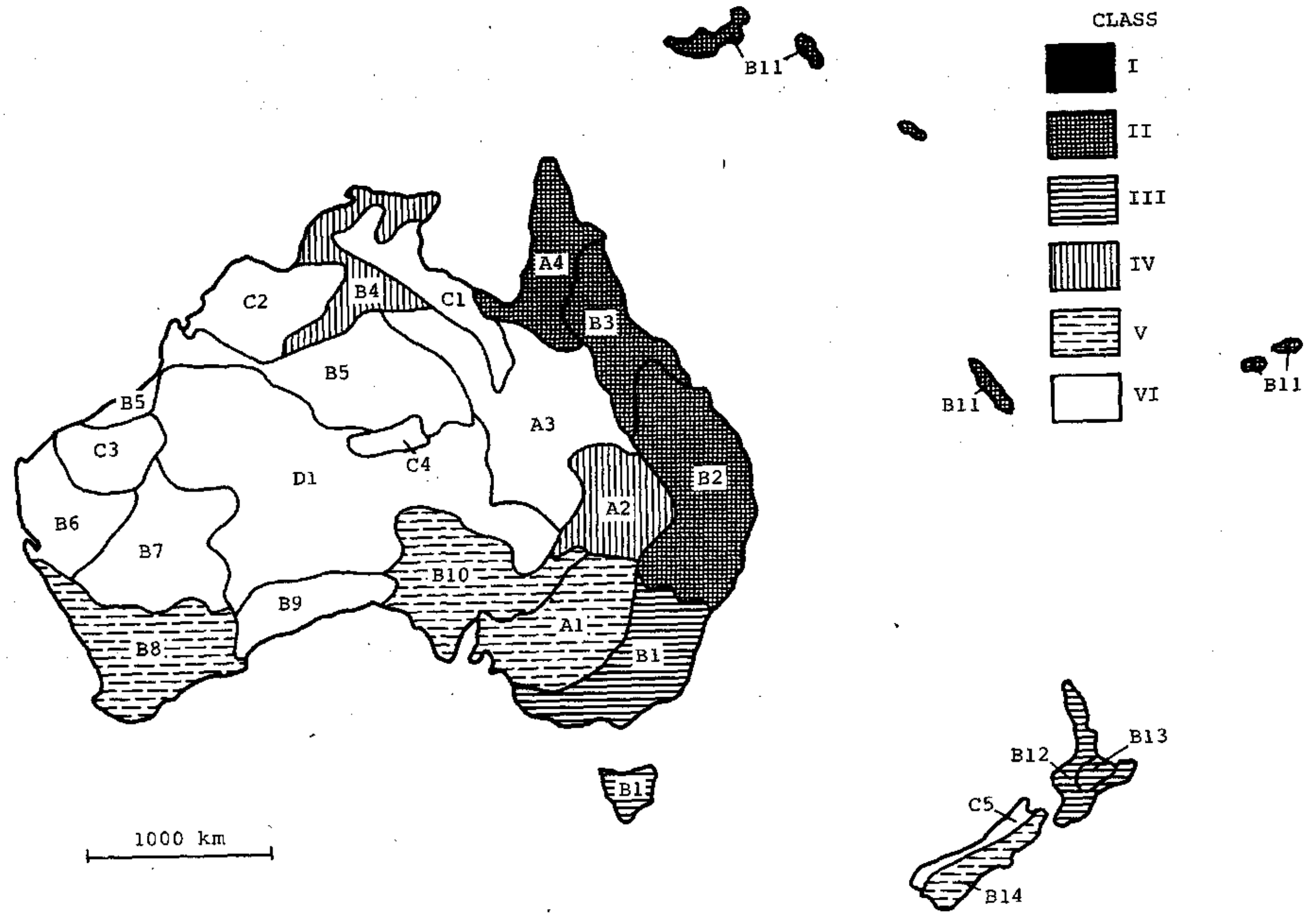

CLASS
I
II
III
IV
V
VI
B11
B11
B11
A4
B4
C1
C2
B3
B5
B5
A3
C3
C4
B2
D1
A2
B6
B7
B10
B9
A1
B8
B1
B1
B12
B13
C5
B14
1000 km

Fig. 9

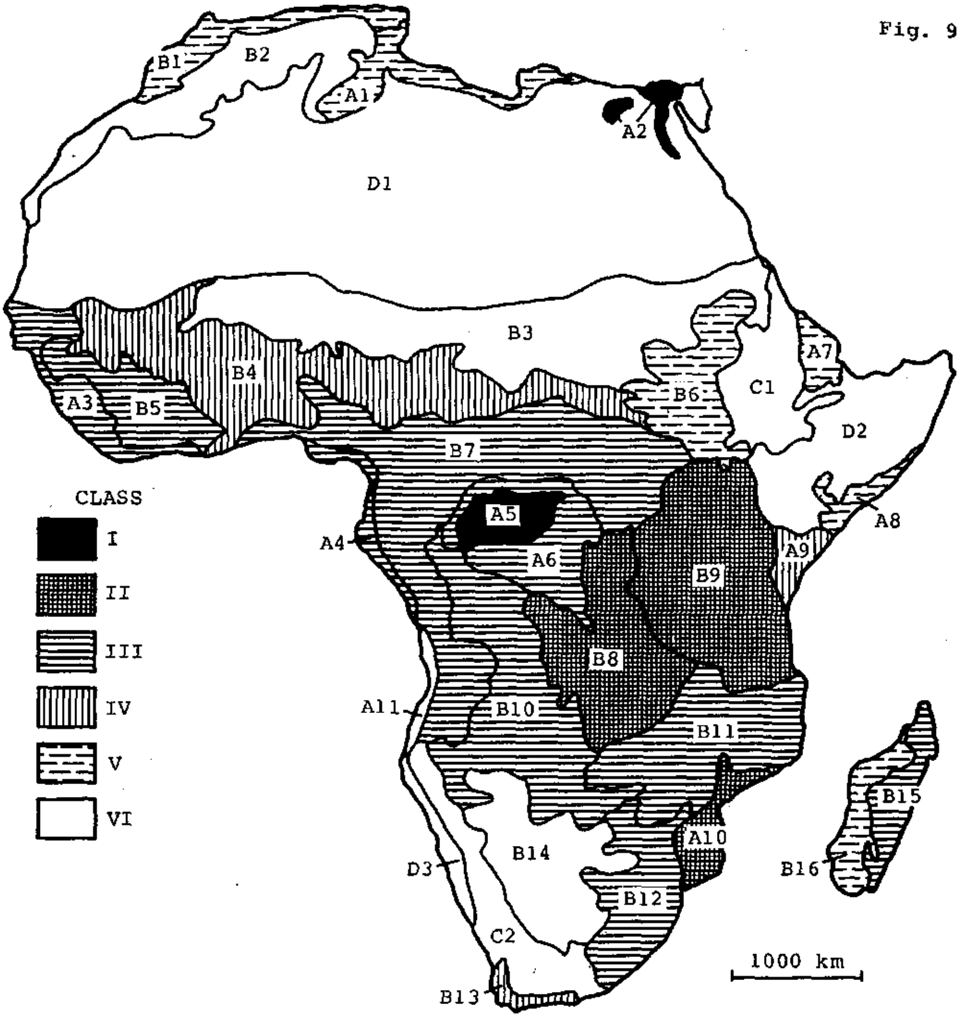

B1
B2
A1
A2
D1
B3
B4
A3
B5
B6
C1
A7
D2
B7
A8
A4
A5
A6
A9
B9
B8
A11
B10
B11
B15
A10
B16
D3
B14
B12
C2
B13
1000 km
CLASS
I
II
III
IV
V
VI

Fig. 10

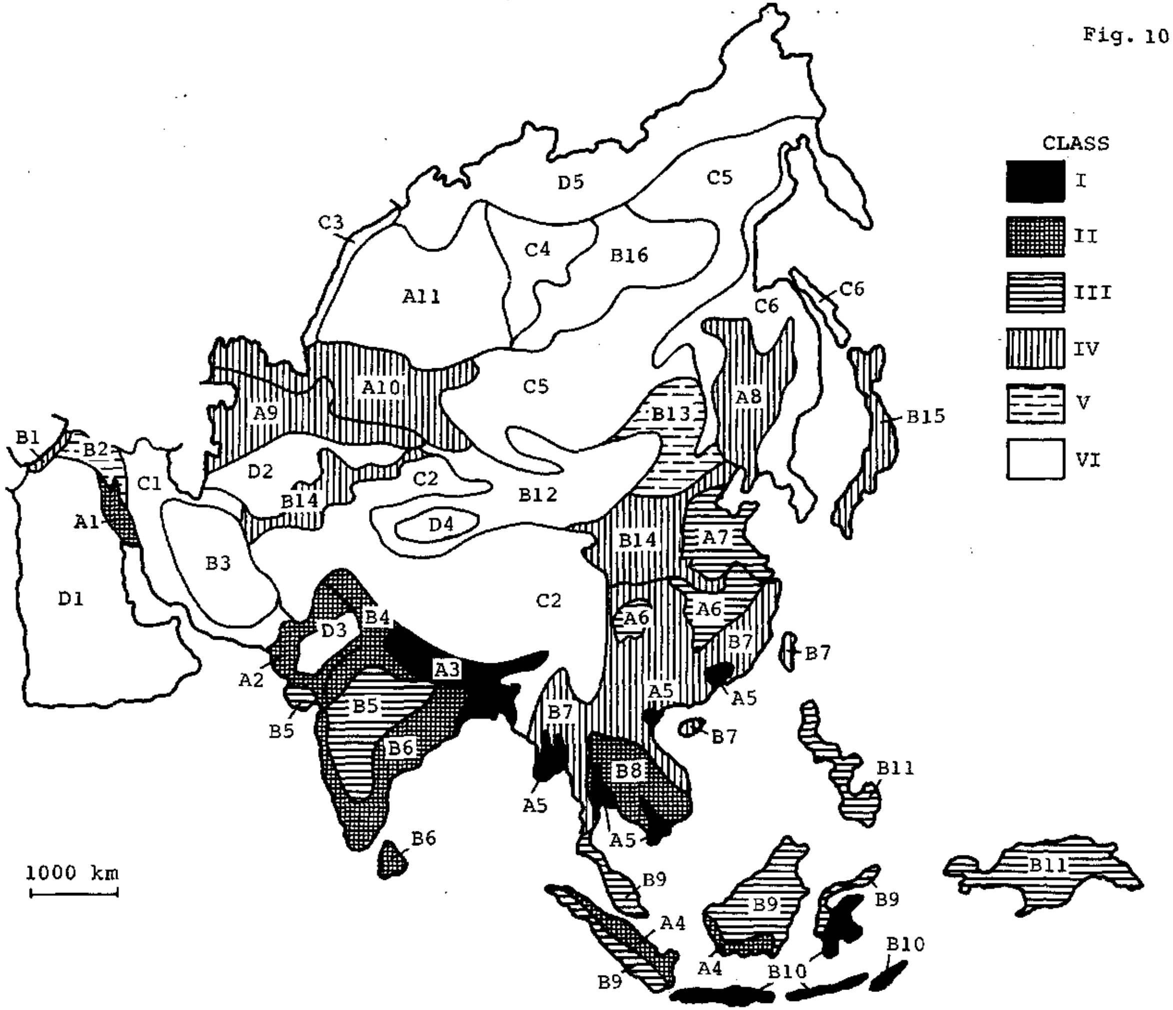
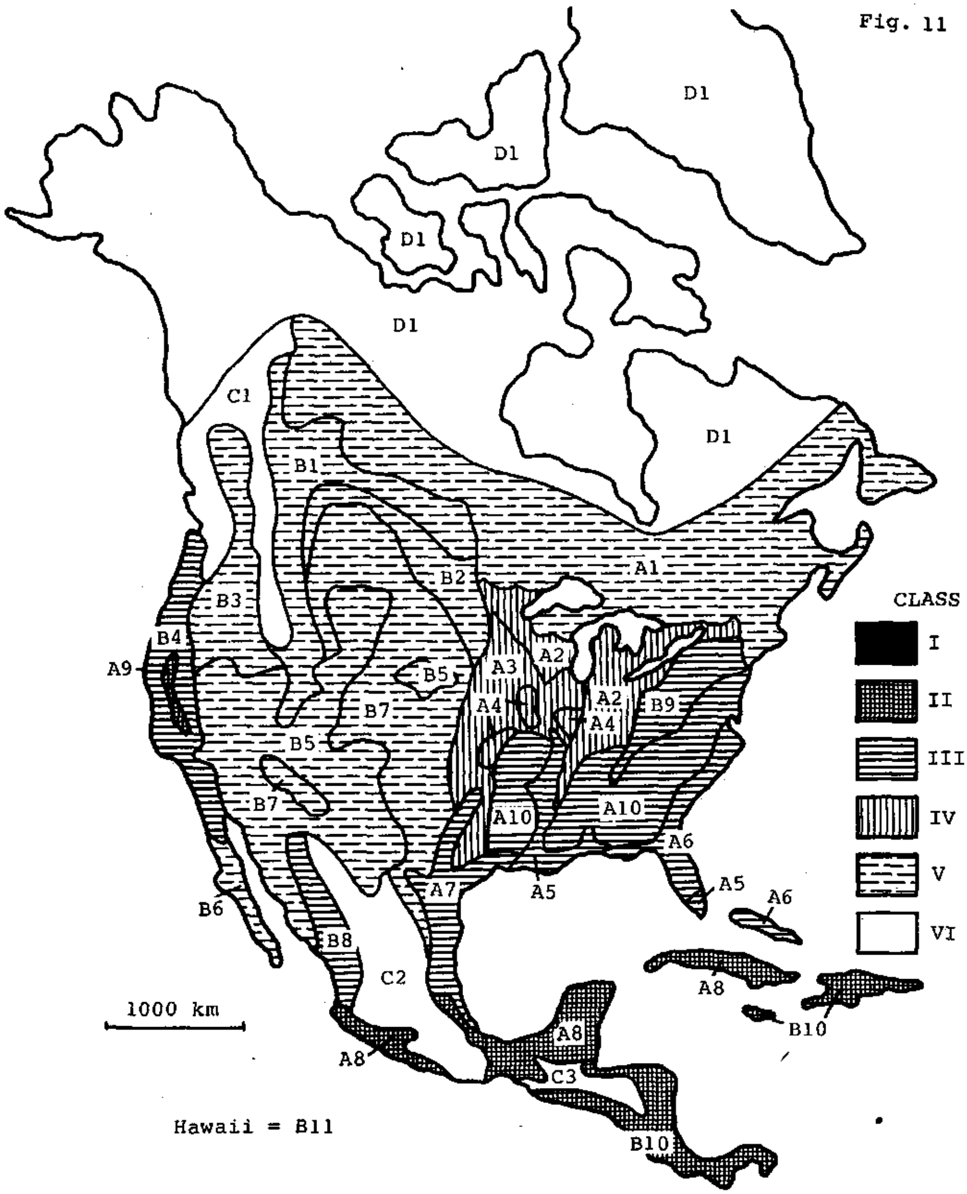

CLASS
I
II
III
IV
V
VI
1000 km
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
C1
C2
C3
C4
C5
C6
D1
D2
D3
D4
D5

Fig. 11


D1
D1
D1
D1
D1
C1
B1
B2
A1
CLASS
I
II
III
IV
V
VI
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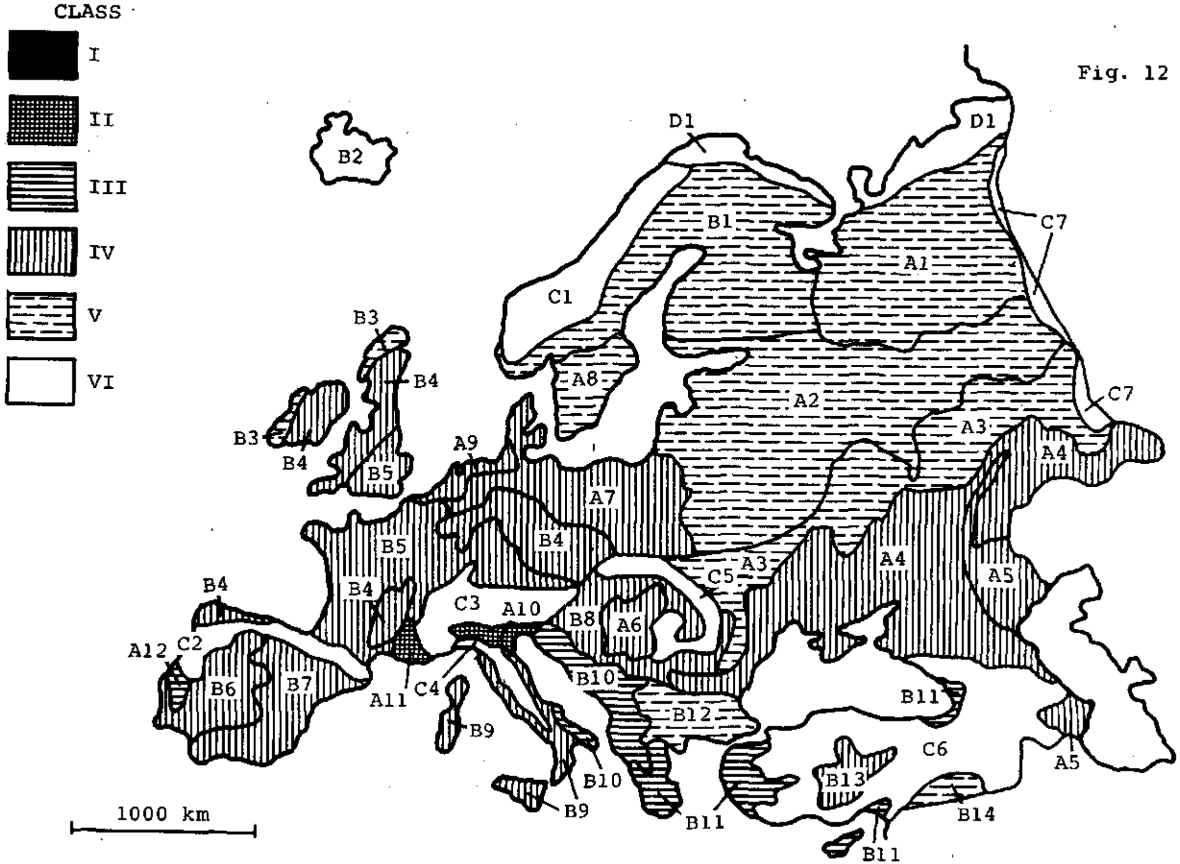
B4
A9
A3
A2
B5
A4
A2
B9
A4
B7
B5
B7
A10
A10
A6
A7
A5
A5
A6
B6
B8
C2
1000 km
A8
A8
B10
A8
C3
B10
Hawaii = B11

Fig. 12


CLASS
I
II
III
IV
V
VI
1000 km
D1
B1
C7
A1
C1
A8
A2
A3
A4
A5
B2
B3
B4
B5
A9
A7
C5
A6
B8
A10
C3
A11
C4
B6
B7
A12
C2
B9
B10
B11
B12
B13
B14
C6

4 DISCUSSION OF THE RESULTS

4.1 High influence of some regions

The maximum production of dry matter (MPDM) and of grain equivalents (MPGE) is highly influenced by:

a the size of some broad soil regions with favourable soil and climatic conditions, and

b some smaller regions with excellent soils and important possibilities for irrigation.

In each continent only a limited number of regions is really important for the computation. More than 50% of the grain equivalent production in a continent could be obtained from 3 or 4 major regions, except for Asia where this number is 10. This means that for the whole world more than half of the maximum production could be grown in 28 out of 222 regions. Therefore the appraisals and assumptions made in these regions have a much higher influence on the final result than those in other regions. We have given these regions special attention.

4.2 The continents

Once more attention is drawn to the fact that the environmental conditions in the various regions are not homogeneous at all. With the help of the fraction of the potential agricultural land (FPAL) and the reduction factors caused by soil conditions (FSC) and by water deficiency (FWD) we have tried to eliminate this difficulty. Moreover the calculations are based on the potential yield of a standard crop to be grown on all suitable land, whereas at the moment in practice there is sometimes a fallow-system of farming and approximately 35% of the area is used to grow non-cereal crops.

South America has been divided into 27 broad soil regions. At present 4.4% is cultivated and 33.5% is potential agricultural land. It is the continent with the most promising possibilities for food production, although soil conditions are not as good as those in other continents, except Australia. There are very large reserve areas, e.g. the Amazone catchment area, although we have only half of the Amazone region indicated as potentially arable. Some regions (see the maps in figures 1 and 7) seem to be rather promising, however, the reliability of the data used in the calculations is often lower than the reliability of the data of other continents.

Australia has been divided into 25 broad soil regions. 3.9% of the continent is cultivated and 23% is potential agricultural land. For food production this continent has the smallest possibilities, caused by shortage of water.

Africa has been divided into 33 broad soil regions. Approximately 5.2% of the continent is cultivated and 23.5% is potential agricultural land. After South America this continent has the best possibilities for increasing food production. The regions surrounding the Sahara desert have low potentialities because of water deficiency. The Nile valley and delta and the Congo basin have the highest productivity class.

Asia has been divided into 54 broad soil regions (some have the same region symbol because conditions are similar). 15.6% of the continent is cultivated and 20.2% is considered to be potential agricultural land. There are various valleys and deltas of high quality. The coastal part of these deltas and the coasts with organic soils are often poor. The large, still uncontrolled rivers give possibilities for irrigation over very large areas, much larger than is irrigated at present. The potential irrigable agricultural land area (PIAL) is very large, it is 67% of the total PIAL of the world. Asia has the largest potential agricultural land area (PAL). It seems that the USSR and China are promising, however this might be caused partly by a perhaps too optimistic view of the soil scientists who prepared the soil maps we used. Regions B5 and A4 may be somewhat optimistic too, although FPAL is 0.5 only.

North America has been divided into 34 broad soil regions. Although it would have been possible to introduce more regions, because soil and climatic conditions are known better than elsewhere, we preferred to make the calculations in a similar way as we did for the other continents. The same applies to Europe.
At present 11.3% of the land is cultivated and we consider 25.9% as being potential agricultural land, which is almost 4% higher than the Americans do themselves. There is a clear transition in the land productivity classes from east to west.

Europe has been divided into 49 broad soil regions, some being combined in the calculations. Approximately 20.2% of the land is cultivated and almost 38% is considered to be potential agricultural land. This is 12% more than is estimated by American specialists. This continent includes the European part of the USSR. The land productivity classes are rather high, although many soils are relatively young and have important potentialities.

Table 12: PAL and IPALI of the continents and the world

	PAL (m ha)	PAL (corr.) (m ha)	% PAL	% PAL (corr.)	% PAL	% PAL (corr.)	% IPALI	% IPALI
S. America	616.5	595.6	34.6	33.5	16.7	17.4	19,1	17,9
Australia	225.7	199.1	26.2	23.2	6.1	5.8	8,8	4,0
Africa	761.2	711.3	25.1	23.5	20.5	20.8	10,5	16,7
Asia	1083.4	886.9	24.7	20.2	29.1	25.9	13.2	30,6
N. America	628.6	627.5	25.9	25.9	16.9	18.4	13.9	17.8
Europa	398.7	398.7	37.9	37.9	10.7	11.7	23.5	13.0
Total	3714.1	3419.1	25.0	23.0	100.0	100.0	12.8	100.0

Table 13: The absolute maximum production of grain equivalents (total and per hectare) of the continents and the world

	MPGE (10^9 ton)	% MPGE	average MPGE ($kg.ha^{-1}.year^{-1}$)
S. America	11106	22.3	18014
Australia	2358	4.7	10447
Africa	10845	21.8	14259
Asia	14281	28.6	13182
N. America	7072	14.2	11250
Europe	4168	8.4	10454
Total world	49830	100.0	13368

4.3 The world

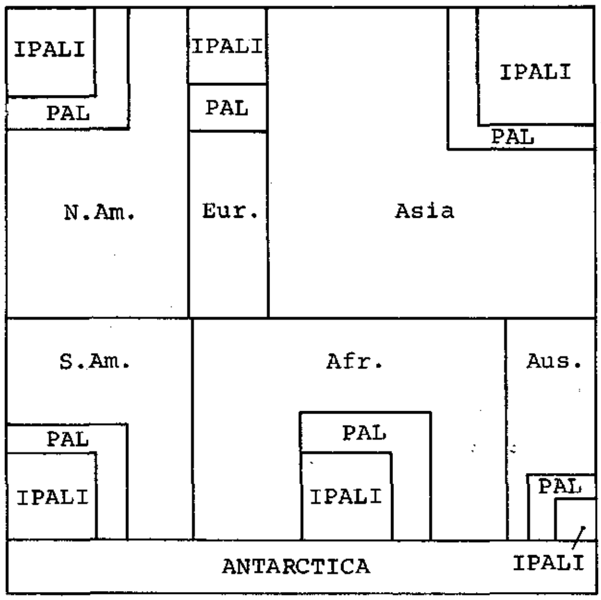
The total figures for the continents and the world totals are given in Table 7 and some percentages in Tables 12 and 13. The total potential agricultural land is 3419 million hectares of which at present 1406 million hectares are cultivated. South America and Africa south of the Sahara together have more than 50% of the total reserve of agricultural land. There is no reason to believe that there is almost no new land available for food production, although much productive land is lost at the present time because of misuse of land. At present approximately 200 million hectares are irrigated. If all available water for irrigation would be used in an efficient way some 470 million hectares could be irrigated of which more than 300 million hectares are in Asia alone (PIAL, Table 12). The diagrams in figures 13 (the continents) and 14 (the world) give an idea about the total areas (A) of the potential agricultural land (PAL) and of the imaginary potential agricultural land, including irrigation (IPALI).

Approximately 73% of the total production of grain equivalents (MPGE) could be produced in three continents (Asia, South America and Africa). These continents have 64% of the potential agricultural land (PAL) and 65% of IPALI. There are nine regions with MPGE > 1000, that is more than 1000 million tons of grain equivalents. The total production of these nine regions (13224 m tons) is approximately ten times the present cereal crop production, and it is 37.7% of the absolute maximum production of the whole world.

The absolute maximum production of grain equivalents is computed as being 49830 million tons, that is almost 40 times the present cereal crop production (1268 million tons, average of the period 1970-1972). The present cereal crop production, however, is grown on approximately 65% of the cultivated land area. If 65% of the potential agricultural land were to be used to grow cereal crops, and the rest for non-cereal crops, the MPGE could be 32390 million tons, 30 times higher than the present production.

The average absolute maximum production per hectare (Table 11), is lowest in Europe and highest in South America, mainly because of differences in climatic conditions. The average absolute maximum production per hectare and per year in the whole world is 13368 kg grain equivalents, whereas the present average yield is 1460 kg per ha for wheat and even less for rice.

The absolute maximum production of dry matter without (MPDM) and including irrigation (MPDMI) is given in the diagrams of figure 9, and for grain equivalents in figure 10. With full application of all irrigation possibilities the


IPALI
PAL
IPALI
PAL
IPALI
PAL
N.Am.
Eur.
Asia
S.Am.
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IPALI
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IPALI
ANTARCTICA

Fig. 13

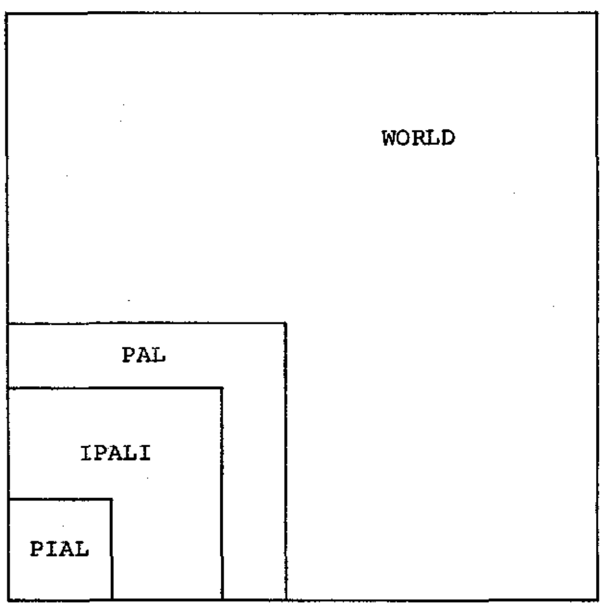
WORLD
PAL
IPALI
PIAL

Fig. 14

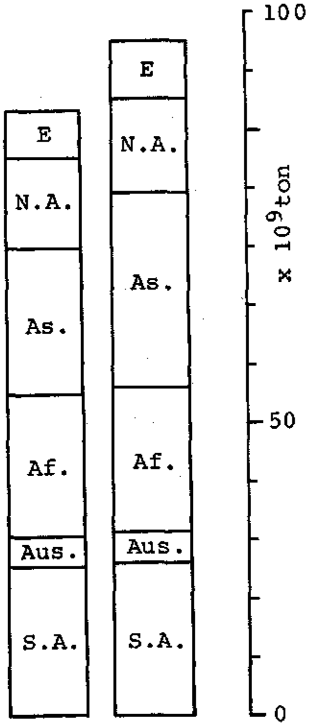

Fig. 15

MPDM MPDMI

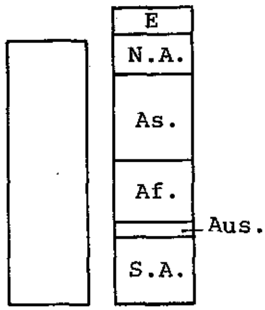

Fig. 16

MPGE

difference in maximum production in grain equivalents is only 5170 million tons or 10% of the total production.

Some people believe that approximately 1500 million ha of old tropical soils in the humid equatorial zone never can be used for intensive agricultural production. If so, we can make the following calculation, assuming A = 1500, FPAL = 0.3, thus PAL = 450. Assuming also FSC = 0.4 and RDM = 75, then MPDM = 450 x 0.4 x 75 = 13500 million tons and MPGE = 5800 million tons of grain equivalents. The absolute maximum of 49830 then has to be changed into 44000 million tons of grain equivalents. This example is given to demonstrate that it is easy to make corrections if they are wanted.

All results seem to give an optimistic view of the food production capacity of the world, in particular for a layman. We repeat once again that various reduction factors have to be introduced by competent specialists in order to get realistic information on the world food problem. It should be quite clear that our computation gives no information about the present situation. We did not pay any attention to factors in the field of economy, and to social, cultural and political obstacles. The interrelationship of some important factors and the complexity of the world food problem has often been demonstrated.

Finally attention is drawn to the new type of land capability classification given in paragraph 3.3. The maximum land productivity classification can be improved if more detailed information is available. It seems, however, worthwhile to make similar computations for other land capability classifications in order to know, besides the present, also the maximum capability of the land. It is beyond the scope of this publication to discuss in detail the results as given in Table 10 and in figures 7-12. In particular the maps give an instructive general view of the differences in productivity of the potential agricultural land.

4.4 Some high yields obtained in practice

It is evident that the present yields of cereal crops are below and mostly far below the absolute maximum as calculated by us, because farm management is not optimal and in large areas of the world farming is still done on a primitive or on a traditional low level. However, some authors have given data on high yields that have been obtained on experimental stations in various parts of the world.

De Vries et al. (1967) reports a rice yield (triple cropping) in the Philippines of 26 tons and Van Ittersum (1971) of 23 tons per ha, per year. For the region including the Philippines we computed a maximum yield crop of 16,8 tons of grain equivalents. This seems to be too low; this number is, however, an average of a much larger area (see the map in fig. 5). For the best land with irrigation a maximum production of 28,6 tons.ha^{-1} is calculated. Van Ittersum (1971) also mentions yields of 11 tons of rice per ha in West Pakistan and Kenya, for these regions we computed 24.2 and 21.5 tons of grain equivalents.

Simonson (1967) reports a maximum yield of wheat in north-western United States of 14.5 tons per hectare, for which we calculated 15 to 18 tons of grain equivalents. In the south-eastern part of the State of Washington some large farms had average yields of 10 tons per hectare.

In the Netherlands the average yield of wheat is 5 tons per hectare. Some farmers have harvested 8 to 9 tons of wheat, whereas according to our computation the maximum would be 10.5 tons of grain equivalents, but this estimate includes the possibility of crop growth after the grain harvest, for example turnips.

Double cropping of rice on Madagascar and in Senegal has given yields of 16.2 respectively 14.0 tons.ha^{-1} (Agron. Trop. 24-08-1969 and 23-10-1968). We have calculated for these regions 17.7 respectively 16.9 tons.ha^{-1}.

A high yield of winter wheat in S.W. Finland is 6.2 tons.ha^{-1} (FAO soils bul. 12, Rome, 1971), and we have calculated 7.2 tons.ha^{-1}.

Van Ittersum (1971) believes that the best farmers can reach a yield of about 25 to 35 percent below the potential one.

5 A COMPARISON WITH OTHER STUDIES

5.1 American study, 1967

In the American report (1967): "The world food problem, a report of the President's Science Advisory Committee", volume II, data are given on potential arable land. The soils of the world are studied on a world soil map, scale 1:15,000,000, prepared by the Soil Conservation Service of the USA. Soils are shown in 13 broad geographical groups and boundaries from a climatic map are superimposed on the soil map. The potentially arable land has been assessed for each continent as shown in Table 14 in which also the comparable data from our study are given. The American table gives the continents and the USSR separately. We have added 0.25 of the USSR figures to Europe and 0.75 to Asia. There is not much difference between the potential agricultural land areas (PAL) in both studies. Our computations are somewhat lower for South America, somewhat higher for North America and much higher for Europe.

In the American report (1967) an additional area of 28% of the total land area of the world has some grazing potential. However, this land gives only a relatively small proportion of the present livestock production. As is mentioned in Chapter 2 we have omitted this production.

The total potential agricultural land area of 3190 million hectares for the whole world is used by Meadows (1972) in his well-known first report for the Club of Rome. Some other American scientists have used the data of this American study in their report, e.g. Simonson (1967), Revelle (1973), and Kellogg and Orvedal (1969).

5.2 The study by Mesarovic and Pestel, 1974

In the study for this second report for the Club of Rome the world has been divided into ten regions. We have rearranged our data of the 222 regions in order to get these ten regions, the results are given in Table 15. The slight differences in the totals of land may be caused by some inaccuracy as a result of the very small scale of the map of the 10 regions in the second report. There are very important differences between the two studies. Mesarovic and Pestel (1974) did not indicate how their figures were obtained. Their remarks on agriculture and soils of tropical regions are pessimistic. They believe that North America and Australia are the only continents with large reserves of agricultural land, and that the tropical regions are unimportant for a solution of the world food problem. They also conclude that the possi-

Table 14: Comparison of the American and our calculations on potential agricultural land (PAL)

	American data (1967)					Our data		
	A	Cultivated		PAL		PAL (corr.)		PAL-cultivated
	(m ha)	(m ha)	(%)	(m ha)	(%)	(m ha)	(%)	(m ha)
S. America	1750	77	4.4	681	38.9	596	33.5	519
Australia	820	32	3.9	153	18.7	199	23.2	167
Africa	3010	158	5.2	734	24.4	711	23.5	553
Asia	4420	689	15.6	894	20.2	887	20.2	198
N. America	2110	239	11.3	465	22.0	627	25.9	388
Europe	1040	211	20.2	263	25.3	399	37.9	188
Total	13150	1406	10.7	3190	24.2	3419	26.0	2013

Table 15: Calculations with our data for the ten regions of the second report of the Club of Rome

	A (m ha)	PAL (m ha)	IMAPLI (m ha)	MPGE (m kg.yr^{-1})	PAL x) (m ha)	Available x) (m ha)
1 America	2156	533	293	5579	392	220
2 W. Europe	445	143	87	1655	155	127
3 Japan	52	21	15	298	8	6
4 Australia	1120	275	97	3077	150	58
5 E. Europe, USSR	2071	491	301	4472	382	280
6 Lat. America	2044	692	385	12599	429	128
7 M. East	1280	122	28	918	86	53
8 Trop. Africa	2181	658	234	9729	423	167
9 S. Asia	881	360	215	7467	278	268
10 China	1278	388	193	4029	122	118
Total	13508	3683	1848	49823	2425	1425
Our total	13530	3727	1900	49830		

x) figures from the report by Mesarovic and Pestel (1974) bilities of increasing the cultivated land area are limited. We do not agree with this part (appendix III.A) of their study, nor with some remarks on irrigation possibilities and other related subjects. For us, however, it was worthwhile to show that our data can easily be rearranged and integrated into larger regions of other studies.

5.3 The differences with other studies

In various publications, in particular in newspapers and weeklies, remarks are made on potential agricultural land. Mostly it is concluded that some 1400 million hectares are cultivated now and a similar area is still available for cultivation in the future. Sometimes it is said that there is almost no possibility of increasing the area of cultivated land. We have tried to start the work on the potential agricultural land again, independent of what has been done before, using the most up-to-date basic information. In addition we have made an attempt to compute the absolute maximum production for 222 regions, to compute the maximum production per hectare of potential agricultural land for each region and to show the regional differences in the availability of the potential agricultural land and its capability to produce a standard crop. We have given as many figures as possible and we have explained the way the calculations have been made.

Wageningen, January 1975

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