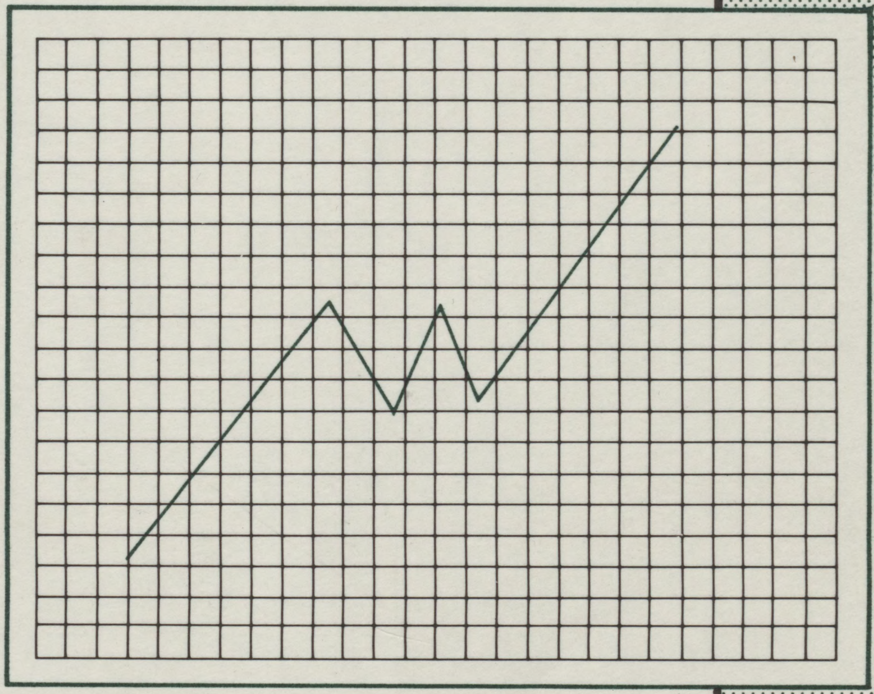

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FOOD PRODUCTION POTENTIAL AND FUTURE CONSUMPTION LEVELS IN THE FINAL STATE OF A STATIONARY WORLD POPULATION

by ADOLF WEBER*

INTRODUCTION

Historical assessment of production potentials and consumption levels

The present contribution deals with a very distant future in that it takes a look at food consumption levels at the time when a country has entered the stage of having a stationary population. The second abstraction lies in the global perspective that food production potentials is considered for all countries of the world. This cannot be done without imagination and without making many assumptions. These abstractions, however, are needed to shed more light on the frequently asked question: "How many people can the earth feed?" It is quite reasonable to assume that there must be a physical limit to the number of people the earth can support. One writer before Malthus and several who came after him have attempted to find definitive answers. A review of previous studies will reveal that the methodology and the data required to make such assessments have been improved during the last two centuries.

It is impossible to review all previous writing in which it was attempted to assess the earth's carrying capacity for man. Sources were therefore selected on a twofold basis. First, only studies written in English or German were chosen. Second, only studies which appeared before the present computer age (Table 1) were summarised.

Johan Peter Süßmilch, a German clergyman, member of the Prussian Academy of Berlin and statistician, was probably the first who, in 1765, presumed to make a quantitative assessment of the earth's carrying capacity[1]. Among the many people he consulted was the mathematician Euler of the Berlin Academy, who was requested to verify the calculations of the doubling time in population growth. Süßmilch assumed that 400 years later - which would be around 2160 - the carrying capacity of the earth would have been reached, with 13,9 billion people.

Süßmilch was certainly far ahead of his time in his speculations on the carrying capacity of the earth. He clearly identified the three factors that determine how many people can be provided with food; namely the availability of arable land, the land's fertility and the type and level of food consumption (including fibre, firewood) by man and his domesticated animals. Süßmilch did not have sufficient information at his disposal to classify the various potentials for the world's agroclimatic regions or determine appropriate measures of food consumption on a scientific basis, as we do now. Therefore, he had no other option than to take his own observations from the Brandenburg-Prussian environment as a frame of reference. The best Brandenburg land produced a harvest of nine times the seed sown but the poorer sandy soils brought only a threefold yield. Therefore, he used an average yield/seed ratio of 5: 1 in his calculations. The food rations of the Brandenburg soldiers, together with other observations, formed the basis of estimating the food consumption requirements of large populations.

In 1891, nearly 125 years later, the British geographer Ravenstein again addressed the subject of assessing the possible carrying capacity of the earth. He was able to draw on far more information about the availability and fertility of land than Süßmilch. He distinguished three types of theoretically possible population densities. For the best agricultural land, Ravenstein calculated 83 persons per square kilometre, for what were known as steppes, 4 and for deserts only 0,4 persons.

In 1912, the German economist Karl Ballod was able to acquire for his assessment more factual knowledge about the climatic diversity of food production conditions in all continents. The emerging science of nutrition had a strong impact on his thinking. This helped him to distinguish food consumption patterns such as the vegetarian-oriented Asian or Japanese diet, which makes fewer demands on the land, and the North American diet, which relies heavily on pastoral products and makes considerable demands on the land. Consequently, the potential world population could, according to the diet chosen and the land required, vary from 1 to 10 billion. Ballod was aware of various yield levels when comparing American, German or Asian yield levels, but he did not realise that the yield levels of his time were only a part of the theoretical potential.

The German geographer Albrecht Penck clarified the assessment with a small set of equations. In each country the population density depends on many factors. Besides the foreign trade position, the fertility of the soil determined the population density, which was also affected by an advanced stage of culture (or a high per capita income), because it increased people's food requirements. However, Penck did not have the data to support his equations empirically. He therefore assessed the population densities on the basis of eleven climatic regions instead of Ravenstein's three forms of land use.

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TABLE 1. Population Supporting Food Capacity of the Earth, Summary of Selected Studies

Author and Year	World's potential population (billions)	Climate and soil assessment	Consumption level *capita*/year
Süßmilch (1765)	13,9	One fourth of the earth's surface utilisable, population density = 6000 people per German mile (= 0,85 ha/capita), productivity as yield/seed ratio of 5:1 observed for Brandenburg	600 kg of grain equivalents (derived from food rations of Brandenburg soldiers) and unspecified amounts of livestock products, fibre, firewood
Ravenstein (1891)	6	Assumed various population densities for arable land, steppes and deserts	–
Ballot (1912)	2,3; 5,6; 22,6	5,6 billion hectares of arable land – author has already stressed the incomplete availability of climate and soil data	American, German, Japanese "standard of life" for food, feed, fibre
Penck (1925)	7,7	Eleven climatic regions	No detailed specification
Pearson & Harper (1945)	0,9 - 2,8	Existing world grain production transformed into carrying capacity	North American, European, Asiatic consumption levels
Osborn (1948)	1,8	Very broad generalisations	Undefined
Brown, Bonner, Weir (1957)	7,7	Japanese land productivity in Asia, European elsewhere	Asiatic consumption level in Asia, European elsewhere
Baade (1960)	30	4,2 billion hectares and 4 to 5 tons per hectare of arable land	650-700 kg of grain equivalents
Clark (1967)	47-167	Detailed climate classification (Thornthwaite) and introduction of standard farmland equivalents	American or Japanese food standards (and Asian standards of timber requirements)
President's Science Advisory Committee (PSAC) (1967)	–	13 soil zones, 17 agroclimate regions (US soil map scale 1:15 000 000), 200 soil and climatic combinations and irrigation considered	–
Mückenhausen (1973)	40	3,1 billion hectares from PSAC	500 kg of grain equivalents (from Baade)
Revelle (1976)	40	4,2 billion hectares from PSAC, (1,1 billion hectares added by irrigation)	912 000 kcal (= 276 kg of grain equivalents) and 10-20 kg of livestock products

SOURCES:

Fritz Baade, *Der Wettlauf zum Jahre 2000* Oldenburg 1960. – Karl Ballod, Wieviel Menschen kann die Erde ernähren? *Jahrbuch für Gesetzgebung, Verwaltung und Volkswirtschaft im Deutschen Reich,* Vol. 36(1912), pp. 595-616. – Harrison S. Brown, James Bonner and John Weir, *The Next Hundred Years.* New York 1957. – Colin Clark, *Population Growth and Land Use.* London 1967. – Eduard Mückenhausen. Die Produktionskapazität der Böden. *Rheinisch-Westfälische Akademie der Wissenschaften. Natur-, Ingenieur- und Wirtschaftswissenschaften. Vorträge.* N. 234, pp. 7-44. – Fairfield Osborn. *Our Plundered Planet.* Boston 1948. – Frank A. Pearson and Floyd A. Harper. *The World's Hunger.* New York 1945. – Albrecht Penck. Das Hauptproblem der physischen Anthropogeographie. *Sitzungsberichte der Preußischen Akademie der Wissenschaften.* Berlin. Vol. 22(1924). pp. 242-257. – President's Science Advisory Committee. *The World Food Problem.* Vol. 1-3. Washington, D.C., 1967. – G. Ravenstein. Lands of the Globe Still Available for European Settlement. *Proceedings of the Royal Geographic Society.* XIII:27. London 1891. Here quoted from Karl Ballod. *op. cit.*, p. 85 and M.M. Shah, G. Fischer, G.H. Higgins, A.H. Kassam, L. Naiken. *People, Land and Food Production – Potentials in the Developing World.* Collaborative Paper. March 1985. CP-85-11. International Institute for Applied Systems Analysis. A-2361 Laxenburg, Austria. – Roger Revelle. The Resources Available for Agriculture. *Scientific American.* 235(3), 1976. pp. 165-178. – Johann Peter Süßmilch. *Die göttliche Ordnung in den Veränderungen des menschlichen Geschlechtes aus der Geburt, dem Tode und der Fortpflanzung derselben.* 3rd rev. ed. Berlin 1765

The American studies by Pearson & Harper (1945) and Osborn (1948) were obviously influenced by the pressing demand for food in war-torn Europe and Asia. Furthermore, they still reflected the serious concern of the American soil conservation movement. Twelve years later, Brown, Bonner & Weir (1957) returned to the continental classification of land productivity and food consumption which had been known since Ballod. However, the three authors obviously did not get as far as the details of production and consumption conditions which the economist (and chemist by training) Colin Clark integrated into his study.

Clark's study of 1967 provided support for the idea that any reliable assessment of the earth's food production potential has to start from a comprehensive climate and soil inventory. This ideal was first achieved through a commission report submitted to the President of the United States of America (PSAC). Subsequent studies based on the PSAC by the soil scientist Mückenhausen (1973) and the natural scientist Revelle (1976) both contained the conclusion that 40 billion people could be nourished on earth. But one has to be aware that both Mückenhausen and Revelle assumed a low food consumption standard. Doubling the per capita food consumption would accordingly halve the potential population to 20 billion people. Since then, the earth's carrying capacity has not aroused the same interest. Today researchers from disciplines concerned with this question are more aware that without the use of a comprehensive soil and climate inventory, new insights can rarely be gained. Moreover, the general public is much more interested in exploring immediate development paths which are thought to be controllable than in quantitatively assessing a very distant future.

Focus and assumptions in this approach

The following three concepts form the basis of our attempt to quantify the earth's carrying capacity: First, the food production potential is assessed using an agronomic model. Second, the stationary population is derived from the demographic model of people's future generative behaviour and thirdly, the food consumption level is determined for each country by balancing food production potentials against stationary populations.

When a numerical perspective of the technical limits of food production is derived, several assumptions are implied. The quantification places emphasis on the technical limits of food production. Unavoidably, it neglects the many ecological, social, political and economic limits which impede the full and timeous use of the food production potential. We are not denying that such limitations exist in certain localities and at certain times, but there is no theoretical framework which would enable us to quantify the respective limits for each country.

The many possible "social" limits of food production largely shape discussion of this subject at present. Discussion is, however, imperative. Each country and society has to learn about when and where limits and boundaries in respect of increased food production will occur and how they will have to be overcome socially and technologically. Without ongoing discussion, the mobilisation of the necessary human and material resources would not get the needed attention. Despite the many abstractions and assumptions made it is thought that our approach will help to clarify the issues involved.

GLOBAL ASSESSMENT

The agronomic approach

A scholarly estimate of the earth's food production potential[2] was undertaken in 1975 by Dutch agronomists of the Agricultural University of Wageningen in the Netherlands[3]. It was part of the report on a project "Food for a doubling world population", which was initiated in response to the Club of Rome's world-wide study "The limits to growth"[4]. The whole book later became known as MOIRA. It is concerned mainly with economics and there is a much smaller agronomic section.

The theoretical framework of the assessment procedure was developed by Dutch agronomists. They considered the photosynthetic potential of food crops as a function of location and climate (solar energy, monthly air temperature, precipitation, evapotranspiration, leaf canopy, etc.). The results were summarised for the latitudes in a table in carbohydrates representing a standard crop[5]. The authors used a system of formulas to estimate the mean monthly gross photosynthesis and converted the results into grain equivalents.

However, conditions for crop cultivation are rarely optimal in the world's agricultural regions. Nutrients are deficient or the water supply is the limiting factor. That means that the pure agroecological approach, in which only agroclimatic inputs are taken into account, has to be complemented. From the world's soil (and water) inventory, the authors introduced reduction factors for poor soils and for water deficiencies. The basis for applying reduction factors (ranging from 0 to 1) was maps of 222 broad soil regions identified by FAO/UNESCO, the scale being 1:15 000 000. Pertinent to this approach of estimating the maximum production of grain equivalents (MPGE) is the appraisal of the potential agricultural land and an assessment of the irrigable arable land.

The original aggregation of grain equivalents in the MOIRA study was conducted for soil zones, continental and world totals (Table 2). The disaggregation to country levels was carried out planimetrically. National boundaries had to be inserted in the published maps of soil zones in the MOIRA study. The allocation of the MPGE from soil zones to individual countries is easy if a country belongs only to one soil zone. Some countries have extremely rugged national boundaries which hamper planimetric accuracy. Most of the larger countries belong to several soil zones. Therefore, in most countries a complex weighting of the various soil zones had to be carried out.

To minimise possible differences between MOIRA's continental results and planimetrically

TABLE 2. The absolute maximum production of grain equivalents (MPGE)

World, regions

Region	Arable land* 1982	Potential agricultural cropland	MPGE tons/ hectare/year	MPGE	MPGE
	Million hectares			10^9t	in %
	(1)	(2)	(3)	(4)	(5)
South America	139	617	18,0	11,1	22,3
Australia	47	226	10,4	2,3	4,7
Africa	183	762	14,3	10,8	21,8
Asia	506	1 081	13,2	14,3	28,6
North and Central America	273	629	11,3	7,1	14,2
Europe	322	399	10,5	4,2	8,4
World	**1 473**	**3 748**	**13,4**	**49,8**	**100,0**

*Includes permanent crops. The arable land of the USSR has been divided into 182 million hectares for Europe and 50 millions for Asia

Source: *MOIRA*, pp. 25-49. - FAO, *Production Yearbook 1983*

derived results for a particular country, a few minor compensatory calculations were applied.

The MOIRA study distinguishes six land productivity classes (Tabl 3). Forty-five per cent of the world's potential agricultural land is theoretically capable of yielding more than 15 tons of grain equivalents. Land of this kind is concentrated in areas where neither frost nor extended droughts interrupt the year's vegetation period; this is typical of the lower latitudes of Latin America, Asia and large parts of Africa.

Figure 1 shows the special distribution of six land productivity classes among the continents. There are few countries which have a potential of less than five tons of GE per hectare (Mongolia, Mali, and Niger) or more than 25 tons of GE per hectare (Egypt and Bangladesh). Most European countries, Turkey, China, Japan, Argentina and the United States of America have a theoretical yield potential of between 10 and 15 tons of GE per hectare. Northern countries, Chile and Australia attain between 5 and 10 tons of GE per hectare, whereas many tropical countries can attain between 15 and 20 tons of GE per hectare.

Moreover, it should be mentioned that the estimates of food production potential are based on potential agricultural land. The land cultivated at present represents only 40 per cent of the world's total potential. It is reasonable to assume that the cropland cultivated in almost every country already accounts for the most fertile and economically viable arable soils. This leads one to conclude that the *theoretical* yield potential of cropland currently being cultivated must be much higher than that of the potential cropland.

The demographic approach

Past experience has shown that as development leads to improvements in education, health and knowledge and as income levels rise, fertility and population growth slow down. Thus recent estimates assume that the human population will not continue to grow indefinitely. Some countries in Central Europe have already attained a stationary population. There will be a time lag, but other countries will eventually follow. Figure 2 shows the stage, for each country's population, when a net reproduction rate of 1 will be reached. It is obvious that the adjustment period will take longer for a few countries in Latin America, in South-East Asia, and almost all countries in Africa and the Near East. The World Bank has estimated the hypothetical size of the stationary population in millions for every country (excluding those with a population of less than one million). At present the countries excluded account for not more than one per cent of the world's food production. The

TABLE 3. Distribution of soil productivity classes in million hectares

Region	Productivity class (GE/tons/hectare) in million hectares					
	I ⩽5	II >5-10	III >10-15	IV >15-20	V >20-25	VI >25
South America	12	-	108	287	185	3
Australia, New Zealand	60	68	26	19	49	-
Africa	93	92	95	335	135	5
Asia	197	51	352	214	135	69
North and Central America	-	342	87	144	48	-
Europe	1	151	224	12	4	-
Total 3 602	**362**	**704**	**892**	**1 011**	**556**	**77**
in %	**10**	**20**	**25**	**28**	**15**	**2**

Source: *MOIRA*, p. 39

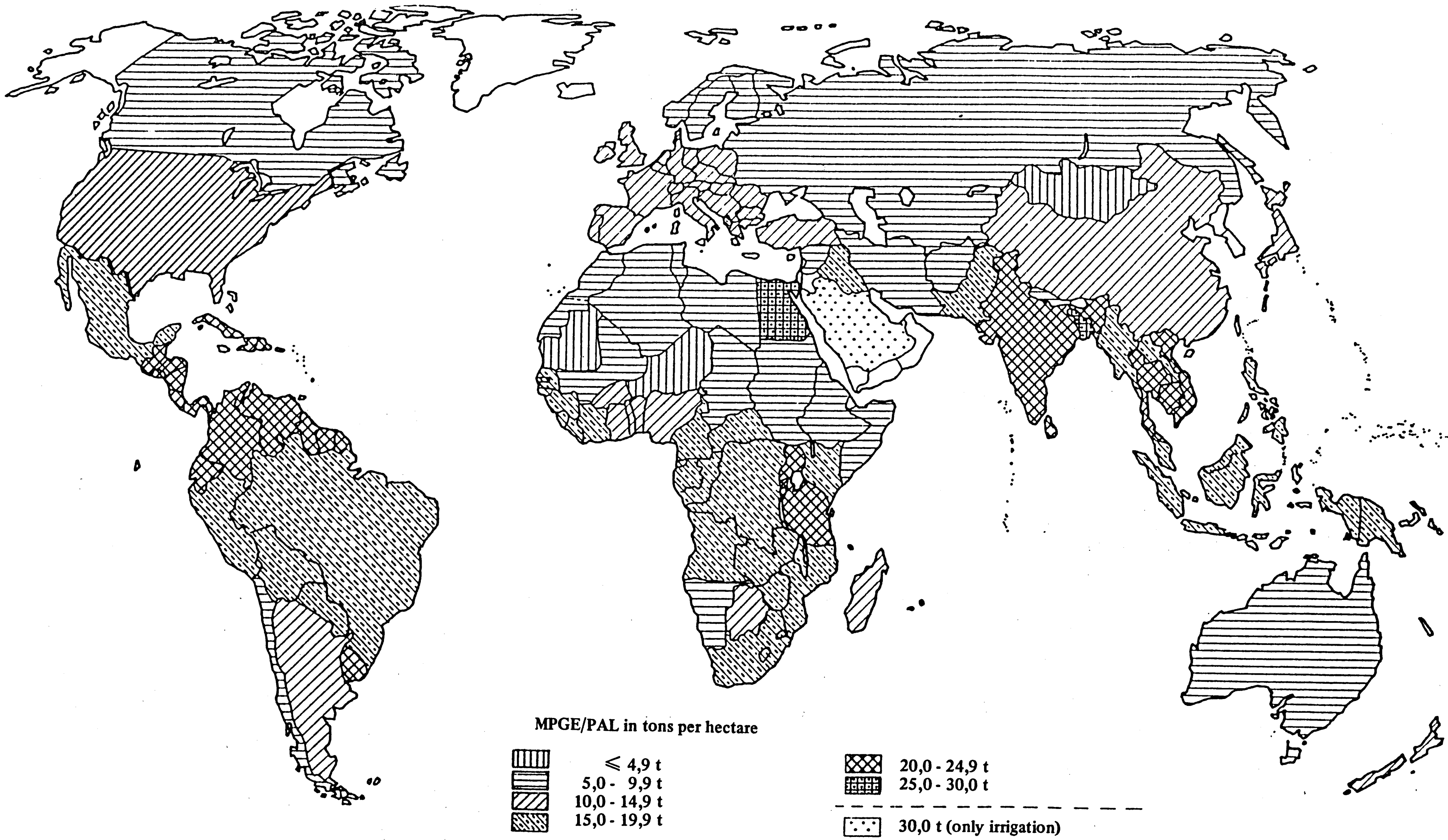

FIG. 1. Maximum production of grain equivalents (MPGE) per hectare of potential agricultural land (PAL) (calculated from MOIRA)

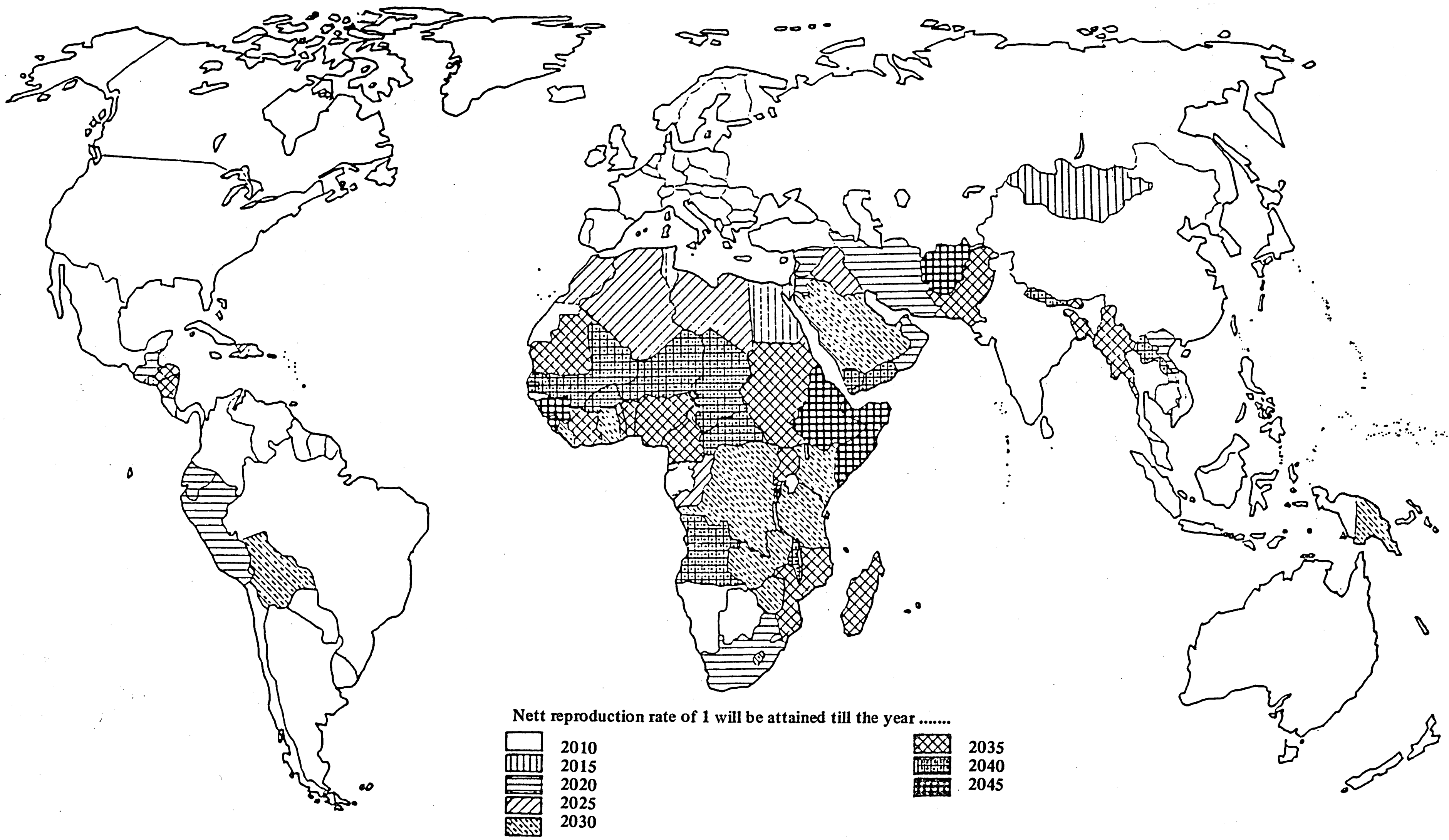

FIG. 2. Probable attainment of a nett reproduction rate of 1

hypothetical size of the stationary population for the world as a whole is estimated at eleven billion people. The nature of these estimates is described by the world Bank as follows: "... provide a summary indication of the long-run implications of recent fertility and mortality trends on the basis of highly stylized assumptions"[6]. The final state of a stationary population will occur, assuming the present norms of population growth, at the end of the next century. Recent investigations by the World Bank have shown that in developing countries the calculated norm of population growth was already substantially lower in 1982 than in 1972[7]. Therefore, continuously falling birth and death rates are highly likely to occur. This would likewise reduce the final stationary population. The world Bank's standard population projection yields a figure of 9,5 billion people in developing countries by the year 2050. If lower norms regarding birth and death rates are adopted, the projection yields only 7,7 billion people or 1,8 billion fewer living in developing countries. The various governments' population policies initiated in the last decade in developing countries are highly likely to become more efficient in the future, and there should be some culturally determined delays as well.

The nutritional approach

The FAO/WHO has stated that the food energy requirement for a moderately active 65 kg man is 3 000 kcal per day and that for a woman weighing 55 kg is 2 200 kcal. Allowances have to be made for the intensity of life supporting activities, for age, sex, weight, climate and individual metabolic rates. However, the exact distribution of these factors which determine the food energy requirement per person among countries is not known. Therefore, to simplify the calculation, a daily food energy requirement of 3 000 kcal per person has been assumed[8]. This corresponds to an annual 332 kg of grain equivalents (GE). In order to allow for seed and waste, a minimum of 400 kg of grain equivalents per capita per annum would have to be produced, providing the minimum food requirements.

A level of 400 kg of grain equivalents per capita per annum guarantees only survival and supposes that the food be evenly distributed among the population. A higher safety level starts when at least 600 kg or more of grain equivalents are available. Then, in addition to the non-edible crop residues and forage usually converted by ruminants into milk and meat, more crop products (grain, oilseeds, roots and tubers) can be transformed by non-ruminants into valuable animal products.

As stated above (Table 2) the food production potential of the earth was estimated at 49,8 billion tons of grain equivalents or 4,52 tons of grain equivalents per capita of the stationary population. The maximum amount of food which can be used in an affluent society which converts grain, roots, tubers and by-products of industrial processing into livestock products, alcoholic and non-alcoholic beverages, and feed for all kinds of pets, will not be much above two tons of GE per capita. At 4,5 tons, therefore, the theoretical food production potential is at least twice as high as the possible maximum use of food. Utilisation rates of 50 per cent and 30 per cent of the food production potential would still yield 2,2 and 1,35 tons of grain equivalents respectively per head of the stationary world population. It should be added that the estimate of the food production potential does not include pastoral products from the remaining grazing areas or any food from the sea or inland waters. These summary calculations reveal that the world as a whole does not have to strive to use 100 per cent of its food production potential, even a 50 per cent utilisation rate would yield plenty of food[9].

Present utilisation of the food production potential

More than half of the energy directly consumed by the average man is derived from cereals. One half of all arable land is devoted to the cultivation of grain. In this paper, therefore, cereal yields are taken as a first approximation in determining what fraction of each country's yield potential has been tapped. The present grain yields have been expressed in Figure 3 as a fraction of the MPGE per hectare of *potential* agricultural land. According to this calculation it was only in the Scandinavian countries and the Netherlands that cereal yields attained between 50 to 60 per cent of the theoretical yield potential from 1981 to 1983. In most parts of Europe, North America, China, Mongolia and Japan, the 1981 to 1983 cereal yields reached only between 30 and 40 per cent of the theoretical yield potential. In developing countries - with a few exceptions such as Afghanistan, Chile, Iran, Nepal - less than 20 per cent of the theoretical yield potential has been used.

The total food production potential in each country is the product of two factors: yield potential x area potential. The yield potential and the area potential represent the two main alternatives in each country when mobilising the total food production potential. In the less densely populated countries, this can be done primarily by area expansion, in the highly populated areas mainly through yield increases [10]. In general both alternatives are pursued simultaneously, depending on their economic feasibility. The many obstacles that exist and the strategies to be followed depend on the specific situation in each country. They will not be discussed here.

The reserves of land that are still arable differ from one continent to another and from one country to another. Europe is known as a densely populated continent. The whole of Europe (excluding the European part of the USSR) uses 35 per cent of its yield potential and 70 per cent of its area potential, but in 1981 to '83 this was only 24 per cent or a quarter of its total food production potential. North and Central America use 13 per cent and all other continents less than 10 per cent of their total food production potential. In China and Japan the utilisation rate is below 20 per cent of the potential (Figure 4). The dotted areas in tropical South

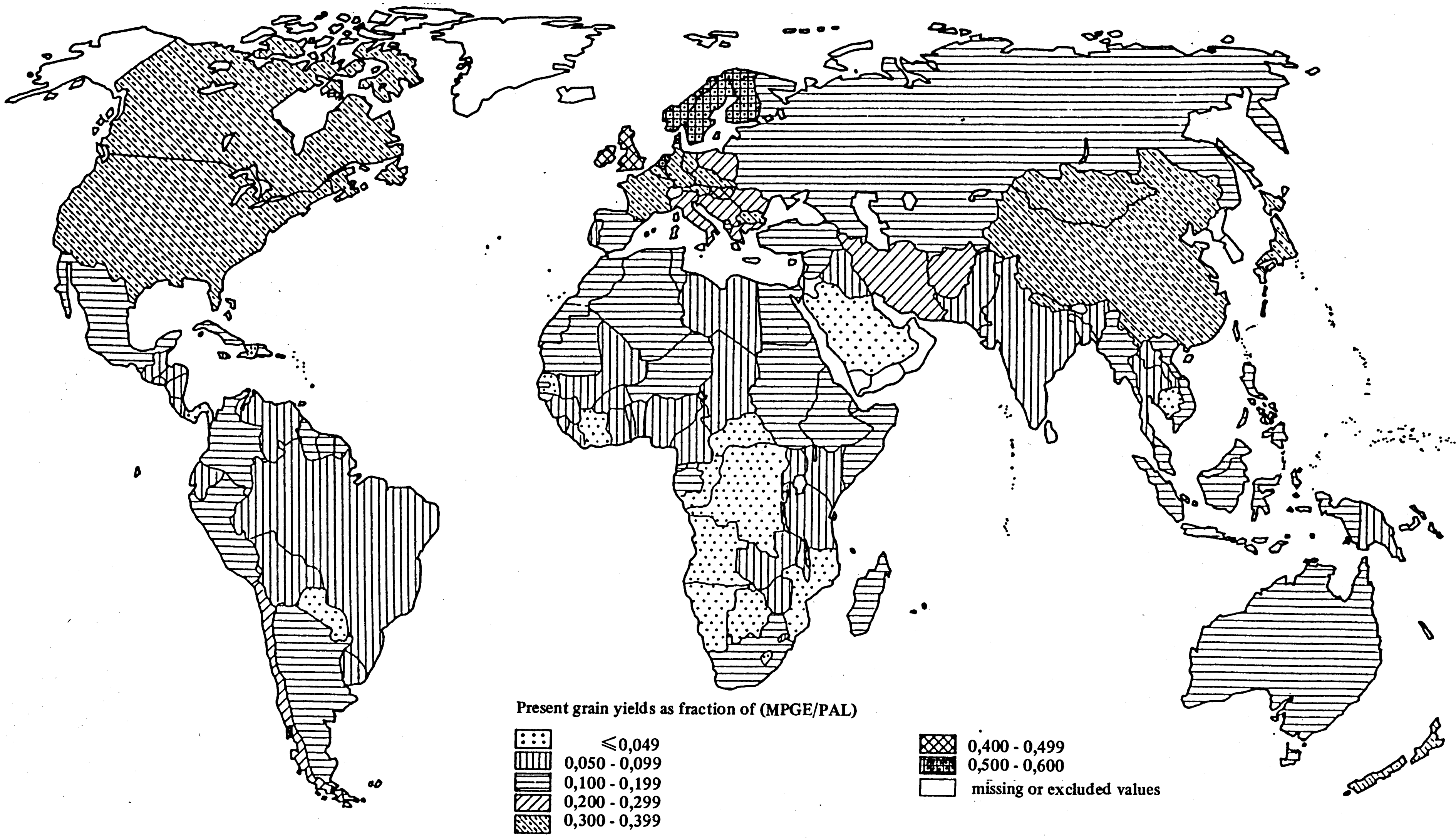

FIG. 3. Present grain yield level (1981-1983) as fraction of the maximum production of grain equivalents per hectare of potential agricultural land (MPGE/PAL) (calculated from MOIRA)

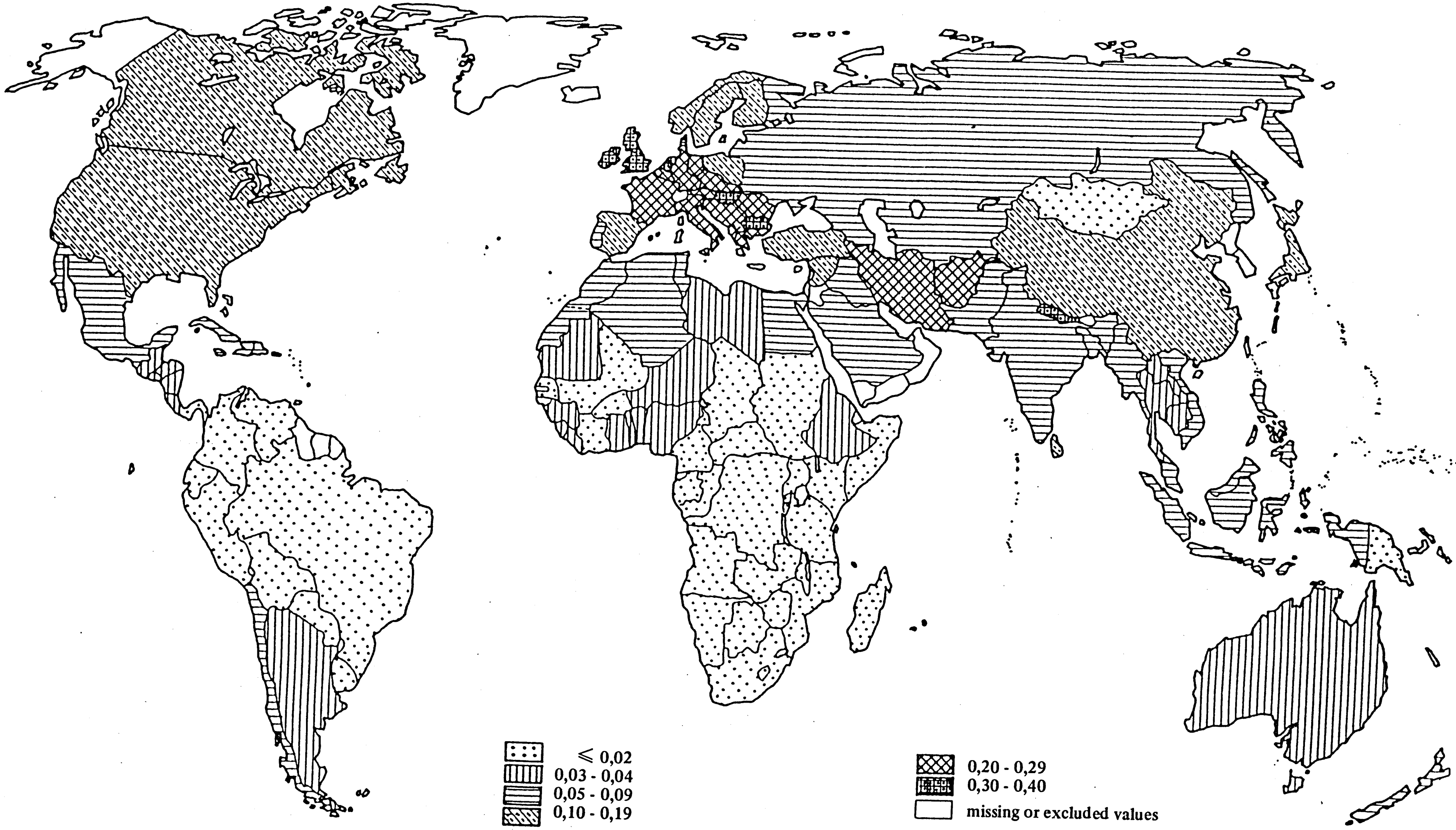

FIG. 4. Present utilisation (1981-1983) of the maximum production of grain equivalents (calculated from MOIRA as present fraction of MPGE/PAL x present fraction of PAL)

America and Africa indicate a large unused potential.

The global outline given above has certain major disadvantages. It does not take into account the present uneven distribution of food between countries nor does it indicate what the probable future food consumption levels would be in each country. These questions will be addressed in the next section.

FOOD CONSUMPTION LEVELS IN COUNTRIES WITH STATIONARY POPULATIONS

In each country population and income densities per unit of arable land determine the state of technologies and the attainable food consumption levels. But population growth and the generation and/or transfer of technical progress do not take place at the same rate everywhere, nor do they always take place in the proportions required for particular locations. Consequently, income and food consumption levels between countries differ enormously. This has been the case in the past and there is no convincing reason to assume that food consumption in the final state of a stationary world population will reach the same level everywhere. Therefore, three utilisation rates of food production potential (10, 30, 50 per cent) are used in the sequence of the following assessment.

In order to better identify those countries where food consumption levels are wholly insufficient at the final stage of a stationary-population, six food consumption classes have been identified (Figure 5). The lowest two classes (⩽ 199 kg, 200-399 kg) represent insufficient food consumption levels, the next two classes (500-599 kg, 600-799 kg) are medium food consumption levels, and all classes from 800 kg GE onwards indicate desirable states of food consumption. The dotted areas in figure 5 are those with a possible per capita production of more than one ton, which permits people to strive for a balanced diet. At the low utilisation rate of 10 per cent of the food production potentials, all countries in Oceania, most countries of the Americas, but only a few in Africa, Asia or Europe would provide more than one ton of grain equivalents per person.

The darker shadowed areas characterise those countries where in the final state less than 400 kg or even less than 200 kg of GE would be available. In both cases hunger, undernourishment and malnutrition would prevail. However, if one considers a higher utilisation rate of 30 per cent, the remaining countries in America (except El Salvador) and in Europe are moving out of the more heavily shadowed areas, which represent zones of wide-spread hunger, undernourishment and malnutrition (Figure 6). Likewise, as in America and Europe, several countries in Africa and Asia with a 30 per cent utilisation rate of the food production potential, exceed the minimum food requirement stipulated above, at 400 kg of GE per person. Europe utilises, undoubtledly, the highest percentage of its total food production potential. A few European countries have already reached the 30 to 40 per cent level (Figure 4). The grain yields of some countries already appear to have exceeded the 50 per cent yield potential on their presently cultivated arable land (Figure 3).

Considering the European experience, it does not seem entirely unreasonable to look at what happens to consumption levels in single countries when one assumes that the utilisation of the food production potentials can be increased to 50 per cent (Figure 7). For two countries in Africa (Ethiopia and Mauritania) and two in Asia (Nepal and Saudi Arabia), the food consumption level would be below 200 kg GE per capita. Saudi Arabia will certainly have - as at present - the purchasing power to buy from the international market. In Mauritania and Nepal the livestock economy based on ruminants which has not been taken into account, plays a large role. Therefore, the net effects are probably less than calculated. These four countries have a population of 372 million people or 3,2 per cent of the final total world population. In order to provide these countries with at least 400 kg of GE per capita year, a total of 98 million tons of GE would be needed (Table 4). This could be provided either by imports or by a higher utilisation of the food production potential.

Less than 400 kg of GE/capita would be available in Afghanistan, Bangladesh, Niger, Nigeria and Rwanda. The inhabitants of this group of countries number 1 235 million of the stationary population or 11 per cent of the world's total stationary population. These five countries would not produce enough food in their own territory if only 50 per cent of their food production potential were utilised, as assumed in Figure 7. In order to reach the above norm of 400 kg of GE/capita/year, 106 million tons of GE have to be made available (Table 4). The countries considered are also described in the FAO/IIASA/UNFPA study for the year 2 000 as being critical. Therefore, if the present trends in population growth persist and the assessment of the existing resources is correct, appropriate efforts to improve the food production in these countries are unconditionally necessary.

It is assumed that a food consumption level of at least 400 kg of GE per capita per annum is considered as an unconditionally stated human right. In this case one could ask how greatly the required physical transfer of 203 million tons of grain would affect a surplus region like North and Central America (Table 5). Even in the final state of a stationary population, the utilisation rate of the food production potential in North and Central America would only increase from 18,5 per cent to 21,4 per cent. This utilisation rate is less than the one that currently applies in Europe. Additional quantities could further be mobilised in South America, Europe, Australia and even in parts of Africa. Even larger quantities could be mobilised for higher minimum requirements because more and more countries will reach a state where the demand for food becomes less than the capacity to produce.

There is not a great deal of time left to adjust

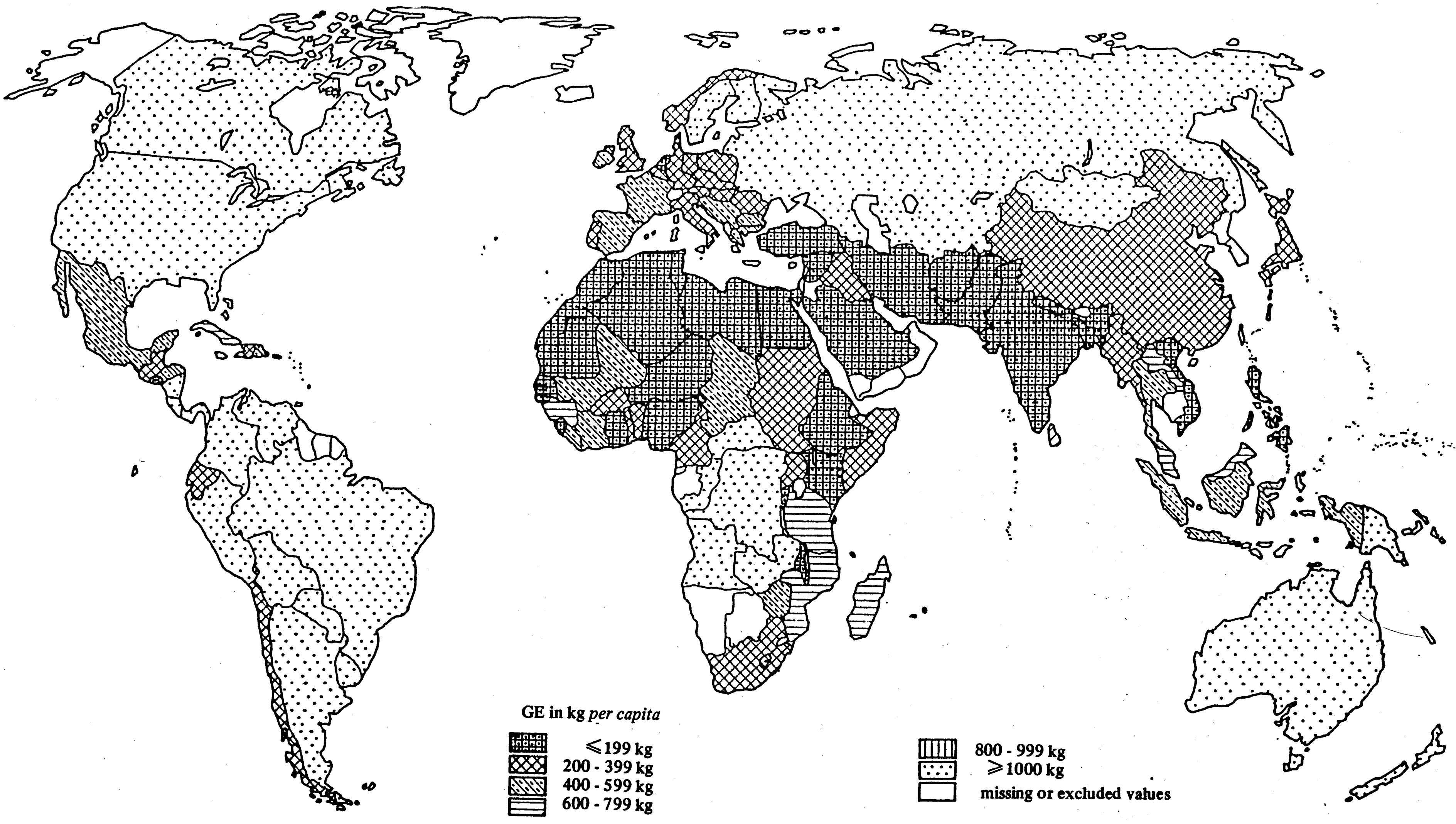

FIG. 5. Grain equivalents (GE) available *per capita* of stationary population assumption: 10% utilisation of MPGE (calculated from MOIRA)

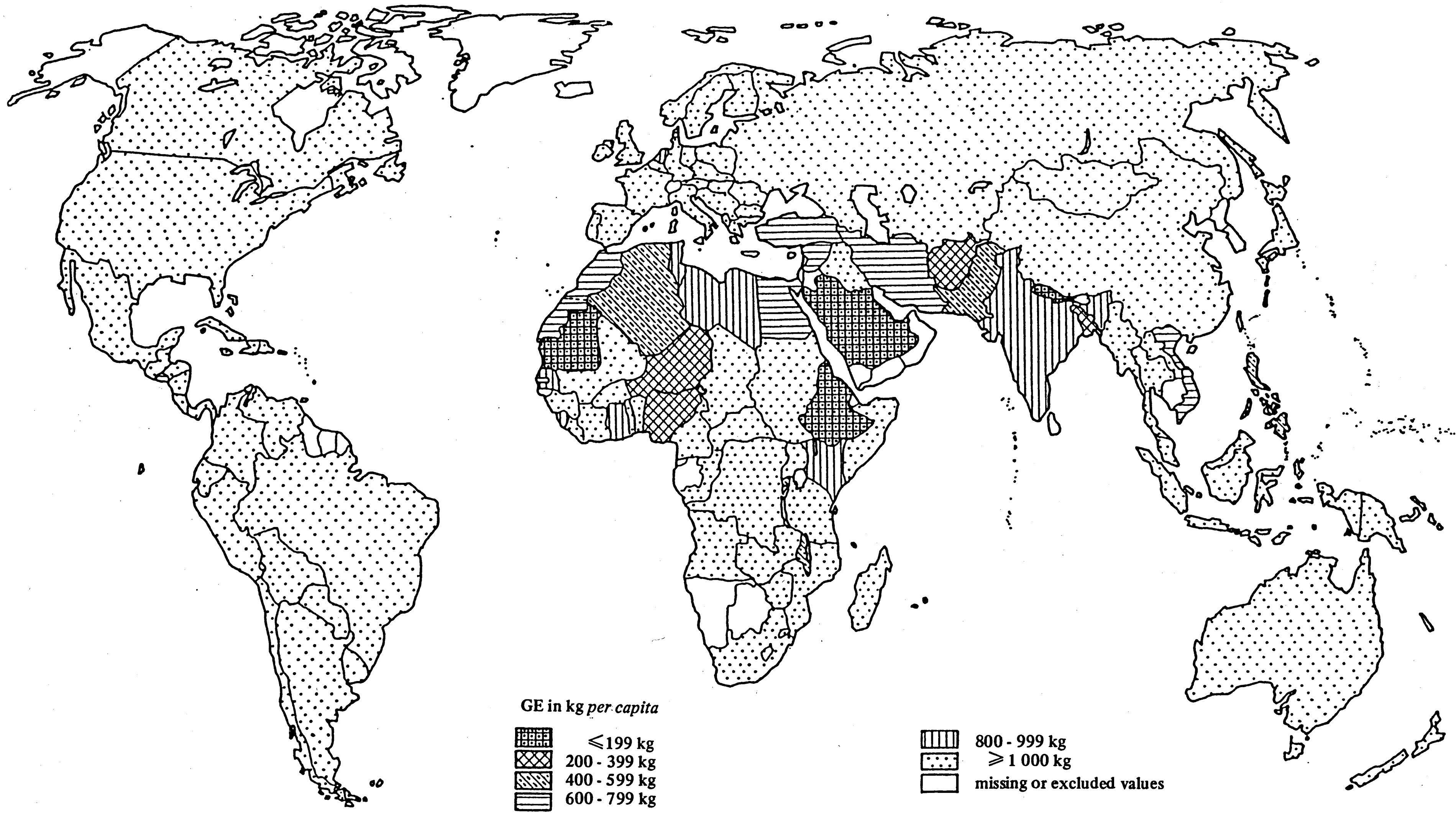

FIG. 6. Grain equivalents (GE) available *per capita* of stationary population assumption: 30% utilisation of MPGE (calculated from MOIRA)

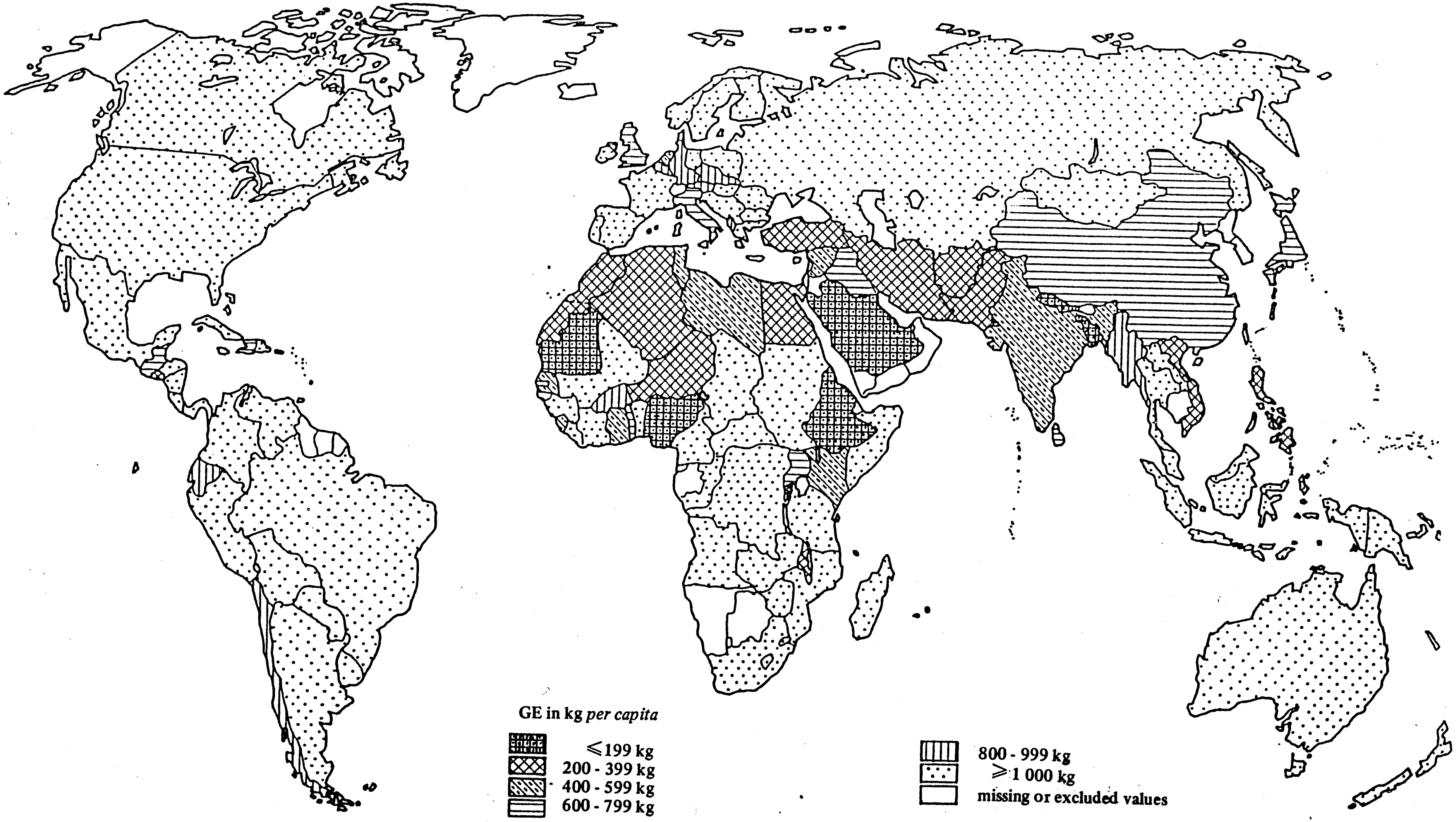

FIG. 7. Grain equivalents (GE) available *per capita* of stationary population assumption: 50% utilisation of MPGE (calculated from MOIRA)

TABLE 4. Countries with calculated insufficient food consumption levels in the final state of stationary population at the 100 % and 50 % utilisation rate of the food production potential

	Country	Stationary population		MPGE/ *capita*/kg		Additional food requirement at 50 % utilisation rate if 400 kg GE/*capita* is assumed consumption norm	
		Mill. (1)	Year (2)	100 % (3)	50 % (4)	*Per capita*/kg (5)	Total mill.t (6)
			Countries with ⩽ 199 kg of GE *per capita*				
1.	Ethiopia	231	2 045	398	199	201	46,4
2.	Mauritania	8	2 035	375	188	212	1,7
3.	Nepal	71	2 040	42	21	379	26,9
4.	Saudi Arabia	62	2 030	65	33	367	22,8
1-4.	**Subtotal**	**372**	-	-	-	-	**97,8**
			Countries with 200 - 399 kg GE *per capita*				
5.	Afghanistan	76	2 045	684	342	58	4,4
6.	Bangladesh	454	2 035	564	282	118	53,6
7.	Niger	40	2 040	775	388	12	0,5
8.	Nigeria	618	2 035	668	334	66	40,8
9.	Rwanda	47	2 040	532	266	134	6,3
5-9.	**Subtotal**	**1 235**	-	-	-	-	**105,6**
1-9.	**Total**	**1 607**	-	-	-	-	**203,4**

the resources to the requirements in the poorest of food-deficit countries. However, even after all adjustments have been made, the food consumption levels in the final stationary state of the world population will probably still remain nearly as uneven as today. This is the most frightening conclusion of the study: According to the calculations made, even 100 years from now there will still be millions of people who will probably not have at their disposal the quantity, quality and variety of food that people will enjoy in the more affluent parts of the world, which will then be more extensive. But it should be less of a problem to raise the standards of food consumption in the poorest countries because larger parts of the world are becoming more wealthy.

ASSUMPTIONS RECONSIDERED AND CONCLUDING REMARK

Before one tries to assess the possible future situation for the world as a whole, and for single endangered countries, one has to bear in mind that several strong assumptions had to be made in order to carry out the calculations.

(i) The calculations were designed to determine the technical limits of food production in almost all countries of the world. The measurements were possible because the agronomists, specifically those of MOIRA, had provided a quantifiable framework. As has already been mentioned, other limits in food production can also be perceived as being ecological, social, political or even economic constraints. However, the non-quantifiable limits have not been considered because they permit only qualitative evaluations about future food production possibilities.

(ii) The accuracy of the estimates at country levels based on MOIRA's maps of broad soil regions should not be overvalued. The food production potential of parts of the countries may have been overestimated or underestimated. However, at the regional or continental level any such errors certainly cancel each other out. It should be reiterated that the estimation of the food production potential does not include pastoral products from grazing areas and any food which is derived from the sea or inland waters.

(iii) For the sake of simplifying the calculation, no trade in food and agricultural commodities between surplus and deficit countries has been assumed. As history shows, this is not a very

TABLE 5. Drawing on the food production potential of North and Central America to meet the food requirements in countries with less than 400 kg of GE per capita

1.	Food production potential[a]	= 7 049 mill. t GE
2.	Expected stationary population[a]	= 652 mill.
3.	Assumed food consumption level[a]	= 2 t GE/*capita*
4.	Requirements in North and Central America	= 1 304 mill. t GE
5.	Utilisation of food production potential[a]	= 18,5 per cent
6.	Requirements in countries with less than 400 kg of GE/*capita*	= 203 mill. t GE
7.	Requirements of 4 and 5	= 1 507 mill. t GE
8.	Yields utilisation rate of food production potential[a] of a (= 6 : 1)	= 21,4 per cent

[a]In North and Central America

realistic assumption. Those countries which have less agricultural resources to enable them to reach self-sufficiency in food, will specialise in non-agricultural activities to produce tradable goods and vice versa.

(iv) The present rigidity of national boundaries prevents large international migrations of agriculturists from taking place. As an example: people could migrate from the "over-crowded" Rwanda, to neighbouring countries like Tanzania or Zaire. In the final state the latter countries would utilise a much lower level of their food production potential. Whether large migrations will finally take place, seems to be merely a matter for speculation at present.

In this contribution I have tried to shed light in quantitative terms on a very distant future. The main aim was to assess and to compare the food production potential with estimated stationary populations for single countries. There can be no doubt that a population smaller than the stationary population would facilitate the task of providing people with higher levels of food consumption in many developing countries. The present very hypothetical calculations and estimates are certainly not as accurate as one would wish them to be. The results presented suggest that the world as a whole is not, even in the very long run, running out of food. The earth has the food production potential to support twice the present population. Extreme Malthusian pessimism is therefore not vindicated. In a few countries, however, the situation might deviate from the trend in climatically unfavourable years or in times of environmental or social stress. Such situations can be overcome or alleviated by policies which support basic human rights, social justice, the spirit of peace, co-operation and assistance.

NOTES

1. Quoted from the 3rd edition. The first edition of 1761 was not accessible to this author. - Johann Peter Süßmilch, *Die göttliche Ordnung in den Veränderungen des menschlichen Geschlechtes aus der Geburt, dem Tode und der Fortpflanzung derselben.* 3rd rev. ed., Berlin 1765.
2. The Dutch agronomists framed the food production potential of the earth (or the theoretical maximum of food production) as the (Absolute) maximum production of grain equivalents (MPGE). If there is no express reference to MOIRA, the three terms are used interchangeably.
3. Peter Buringh, Henk D.J. van Heemst & G.J. Staring, *Computation of the Absolute Maximum Food Production of the World.* Wageningen 1975. Note: The results were later published in Chapter 2 of: Hans Linnemann, Jerrie de Hoogh, Michiel A. Keyzer & Henk D.J. van Heemst with contributions by Rein J. Brolsma, J.N. Bruinsma, P. Buringh, G.J. Staring, Cornelis T. de Wit: *MOIRA (Model of International Relations in Agriculture).* Amsterdam 1979. Here quoted from and referred to as MOIRA.
4. Dennis Meadows, Donella Meadows, Erich Zahn, Peter Milling: *Die Grenzen des Wachstums. Bericht des Club of Rome zur Lage der Menschheit.* Stuttgart 1972.
5. The standard crop is conceived as a C3 plant, "with the properties of a cereal" (MOIRA, p. 27). The ratio of straw to grain is calculated at 1: 1. It is known that some C4 plants, like maize, sugar-cane or sorghum have between 25 °C and 35 °C higher photosynthetic performances and are normally grown in the warmer climates. However, the optimal mix of crops at each location will finally be determined by the profitability of and the demand for crops and not by their absolute photosynthetic efficiency. Further, one has to be aware that the conceived "standard crop" is a theoretical concept developed to cover all food crops (not only cereals) and all regions of the world. Because of cereals' world-wide importance in cultivation and human food, Grain Equivalents (GE) are used in MOIRA and in this study as an indicator of the food production potential or the MPGE (Maximum Production of Grain Equivalents). However, this also does not exclude the possibility that in some areas permanent crops (trees, bushes, etc.) vegetables, industrial crops or spices (aroma) have desirable properties or ingredients sought by man which make them better able than cereals to exploit the food production potential afforded by the location.
6. The World Bank, *World Development Report 1984.* Washington, D.C. 1985, p. 282.
7. The World Bank..., op. cit. p. 187ff.
8. The production and consumption of textile fibres are neglected here because 1 kg of fibres per capita per annum would suffice to provide decent clothing. 1 kg of fibres corresponds roughly to 10 kg of grain equivalents.
9. Buringh observed in 1977: "However, at present we do not need a level of food production that is 30 times the present production; in the near future when the population is doubled, we will perhaps need three times the present food production. This food can be produced and often even without reclaiming the land." - Peter Buringh, Food Production Potential of the World. *World Development,* Vol. 5 (1977), pp. 477-485.
10. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development. An International Perspective.* Revised and expanded edition. Baltimore and London 1985, p. 118 ff.

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