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People, Land and Food Production - Potentials in the Developing World

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PEOPLE, LAND AND FOOD PRODUCTION - POTENTIALS IN THE DEVELOPING WORLD

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FOREWORD

Understanding the nature and dimension of the land and water resources available for food and agriculture development, and the policies available to develop them, have been among the focal points of the work of the Land and Water Development Division of the Food and Agricultural Organization of the United Nations and of the Food and Agriculture Program at the International Institute for Applied Systems Analysis.

As we anticipate, over the coming decades, a technological transformation of agriculture which will be constrained by resource limitations and which could have environmental consequences, a number of important questions arise:

(a) What is the stable, sustainable production potential of the world? of regions? of nations?

(b) How does this production potential in specific areas (within countries and groups of countries) compare to the food requirements of the future populations of these areas?

(c) What alternative transition paths are available to reach desirable levels of this production potential?

(d) What are the sustainable and efficient combinations of techniques of food production?

(e) What are the input requirements of such techniques?

(f) What are the policy implications at national, regional and global levels of sustainability?

Stability and sustainability are both desirable properties of agricultural land resources development. We hold ecological considerations to be of critical importance in answering the questions posed above.

This paper presents the results of a recent study entitled "Land Resources for the Populations of the Future" carried out by the Food and Agriculture Organization of the United Nations in collaboration with the Food and Agriculture Program of the International Institute for Applied Systems Analysis with financial support from the United Nations Fund for Population Activities.

The study was designed to quantify potential population supporting capacities of land resources in the developing regions of the world, based on ecological and technological limits to food production. An understanding of these limits is critical to agricultural policy formulation and development planning. This paper highlights policy implications for developing countries.

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EXECUTIVE SUMMARY

The population of the developing countries was 1.7 billion in 1950. Today it is 3.6 billion and by the year 2000 it is expected to be 4.9 billion. Looking even further ahead, by the year 2100, when most countries are expected to have reached stationary population levels, the present-day developing countries will have a population of 8.8 billion out of an expected world population of 10.2 billion.

Many developing countries have in recent years been unable to expand their food production fast enough to keep up with increasing demand, stemming from rising incomes as well as population growth. There is considerable concern at their diminishing self-sufficiency and food security, and the consequent increase in their import requirements.

Though the major obstacles to increasing agricultural production in many developing countries is shortage of capital investment, modern inputs, skills and research capabilitiy, the limitation of the natural resource base, production potential of soil and climate, is also important. The strategy for agricultural development: which area to develop, how much investment to put, which crops to promote, what level of farming technology is appropriate, depend on the land and climate resources in each country.

Economists customarily assume that under competitive production arrangements the best land will be cultivated first. Yet within a country, the historical legacy of settlement patterns, the changing technology, such as development of a new high yielding variety for a particular crop, changing price structure, etc. can easily lead to a situation where a country may be putting in resources to develop a not so productive region when another region offers a much greater potential.

Thus a knowledge of the production potential of different areas of a country, suitability of its soil and climate for different crops and potential output that can be obtained under different levels of input intensification is valuable for guiding current policies.

There is an urgent need for each country to look at its long-term food and agricultural requirements and assess them against the possibilities of sustainable production from its own land resources. Any shortfalls in this will have to be made up by imports which in turn will have to be financed by appropriate exports.

The extent to which land resources of terrain, soil, climate and water, can be utilized to produce food and agricultural products is limited. The ecological limits of production are set by soil and climatic conditions as well as by the specific inputs and management applied. Any "mining" of land resources beyond these ecological limits will, in the long run, only result in degradation and ever-decreasing productivity of land and of inputs, unless due attention is paid to the conservation and enhancement of the natural resource base.

This paper summarizes the methodology and results of the "Land Resource for Populations of the Future Project" carried out by the Food and Agricultural Organization of the United Nations (FAO) in collaboration with the Food and Agricultural Program of the International Institute for Applied Systems Analysis (IIASA) with support from the United Nations Fund for Population Activities (UNFPA).

This FAO/IIASA/UNFPA study represents the most comprehensive effort so far attempted to develop a methodology and quantify the potential food production and population supporting potentials in the developing countries. The study covers 117 developing countries in Africa, Central and South America, and Southeast and Southwest Asia. East Asia is not included in the study, mainly because of insufficient availability of climatic data for China.

The methodology of the study essentially involved assessing the potential rainfed food production by comparing the soil and climatic characteristics of the land resources in each country with the growth requirements of 17 major food crops and livestock (from grassland). The estimates are based on agroeconomic principles and a hierarchic scheme of refinement which integrates soil, climate and genetic data to arrive at yield input relationship for a given crop in a given soil under a given climate.

The soil data was obtained from the FAO/UNESCO World Soil Map and the climate data derived from FAO Climate Data Bank consisting of monthly records from some 3500 weather stations of rainfall, maximum and minimum temperatures, vapour pressure, wind speed and sunshine duration.

The computerized land resources inventory comprised of a mosaic of land units with particular combinations of soil and climate conditions by location in each country. For example, Africa was divided into altogether 18,713 distinct land units.

Potential productivity was assessed at three different levels of technology and input use. The low level uses traditional crop varieties, crop mixes and fallow periods; no fertilizers or other agricultural chemnicals; manual labour with hand tools; and no explicit long-term soil conservation measures. The intermediate level introduces limited use of improved varieties and agricultural chemicals; reduced fallow; animal traction as well as manual labour; some simple conservation measures; and optimum crop mixes on half of the land. At the high level there is a move to high-yielding varieties; the optimum use of chemicals; minimum fallow; full mechanization and conservation measures; and optimum crop mixes on all of the land.

In determining the potential area of rainfed cultivatable land and grassland, deductions were made for non-agricultural (habitat, industry, mining, etc.) land use, as well as areas under present and projected (year 2000) irrigation. Losses of land and of productivity as a result of soil degradation were also taken into account. Allowance was made for seed requirements, and for waste.

The potential rainfed production of dietary energy and protein was then computed for each land unit at each input level and this, together with production from irrigated areas, was compared with minimum dietary energy requirements (expressed as national averages per caput), first for the actual population in 1975 and second for that projected for 2000 under the United Nations medium variant. On this basis "critical" areas and countries were identified that appear to have insufficient land to produce, at one or more of the different input levels, the minimum nutritional requirements of their inhabitants.

The methodology used in the study and resource data base generated provides quantified information for analytical applications. For example:

- What is the extent and quality of arable land resources in different parts of a country?
- Where (within a country) are these land resources located and how do they relate to the present population distribution?
- What crops are ecologically viable (cf. presently grown crops) and what are the potentials for production under alternative levels of farming technology?
- What will be the effects of unchecked land degradation, especially soil erosion, on future productivity of land resources and what measures are

necessary to prevent such degradation?

- What are likely to be the future (year 2000) food and agricultural requirements and how can these be met from the available land resource base, i.e. land extensive and/or input intensive agricultural development strategies.

From the assessment of agro-ecological production potential of different countries of the world, some questions of trans-national concern are also explored:

- Which set of neighbouring countries may constitute a natural cooperative unit for food trade and food security?
- What levels of international assistance will be needed to promote a certain level of global agricultural development?

In interpreting the results and policy implications of the study, certain assumptions and limitations should be borne in mind. For example:

- The study assumed that all potential arable land is used for seventeen major food crops. In reality land is also required for the production of other food crops (e.g. vegetables, beverage crops, etc.), non-food crops (cotton, tobacco, etc.) and forest areas. To allow for these requirements, the results of the study would have to be reduced by at least* one third.
- The quantified results for the three levels of farming technology, namely low, intermediate and high, provide a scale along which each country's presently practiced level of farming technology and future requirements need to be assessed.
- Livestock production from grassland only has been considered. In most developing countries integrated crop and livestock production systems are practiced. The livestock supporting potential of crop residues and crop-

*The factor of one third reduction is estimated on the basis of crop acreage data reported by the FAO AT2000 study for the year 1975.

byproducts should also be considered.

- In quantifying the population supporting potential, country level minimum per capita calorie requirements have been assumed. In reality, actual demand will be higher due to, for example, inequitable distribution. This consideration will reduce the population supporting potential in various countries.
- The study does not consider the potential fish production and its contribution to population supporting potential.
- The ultimate potential of irrigated production in each country has not been considered. The actual (year 1975) and the planned (year 2000) irrigated areas and production in each country have been taken into account in estimating population supporting potentials. The results would need to be revised in light of massive expansion of irrigated production (e.g., as in the case of Saudi Arabia).
- The study assumed average mean climatic patterns. The effects of neither the short-term weather fluctuations (e.g. rainfall) or the long-term changes in climate have not been considered. These aspects can be incorporated if the data and methodology for predicting climate change at the level of analysis considered in this study were available.

The study's major contribution is the development of a methodology and land resource data base for the ecological and technological assessment of food production potentials and population supporting capacities. This information is suitable for the design and analysis of crop and region-specific agricultural development policies. In particular the approach allows an explicit consideration of ecological and technological aspects which together with economic, social and demographic issues provide the basis for viable medium and long-term planning of sustainable agricultural development.

The most fruitful avenue for further work and application of the methodology developed in this study is in relation to detailed country food and agricultural planning studies based on further refinements and improvements of the methodology and resources data base,* and taking into account other food and non-food crops, the overall national economy as well as the linkages to the international economy. A first such case study of Kenya is presently being carried out by FAO and IIASA in collaboration with the Government of Kenya.

The coming two decades and beyond will see an ever increasing number of mouths to be fed in the developing world and only with integrated ecological and socio-economic studies will it be possible to adequately plan and provide for the well-being of future populations in the developing world on a sound environmental basis.

*Shah, M.M., Higgins, G., Kassam, A.H. and Fischer, G. (1985b). Land Resources and Productivity Potential - Agro-Ecological Methodology for Agricultural Development Planning (Detailed Country Studies), forthcoming.

1. INTRODUCTION

Though the major obstacles to increasing agricultural production in many developing countries is shortage of capital investment, modern inputs, skills and research capabilitiy, the limitation of the natural resource base, production potential of soil and climate, is also important. The strategy for agricultural development: which area to develop, how much investment to put, which crops to promote, what level of farming technology is appropriate etc., depends on the land and climate resources in each country.

Economists customarily assume that under competitive production arrangements the best land will be cultivated first. Yet within a country, the historical legacy of settlement patterns, the changing technology, such as development of a new high yielding variety for a particular crop, changing price structure, etc. can easily lead to a situation where a country may be putting in resources to develop a not so productive region when another region offers a much greater potential.

Thus a knowledge of the production potential of different areas of a country, suitability of its soil and climate for different crops and potential output that can be obtained under different levels of input intensification is valuable for guiding current policies.

This paper reports on a study carried out to assess potential productivity of soils and climates for most of the developing countries of the world. The potentials are estimated for 17 major food crops and grassland/livestock for each land unit of 100 km^2. The estimates are based on agroeconomic principles and a hierarchic scheme of refinement which integrates soil, climate and genetic data to arrive at yield input relationship for a given crop in a given soil under a given climate.

Many estimates of the production potential of the globe are available. Most of them indicate a vast food production potential of the globe. The question then is, why do this again? The answer lies in the motivation with which our study is done. Many of the past studies were carried out by individuals to explore the question of earth's carrying capacity from a global point of view. The very large production potentials found there reassured the researchers that resource limitations are not critical in food production and drew attention to the major constraints of economic resources in increasing food production. One of the past studies (MOIRA) estimated country-wise the production potential for one aggregated commodity, namly consumable protein. These estimates were then used as asymptotes in economically estimating production functions from historical data.

Our study on the other hand is directed to improving national agricultural policies to facilitate agricultural development in the LDC's. The details of land and crops considered are necessary for such a purpose. What are the kind of policy questions that can be answered better by a knowledge of the regional, crop-specific production potential of the country? For example:

- Can the country be ever self-sufficient in food production? What are the economic costs of various levels of self-sufficiency?
- In which crops has the country got comparative advantage? Which crops should it specialize in?
- Which areas of the country offer maximal return to investments for agricultural development? What incentives for resettlement of populations may be given?
- If the country wants to impose land ceilings for realizing objectives of equity, what are equitable sizes of land holdings in different parts of the country?

- What type of technological development (a high yielding variety of rice or a drought resistant variety of sorghum?) would be most valuable for a country, given its resource base?

From the assessment of agro-ecological production potential of different countries of the world, some questions of trans-national concern can also be explored:

- Which set of neighbouring countries may cnstitute a natural cooperative unit for food trade and food security?
- What levels of international assistance will be needed to promote a certain level of global agricultural development?

The Agro-ecological Zone (AEZ) potential estimates at the detail that we have made, have some analytical applications. One expects that the more area in a country is devoted to a particular crop the less suitable is its land and climate for that crop. Econometric estimates of such diminishing returns are difficult to make. The AEZ estimates can be used to obtain estimates of diminishing return to areas for different crops (as well as to inputs). In fact, the estimates can be used to identify a complete production possibility surface, albeit implicitly in the form of a linear program, which is not confined to just past data but embodies future potential as well. This can be of considerable importance for planning agricultural development in many LDC's.

Though we do not explore all these questions in this paper, we have hinted at them to show the potential usefulness of the results that we do want to present. In particular, here we ask the following questions:

- What is the extent and quality of arable land resources in different parts of a country?

- Where (within a country) are these land resources located and how do they relate to the present population distribution?
- What crops are ecologically viable (cf. presently grown crops) and what are the potentials for production under alternative levels of farming technology?
- What will be the effects of unchecked land degradation, especially soil erosion, on future productivity of land resources and what measures are necessary to prevent such degradation?
- What are likely to be the future (year 2000) food and agricultural requirements and how can these be met from the available land resource base, i.e. land extensive and/or input intensive agricultural development strategies.

Even when one accepts the usefulness of AEZ base estimates of the production potential, one may still ask the question: can such estimates be made? Can these be reliable?

Our belief is that the answer to both these questions is "yes". The methodology used relies on well-understood physical processes and some of these are in the nature of conservation principles. For example, no matter how well the soil is, how much input is applied, the limits of photosynthetic efficiency and the available sunlight would determine the maximum amount of CO_2 that can be assimilated and plant matter formed. These upper bounds on production would be reduced when soil is poor or when adequate water or nutrients are not available.

The methodology is in the nature of estimating engineering production functions. Its reliability seems acceptable to us on the basis of available evidence. But what is worth noting is the difficulty of estimating agricultural production functions or yield response functions using conventional econometric techniques. Not only data for various crop specific inputs are not available but there is usually a serious problem of multicollinearity. Spread of high yielding varieties, progress of irrigation and fertilizer intensification all take place together, and their separate impacts are difficult to identify from time series data. Moreover, cross-section data get confounded by differences in soil, climate and other agricultural practices. Thus a methodology that integrates these differences and is based on more universal principles of physics, soil science and agronomy can be very useful.

A quantitative understanding of the *ecological, socio-demographic* and *economic* nature and dimension of the world food and agriculture system is a prerequisite to designing and implementing an appropriate mix of policies for rational and sustainable development. These issues are particularly relevant in the developing countries where the food and agriculture sector is normally the most important single sector of the economy and where the majority of the population depends for its livelihood on this sector. In many of these countries the inability of food production to keep pace with population growth and food demand has led to diminishing self-sufficiency and food security as well as to increases in food imports.

The population of the developing countries was 1.7 billion in 1950. Today it is 3.6 billion and by the year 2000 it is expected to be 4.9 billion. Looking even further ahead, by the year 2100, when most countries are expected to have reached stationary population levels, the present-day developing countries will have a population of 8.8 billion out of a world population of 10.2 billion (UN, 1980). In the 1970s the deteriorating world food situation -- basically in the developing countries -- was with us. This situation still persists in some parts of the world and will reach a major crisis with wide-spread human suffering unless the fundamental resource, namely land for food and agricultural production, is preserved in the long term and utilized rationally in terms of environmental and economic considerations. The alternative, if one can call it an alternative, will be that nature will eventually intervene and force a balance between levels of populations and what may have remained (following misuse by man) of the land resource base. There is a pressing need for each country to take stock of the extent and present state of its natural resources and assess these in the context of long-term sustainable and viable development.

The importance of food production and agricultural development in the developing world is well reflected by the increasing number of socio-economic studies devoted to this subject. The issue of whether the land resources in the countries concerned are (and will be) able to produce enough, has been largely ignored or at best glossed over in many of these studies. The results of FAO/IIASA/UNFPA study, presented in this report, is concerned with the development of a methodology and a resource data base to quantify the above mentioned type of information for most* countries in the developing world. Prior to describing the methodology and the results, we first present a review of past studies on assessment of arable land resources, food production and population supporting potentials.

1.1. Previous Studies on Assessment of Arable Land Resources, Food Production and Population Supporting Potentials

Though there have been a number of previous attempts to assess the population potential of the world, only a few studies have considered agro-climatic conditions of the land resource base prior to assessing the food production potential and in turn the population supporting potential. Among the earliest studies are those of Ravenstein (1891), Penck (1925), Pearson (1945), Osborn (1948) and Brown (1957).

*Among the developing countries, China, Democratic Republic of Korea, Republic of Korea and some small island states in the developing world are not included in the study.

Ravenstein (1891) assumed certain maximum population densities (persons per hectare) for woodland, grassland and desert lands and stated that on this basis, the world could support 6 billion people. Penck (1925) followed a similar procedure, except that he considered 11 climatic zones, and arrived at a world carrying capacity of 7.7 to 9.5 billion with an absolute upper maximum of 16 billion. Pearson (1945) was probably the first study to estimate the arable land resources of different regions of the world from a consideration of rainfall, temperature, topographic and soil attributes. These attributes were first considered individually to estimate the availablity of arable land and then combined to derive the potential arable land in six regions of the world (Table 1). At the world level, the potential arable land was estimated to be 1.04 billion hectares in comparison to the then existing area under food crops of 0.62 billion hectares. Interestingly, the author suggested that intensification (more fertilizers, labour, etc.) on present acreage was the main option to increase food production since "there is little immediate or even long-term prospect of materially expanding world food production by bringing in new acreage". The study considered the existing levels of food production in each region and, assuming intakes according to North-American, European, and Asiatic standards, concluded that the world could support 0.9, 2.1 and 2.8 billion people respectively (Table 1).

Osborn (1948) estimated that there was a maximum of 1.62 billion hectares of arable land in the world since "a very large proportion of the originally habitable areas have already been so misused by man that they have lost their productive capacity." The world population in the 1940s was estimated to be 1.6 billion and hence about a hectare of land was available per person at the world level. However, as the population in the world was unevenly distributed in relation to the arable land resources, there was already a critical shortage of cul-

Table 1. Results of Past Studies: Estimates of Arable Land, Yields and Population Potential

	Pearson-Harper[1] (1945)	U.S.[2] (1967)	Clark[3] (1967)A	Clark[3] (1967)B	Revelle[4] (1976)	Buringh[5] (1975)	Buringh[6] (1977b)	Buringh[7] (1977b)
Potential Arable Land								
(Mill. Ha)								
Europe	360	530	1512	1512	600	399	367	(211)*
Australia/New Zealand	24	153	268	358	125	199	99	(32)
North America	231	465	1006	1012	695	627	526	(239)
South America	69	681	1835	2939	715	596	383	(77)
Africa	97	734	1555	2853	995	711	477	(158)
Asia	243	627	1505	2266	1100	887	610	(689)
World	1044	3190	7681	10740	4230	3419	2462	(1406)
Potential Yield								
Europe						10.5	2.1	5.2
Australia/New Zealand					3MT/Ha	11.8	1.8	5.9
North America					grain-	11.3	2.3	5.6
South America					equi-	18.6	1.9	9.3
Africa					valent	15.3	1.5	7.6
Asia						16.1	2.1	8.0
World						14.5	2.0	7.2
Potential Population								
(Million)								
Europe	765/575/244						853	728
Australia/New Zealand	29/21/9						190	235
North America	577/434/184						1303	890
South America	146/110/46						803	474
Africa	160/121/51						787	795
Asia	1154/866/368						1420	3661
World	2831/2127/902	40000	47000 to 147000		41000	-	5356	6673

* cultivatable land in 1976

[1]Potential yields not used in assessing the population supporting potential of each region. The existing world grain production translated into population supporting potential by assuming Asiatic/European/North-American consumption levels. The figures shown under potential population correspond to these assumptions.

[2]The total world arable land area from this study was subsequently used by Muckenhausen (1973) to estimate population supporting potential at almost 40 billion people.

[3]Potential arable land estimated in terms of standard land, i.e. farm land in humid temperate areas producing one crop per year. Land required (for food and forestry) estimated to be 2250 m^2 per person if American type diet and 880 m^2 if subsistence diet comprising of predominantly cereals. The first assumption implies a world population supporting potential of 47 billion and the second implies a population of 147 billion; in these calculations Clark assumed 10.7 billion hectare of arable land area rather than 7.7 billion hectare. The former is derived on the assumption that some of the land in the tropics is equivalent to five times the standard farm land and the latter assumes two times the standard farm land.

[4]Potential arable land given in terms of gross cropped area (including areas with irrigation). Underlying these estimates is the assumption that 1.5 billion hectare in the tropics (except Java) is arable but cannot be cultivated by currently available high-yielding technologies on a large scale. Revelle assumed that 10% of the arable area would be required for non-food crops, i.e. potential arable land area of 3.8 billion hectare for food crop production. With a yield of 3MT/Ha (grain equivalent) and accounting for 10% losses of production, Revelle concluded that 40 billion people can be supported with an intake of 2500 kcal per capita per day.

[5]In this study the estimates of potential arable land including land that can be irrigated are derived for 222 broad soil regions of the world. The assumed yield levels for each region are the maximum photosynthesis of a grain-equivalent crop (wheat or rice). Data on maximum ultimate production potential for each region was quantified in this study; the implications of these results for population supporting potentials were considered in a subsequent study, Buringh (1977b).

[6]In this study (Buringh, 1977b), the results are derived on the basis of information available from the previous study (Buringh, 1975). The potential arable land is estimated assuming the labour-oriented agriculture is practiced, i.e. no mechanization, no chemicals, etc. the potential yield are in MT per hectare of grain production. The population supporting potential was estimated with the following assumption:

- production on 86% of arable land is considered; balance of land for non-food crops
- half the production is available for human consumption; the remainder being accounted for by 15% for seeds, 15% for feed and 20% for storage losses.

[7]The above study (6) also quantified the potential grain production and population supporting potential if modern agricultural technology is practiced on all presently cultivated land. The potential yield (in grain-equivalent) has been assumed to be half the maximum photosynthesis yield estimated in the Buringh (1975) study. Additional assumptions as in (6) above.

tivatable land in some parts of the world.

Brown (1957) suggested that the world could support 7 billion people on the assumption of a yield of 3 metric tons per hectare grain equivalent on a potential arable land area of 1.4 billion hectares.

Baade (1960) concluded that the 1950 cultivated area of the world could be increased by two to three times and, with a cereal yield of 4 to 5 metric tons, the world's arable land resources could support over 30 billion people.

Clark (1967) derived estimates of the potential arable land in seven areas of the world. On the assumption that the agricultural productivity of land depends "entirely on climate; no exclusion is made for poor soils, the description of which is largely a matter of opinion, and which in any case can be improved by fertilization, if we really need their output." The climate classification of Thornthwaite (1933) was used in this study and the potential arable land was estimated in terms of "standard land", i.e. farm land in humid temperate areas producing one crop per year. Tropical areas were assumed to be capable of producing two or alternately five sequential crops a year. The results of estimated potential arable land are given in Table 1. The calculation of population supporting potential, at the world level, of the total arable land took into account estimates of forest land requirement but excluded fish production. Clark (1967) concluded that the world could support between 47 billion and 147 billion people. The lower estimate assumes an American type diet and the upper estimate is on the basis of a predominantly cereal subsistence diet.

In 1967, a study on the world food problem was published by the U.S. President's Science Advisory Committee (U.S., 1967). Here the approach taken was to superimpose 17 agro-climatic zones on a world soil map (1:15 million scale soil map prepared by the U.S. Soil Conservation Service) and from an analysis of about 200 soil-climate combinations, estimates of potential arable, grazing and non-arable land were obtained for seven regions of the world (Table 1). The question of how much land can be irrigated was also considered. This study estimated that a total of 3.19 billion hectare of land was arable in the world. These results were subsequently used by Meadows (1971) and Muckenhausen (1973). "The Limits to Growth Study" of the Club of Rome (Meadows, 1972) assumed that 0.4 hectares per person are needed to supply the human agricultural requirements. Here the world was considered as one unit and the main conclusion of the study was that by the year 2000, there would be a desparate shortage of cultivatable land in some parts of the world since the water availability limits would be reached well before the land limits. Muckenhausen (1973), on the other hand, concluded (on the basis of the production of the major soil groups as given in U.S. (1967)), that the world could feed more than 10 times the existing population, i.e. between 35 and 40 billion people.

FAO (1970), on the basis of a land resources map derived from the FAO/UNESCO soil map of the world (FAO, 1971-81) and a climate classification (adequacy for separating crop ecological regions) quantified the potential arable land in four developing regions, namely,

Latin America: 570 million hectare

Africa South of the Sahara: 304 million hectares

Northeast and Northwest Africa: 19 million hectares

Asia and the Far East: 252 million hectares

It should be noted that in this study altogether sixty-four developing countries were included and in fact detailed estimates of the potential arable land were made for thirty-eight countries; for the remaining twenty-six countries "best feasible estimates" were made from informed judgement.

Revelle (1976), on the basis of climate data (temperature, annual precipitation/evapotranspiration) and the above mentioned world soil map, estimated the potential arable land in seven areas of the world (Table 1). At the world level, the potential arable land without irrigation was estimated at 4.6 billion hectares and with irrigation at 5.7 billion hectares. Of this total, 1.5 billion hectares were estimated to be in the humid tropics and Revelle states that except for Java (Indonesia), this area could not be put under high yielding agriculture on a large scale since technology for this humid environment was not currently available. Hence land that could be cultivated with high-yielding technology amounted to 4.2 billion hectares in the world. Assuming that 10% of this land area would be required for fibres, beverages and other non-food crops, the remaining 3.8 billion hectares, with an assumed average grain yield of 3 metric tons per hectare (this yield being equal to half the realized yield in the U.S. Midwest), could support more than 40 billion people. Here the assumption was that 10% of total production (grain-equivalent) is wasted through losses and that average human consumption is 2500 kcal per capita per day. In addition to the potential arable land for crop production, Revelle also estimated that there was about 3.6 billion hectares of grazing land capable of producing 25 to 50 million MT of live weight animal products in the world.

Following the publication of the 1:5 million scale FAO/UNESCO soil map of the world, the MOIRA (Model of International Relations in Agriculture) study, Linnemann et al. (1979), made a first detailed assessment of the potential arable land and the absolute maximum photosynthetic food production potential of six regions of the world. This was done in terms of consumable protein. The MOIRA approach was further taken by Buringh (1975) to group the soil information from the FAO/UNESCO world soil map into 222 broad soil regions. The details of soils, vegetation, topography and climates (temperature, precipitation, sunshine, relative humidity and wind) in each of these soil regions, together with possibilities of irrigation, were used to derive estimates of the potential arable land, average soil productivity, average water availability, land area that could be irrigated and maximum yield per hectare as well as maximum production potential of a standard cereal (wheat or rice) crop. The maximum photosynthesis yield level was derived by assuming that there were no pest and disease constraints, no land degradation and that enough fertilizers and adequate crop varieties would be available. In computing the estimates of maximum production potential, reduction factors to account for deficiencies in climate, soil conditions and/or water availability were introduced. The results of this study are available for 222 regions (not corresponding to any political-country boundaries) of the world. The aggregated results by six main areas of the world are shown in Table 1.

Buringh (1977a) felt that estimating the maximum food production potential of the world, as above, was "somewhat crazy, because such production cannot be realized" and in consequence (Buringh and Van Heemst, 1977b) presented an estimate of the world food production based on labour-oriented agriculture, i.e. no mechanization and no chemicals but with the use of crop varieties and practices of crop rotation appropriate for local climate and soil conditions. This study essentially used the Buringh (1975) results, except that maximum yields were assumed to be reduced by half. In this second study, estimates of maximum potential food production, i.e. all potential arable land under labour-oriented agriculture, was translated into population supporting potential by assuming a human consumption level of 2000 kcal per capita per day. In deriving these estimates, the study assumed that only 50% of grain production is consumed since 15% is required for seed, 15% for feed and 20% is accounted for by storage losses. Additionally the study also estimates the population supporting potential, of the presently used land areas in each of six regions of the world, by assuming modern agricultural methods; these yields are assumed to be half the maximum photosynthesis yields as assumed in the Buringh (1975) study. A summary of the results of this study are given in Table 1.

Ceres (1978) on the basis of potential arable land reported in IBRD (1978) and Pawley (1971), quantified the world potential arable land to be 2.5 million hectares with the following regional distribution:

Developed countries: (North America, Europe, Oceania, South Africa)	854 million hectares
Africa:	466 million hectares
Latin America:	588 million hectares
Near East:	112 million hectares
Asian Centrally Planned:	204 million hectares
Far East:	272 million hectares

In quantifying the future potential for expanding cultivated acreage, most of the studies described above have not considered some key aspects. For example:

- what type of crops might be grown on the new land
- what level of inputs might be required
- what level of soil degradation may be incurred.

The FAO (1978-81) and FAO/IIASA/UNFPA (1983) studies explicitly consider such aspects.

1.2. FAO/IIASA/UNFPA Study

The study, entitled "Land Resources for the Populations of the Future", has been carried out by the Food and Agriculture Organization (FAO) of the United Nations in collaboration with the Food and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA) with the financial support of the United Nations Fund for Population Activity (UNFPA). The primary aim of this FAO/IIASA/UNFPA study was to:

(a) develop a methodology to assess the food production potential of the land resources in developing countries, incorporating the crop and technology-specific land suitability assessment model developed by the FAO Agro-ecological Zones Project (FAO, 1979-81); and

(b) by applying the methodology developed in (a) to the land resources data base, determine how many people could be fed and supported by the production potential of domestic land resources in individual length of growing period zone and major climate in each country.

The study provides a detailed assessment of the food production and population supporting potential of one hundred and seventeen countries in five regions of the developing world, namely, Africa, Southwest Asia, Southeast Asia, Central America and South America.

The FAO/IIASA/UNFPA study described in the rest of this report differs from the past studies (section 1.1 above) in a number of ways:

- Countries are individually considered and arable land resources within a country are disaggregated by unique soil-climate combinations (land units of 10,000 hectares referred to as agro-ecological cells).
- Production potential of fifteen of the most widely grown food crops (and also livestock from grassland) in the world are assessed individually and also in various combinations.
- Sustainability of production is explicitly considered in relation to fallow periods as well as in relation to various soil erosion/productivity losses as related to the degree of soil conservation measures assumed.
- The assessment of food production potential is carried out at three alternative levels of farming technology, namely:

Low Level: equivalent to presently practiced subsistence agriculture in several areas of the world

High Level: equivalent to presently available high-yield farming technology

Intermediate Level: a combination of the above low and high levels.

- The results of the estimates of the food production potential are translated into population supporting potential for each country and compared to the people actually living (derived from national population census data) in various parts of each country (in the year 1975); additionally results are also expressed in terms of the 2000 projected population (UN, 1979) in each country.
- The assessment takes into account non-agricultural land requirements and production from present and planned irrigation development.

The results of the study quantify the food production potential of all arable rainfed land resources together with the prersent (year 1975) and planned (year 2000) irrigated production. We do not say that the production potential will be realized by the year 2000 or that it may even be possible to realize the production potential by the year 2000. Moreover, striving for complete food self-sufficiency may be improbable economically and also undesirable ecologically. For each country, the methodology and the resource data base provides a first assessment of crop-specific production potentials which, together with country-specific methodological and data refinements, could form a techno-ecological basis for long-term policy formulation for the food, population and agricultural resource development issues in developing countries.

2. METHODOLOGY AND RESOURCES DATA BASE

The inter-disciplinary* methodology (Fig. 1) developed by the study to assess the potential population supporting capacities of land includes the following principles:

i. land suitability is only meaningful in relation to a specific use, e.g. land suited to the cultivation of cassava is not necessarily suited to the cultivation of white potato (land unit characteristics and crop production models);

ii. suitability refers to use on a sustained basis, i.e. the envisaged use of land must take account of degradation, e.g. through wind erosion, water erosion, salinization or other degradation processes (by means of fallow land and soil conservation;

iii. evaluation of production potential is made with respect to specified levels of inputs, e.g. whether fertilizers are applied, if pest control is effected, if machinery or hand tools are used (farming technology);

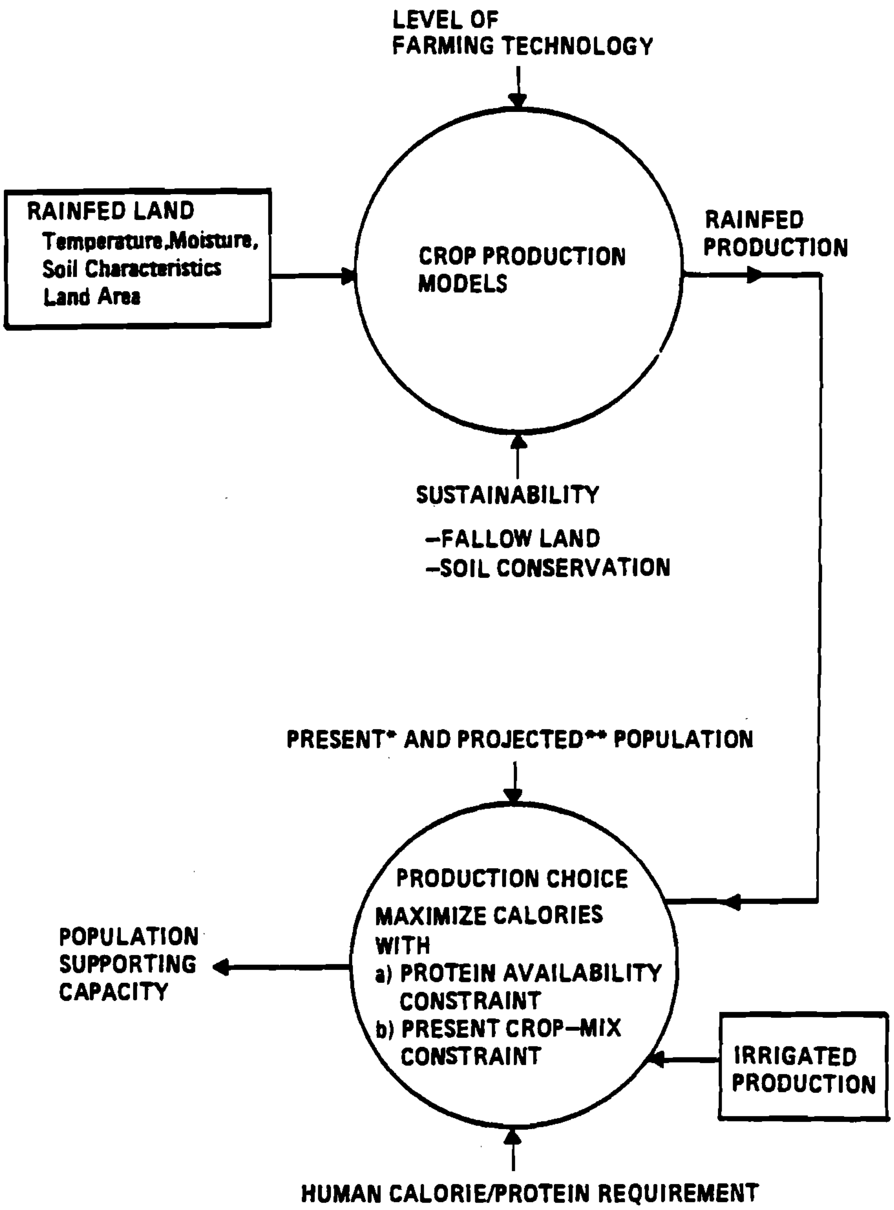
iv. different kinds of land use, e.g. production of wheat or phaselous bean or white potato, are compared at least on a simple food-value basis, i.e. productivity for each use is assessed by comparing the caloric and protein value of the alternative crops (crop choice);

v. population supporting capacity is assessed by a comparison of present and projected population with the population that can be supported by the potential food production.

The first four principles are described in a "Framework for Land Evaluation" (FAO, 1976a) and form an important part of the overall methodology.

*Crop-ecology, agronomy, climate, nutrition, economics and systems analysis

Fig. 1 OVERVIEW OF METHODOLOGY
– ASSESSMENT OF FOOD PRODUCTION AND POPULATION SUPPORTING POTENTIALS



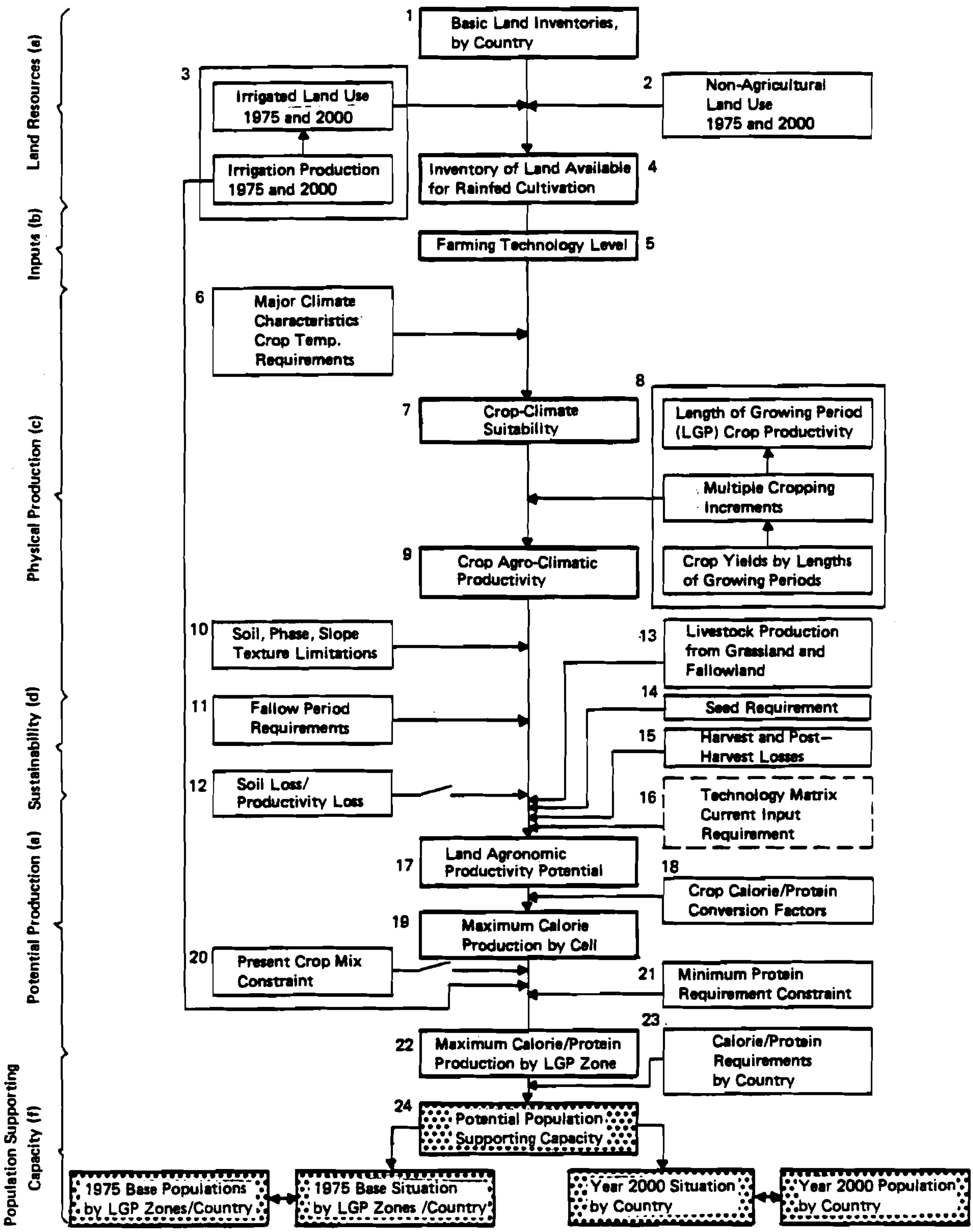
*YEAR 1975
**YEAR 2000

Limits to food and agriculture production are set by soil and climate conditions and by the use, and management, of the land. In the long run, any "mining" of land beyond these techno-ecological limits will result in degradation and decreased productivity. Accordingly, within an overall upper ecological limit, there are technology-specific finite levels of sustainable food and agriculture production obtainable from any given land area and hence corresponding maximum levels of population that can be supported.

Fig.2 schematically illustrates the methodology developed to assess food production potential and population supporting capacities, the block numbers in the figure relating to step descriptions in the present section.

The starting point of the study was the creation of a computerized land and climate resource data base for each country. This consisted of an overlay of a specially compiled climatic inventory (providing spatial information on temperature and moisture conditions) onto the FAO/UNESCO Soil Map of the World (FAO, 1971-81) (providing spatial data on soil, texture, slope and phase). It should be noted that considerable time and effort were invested by the staff of the Land and Water Division of FAO in computerizing this land resources inventory for each country. The procedure involved the measurement of each soil mapping unit as it occurs in each length of growing period zone and major climate in each country. This measurement was achieved by a 2 mm (100 km^2) grid count (corrected for reported areas of countries' land masses) of the land inventory map, i.e. overlay of the climate map onto the soil map for each country. Information on the extents and composition of each mapping unit according to the listings given in the texts of the soil map were used to derive the individual extents of each soil type in each mapping unit, by slope, texture class and phase.

Fig.2 FAO/IIASA/UNFPA LAND RESOURCES FOR POPULATIONS OF THE FUTURE: METHODOLOGICAL FRAMEWORK



2.1. Climate Inventory

The choice of the parameters used in the climatic inventory was based on climatic adaptability attributes of the crops considered in the study. Crop adaptability is temperature dependent: prevailing temperature conditions determine which crops can be grown and which cannot. The climatic inventory was therefore designed to match compiled information on the climatic requirements of plants according to crop adaptability groups (Kassam, 1977a), Table 2a.

The climatic information was compiled from the FAO Climate Data Bank (FAO, 1976) consisting of monthly records from some 3500 weather stations of rainfall, maximum and minimum temperatures, vapour pressure, wind speed and sunshine duration. Fourteen temperature regimes referred to as *major climates* were delineated as shown in Table 2.

Providing that temperature requirements are met, the degree of success in the growth of a crop is largely dependent on how well its optimum length of growth cycle fits within the period when sufficient water is available for growth. Quantification of moisture conditions was based on a water balance model comparing precipitation (P) with potential evapotranspiration (PET) and allowing for a reference value of 100 mm of soil moisture storage (S).

The moisture availability period (i.e. the period where P+S is greater than 0.5 PET) with mean daily temperatures above 5°C was considered suitable for crop growth, and defined as the length of *growing period* (LGP). Two major types of length of growing period zones (LGP zones) were inventorized: a *normal* LGP zone with a humid (an excess of P over PET) period and an *intermediate* LGP zone without a humid period. These lengths of growing period zones were delineated by isolines of 0, 75, 90, 120, 150, 180, 210, 240, 270, 300, 330 and 365 days of growing period (Table 3).

Table 2. Characteristics of major climates

MAJOR CLIMATES	Major climates during growing period		24-hr mean (daily) temperature (^{o}C) regime during the growing period	Suitable crop group*
	No.	Descriptive name		
TROPICS All months with monthly mean temperatures, corrected to sea level, above 18^{o}C	01	Warm tropics	More than 20^{o}	II and III
	02	Moderately cool tropics	15^{o}-20^{o}	I and IV
	03	Cool tropics	5^{o}-15^{o}	I
	04	Cold tropics	Less than 5^{o}	None
SUB-TROPICS One or more months with monthly mean temperatures, corrected to sea level, below 18^{o}C but all months above 5^{o}C	05	Warm/moderately cool sub-tropics (summer rainfall)	More than 20^{o}	II and III
	06	Warm/moderately cool sub-tropics (summer rainfall)	15^{o}-20^{o}	I and IV
	07	Warm sub-tropics (summer rainfall)	More than 20^{o}	II and III
	08	Moderately cool sub-tropics (summer rainfall)	15^{o}-20^{o}	I and IV
	09	Cool sub-tropics (summer rainfall)	5^{o}-15^{o}	I
	10	Cold sub-tropics (summer rainfall)	Less than 5^{o}	None
	11	Cool sub-tropics (winter rainfall)	5^{o}-20^{o}	I
	12	Cold sub-tropics (winter rainfall)	Less than 5^{o}	None
TEMPERATE One or more months with monthly mean temperatures, corrected to sea level, below 5^{o}C	13	Cool temperate	5^{o}-20^{o}	I
	14	Cold temperate	Less than 5^{o}	None

* Crop Adaptability Group I with photosynthesis pathway C_3: Spring wheat, winter wheat, highland phaselous bean, white potato, winter barley.
Crop Adaptability Group II with photosynthesis pathway C_3: Paddy rice, lowland phaselous bean, soyabean, sweet potato, cassava, upland rice, groundnut, banana/plantain, oil palm.
Crop Adaptability Group III with photosynthesis pathway C_4: Pearl millet, lowland sorghum, lowland maize, sugar cane.
Crop Adaptability Group IV with photosynthesis pathway C_4: Highland sorghum, highland maize.

Table 3. Classification of length of growing period (LGP) zones

	Number of days when water is available for plant growth
Normal LGP	1-74, 75-89, 90-119, 120-149, 150-179, 180-209, 210-239, 240-269, 270-299, 300-329, 330-364, 365^-, 365^+
Intermediate LGP	1-74, 75-89, 90-119, 120--149, 150-179, 180-209

Notes:
A normal LGP has a humid period, i.e. excess of precipitation over potential evapotranspiration.
An intermediate LGP has no humid period.
365^- year round humid growing period.
365^- year round growing period.
Isolines of 0 days dry and 0 days cold are also delineated.

2.2. Soil Map

The FAO/UNESCO Soil Map of the World (FAO, 1971-81), provides data on the distribution of 106 soil units of 26 major soils inventorized in over 5000 soil mapping units. The map also provides information on the texture (coarse, medium or fine) of the dominant soil in the mapping unit, the slope characteristic (level to gently undulating, rolling to hilly and steeply dissected to mountainous) and phases of land characteristics which are of significance in land use -- for example, stoniness, salinity or alkalinity.

2.3. Land Resources Inventory

Overlay of the climatic inventory on the soil map allowed delineation of land units each with a specific combination of soil and climatic conditions (Higgins and Kassam, 1980). These land units were registered in a computerized land inventory (Fig.2, Step 1) of extents of soil units, by slope, texture class and phase, as they occurred in each length of growing period zone, in each major climate and in each country. These unique land units, referred to as agro-ecological cells, provide the smallest (10,000 ha) unit of analysis in the study. The land inventory consisted of the following number of agro-ecological cells in each region of the study:

	Number of Agro-ecological Cells
Africa	18,713
Southwest Asia	3,770
Southeast Asia	10,709
Central America	4,937
South America	6,032
Total	44,161

It should be noted that within a particular length of growing period in a country, land units with identical soil attributes have been aggregated and hence the extents of some of the agro-ecological cells in the inventory may be larger than 10,000 Hectares.

The computerized land resources inventory includes all land available in each country. Land requirements for non-agricultural land use and irrigated land use need to be taken into account in deriving the balance of land available for rainfed agricultural production.

2.4. Non-Agricultural Land Use

Non-agricultural land uses (Fig.2, Step 2) include areas for habitation, transportation, industry, mining, conservancy, recreation, etc. These requirements depend largely on population pressures, land-use practices and environmental conditions. No comprehensive estimates of non-agricultural land requirements are available. In the study, allowance for non-agricultural land uses equivalent to a per capita requirement of 0.05 hectare per person was made on the basis of some compiled data (Zarqa, 1981; and Hyde, 1980).

2.5. Irrigated Land Use

Production from irrigated areas (Fig.2, Step 3) is a most important component of national agricultural production, particularly in arid and semi-arid areas. Accordingly both the land under current and projected irrigation and the production therefrom need to be taken into account in the assessment of potential population supporting capacities.

Data for year 1975 and year 2000 irrigated crop areas and production in each country are recorded in FAO (1981). The present (year 1975) and planned (year 2000) irrigated crop areas and production were allocated to particular land units in the country land inventory by a consideration of soil and climatic conditions (Wood, 1980). This irrigated production was translated in calorie and protein equivalent and incorporated in the assessment of population supporting potentials (in the relevant length of growing period zones).

2.6. Rainfed Production Potential

The above "deductions" for non-agricultural and irrigated land use in the total land inventory for each country resulted in the quantification of the land resources available for rainfed cultivation (Fig.2, Step 4).

The physical crop production potential (Fig.2, Steps 6-17) of any given land area depends on the soil and climatic conditions as well as the farming technology utilized (Fig.2, Step 5). Three alternative levels (Table 4) of farming technology are considered in the study as follows:

- *Low Level:* Traditional seeds, no fertilizer or chemicals, no soil conservation and continuation of presently grown mixture of crops on all potentially cultivatable rainfed land
- *High Level:* Improved seeds, recommended fertilizers and chemicals, full soil conservation measures and most productive cropping patterns on all potentially cultivatable rainfed land.
- *Intermediate Level:* A mix of the low and high levels.

The presently (year 1975) grown mixture of crops, reflecting local preferances, is expressed in terms of percentages of areas occupied by each of the

Table 4. Attributes of input levels

Attribute	Low Input Level	Intermediate Input Level	High Input Level
Production System	Rainfed cultivation of presently grown mixture of crops.	Rainfed cultivation with part change to optimum mixture of crops.	Rainfed cultivation of optimum mixture of crops.
Technology Employed	Local cultivars. No fertilizer or chemical pest, disease and weed control. Rest (fallow) periods. No long-term soil	Improved cultivars as available. Limited fertilizer application. Simple extension packages including some chemical pest, disease and weed control, Some simple long-term conservation	High yielding cultivars. Optimum fertilizer application. Chemical pest, disease and weed control. Minimum rest
conservation	measures. measure.	(fallow) periods.	Complete conservation measures.
Power Resource	Manual labour with hand tools	Manual labour with hand tools and/or animal traction with improved implements.	Complete mechanization including harvesting.

crops considered by the study. This information was obtained for each length of growing period zone, within countries, from sub-national administrative crop area data. Table 5 shows a summary of these results for warm tropical climate by length of growing periods and region. The distribution of food crops within length of growing period zones is, in general, consistent with ecological requirements of cultivation. Apparent anamolies, in certain growing periods (e.g. 0 days dry), is accounted for by irrigated production.

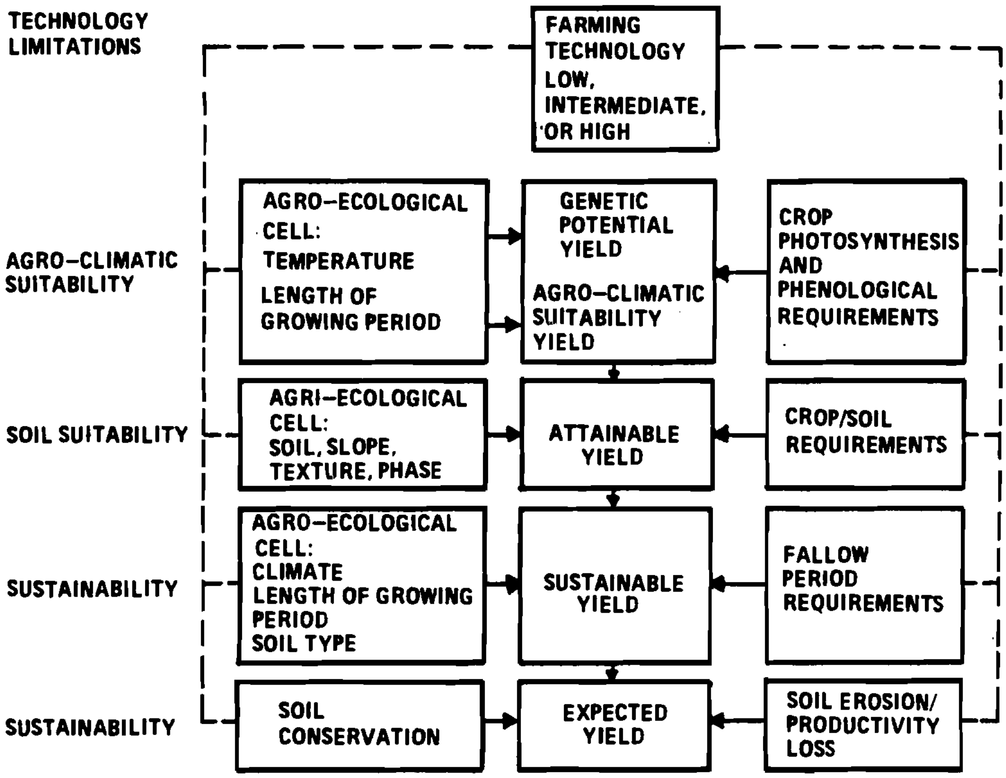
Land productivity for fifteen of the most widely grown food crops, namely, wheat, rice, maize, barley, sorghum, pearl millet, white potato, sweet potato, cassava, phaselous bean, soyabean, groundnut, sugar cane, banana/plantain and oil palm and also grassland (livestock production) was assessed for each of

Table 5. **Present Crop Distribution (Rainfed and Irrigated) by Major Climate and Length of Growing Period Zone.**

Length of growing period (days)	% Zone area occupied	Climate I: Warm Tropics				
		Africa	Southwest Asia	South America	Central America	Southeast Asia
365^{+} (N)[1] humid	>50					Rice
	25-50	Cassava		Maize		
	10-25	Maize/Banana/Rice/Groundnut		Groundnut/Banana		Oil Palm/Maize
	5-10	Beans/Oilpalm		Cassava/Rice		
270-365^{-} days (N) humid	>50					Rice
	25-50	Cassava		Maize	Maize	
	10-25	Maize/Rice		Rice/Sugarcane/Beans	Sugarcane	Maize
	5-10	Groundnut/Banana/Oilpalm		Soybean/Cassava	Rice/Beans/Banana	Cassava
180-269 days (N) subhumid	>50					Rice
	25-50	Maize		Maize/Rice	Maize/Sugarcane	
	10-25	Millet/Groundnut/Cassava		Beans		
	5-10	Beans/Rice/Sorghum		Cassava/Sugarcane	Beans/Rice	Maize
75-179 days (N) arid/semi-arid/subhumid	>50					
	25-50	Millet		Maize	Maize/Sugarcane	Sorghum/Rice
	10-25	Banana/Beans/Maize		Beans/Cassava/Sorghum		Millet/Groundnut
	5-10			Rice/Banana	Beans/Sorghum	Wheat
1-74 days (N) arid	>50					Millet
	25-50	Sorgum/Millet		Maize	Wheat/Sorghum	
	10-25	Beans/Maize		Rice/Sugarcane	Soybean	Sorghum/Wheat
	5-10	Banana		Banana/Beans/Sorghum	Beans/Maize	Groundnut/Rice
0 days dry	>50	Sorghum	Sorghum			
	25-50		Millet	Rice/Sugarcane		Millet
	10-25	Millet	Maize	Maize		Wheat/Rice
	5-10	Maize/Banana		Wheat		Sorghum
1-74 days (I)[2] arid	>50					
	25-50	Maize	Sorghum/Millet	Maize/Beans/Cassava		
	10-25	Sorghum/Banana/Cassava		Sugarcane		
	5-10	Beans/Millet	Barley/Maize			
75-179 days (I) arid/semi-arid	>50		Sorghum			
	25-50	Maize	Millet	Maize/Beans		
	10-25	Millet/Sorghum/Cassava	Maize	Sugarcane/Cassava		
	5-10	Banana				
180-209 days (I) subhumid	>50					
	25-50			Maize/Cassava		
	10-25			Beans		
	5-10			Soybean		

the agro-ecological cells on the basis of crop production "models" (Figure 3). The three main components of a crop production model are: agro-climatic suitability, soil suitability and sustainability of production.

Fig.3 CROP PRODUCTION 'MODEL'



2.6.1. Agro-Climatic Suitability

For each crop that can be grown in a particular unit of land, there is a maximum agro-climatic yield potential dictated by climatic conditions. The photosynthetic and phenological requirements (Kassam 1977a-b, 1979a-b) were matched to the climatic attribute of each agro-ecological cell in quantifying the agro-climatic yield potential (Table 6) of each crop. It should be noted that agro-climatic yield constraints due to pests, diseases, weeds, workability and rainfall variability have been considered in arriving at these potentials, as have increases in yield from sequential cropping as well as intercropping.

Table 6. Examples of Rainfed Crop Yields under Various Climatic Conditions (Metric Tons per Hectare Dry Weight) – Low Level of Farming Technology

Major Climate and Length of Growing Period Zone (Days)	Crop			
	Pearl Millet	Wheat	Cassava	White Potato
Warm Tropics				
75-89	0.3(0.4)	NS	0.1(0.1)	NS
150-179	0.8(1.7)	NS	0.9(1.0)	NS
270-299	0.1(0.2)	NS	2.3(3.0)	NS
365⁻	0.1(0.2)	NS	1.9(2.5)	NS
Cool Tropics				
75-89	NS	0.1(0.1)	NS	0.3(0.4)
150-179	NS	1.1(1.5)	NS	1.8(3.1)
270-299	NS	0.2(0.3)	NS	0.5(1.2)
365⁻	NS	0.2(0.3)	NS	0.2(0.3)
Cool Sub-Tropics (Winter Rainfall)				
75-89	NS	0.1(0.1)	NS	NS
150-179	NS	0.9(1.0)	NS	NS
270-299	NS	0.8(0.9)	NS	NS

Figures in parenthesis refer to yield, including increments due to multiple cropping.
NS: Not suitable

2.6.2. Soil Suitability

Soil conditions (soil, slope, texture and phase) may constrain the agro-climatic yield potentials and determine attainable yield. Crop-specific soil limitation ratings (Table 7) -- for main soils – (Sys and Riquier, 1980), were formulated by matching the properties of all soil units to the soil requirements of crops and applying these to the soil conditions of agro-ecological cells in estimating the attainable yields for all crops that could be grown in the cell.

2.6.3. Sustainability of Production

The crop yield potential on the basis of agro-climatic and soil suitability assessment can be obtained on a sustainable basis only if any necessary fallow

Table 7. Limitation Soil Ratings for Maize by Level of Farming Technology.

Soil	Low Level	Intermediate Level	High Level
Lithosols	N2	N2	N2
Acric Ferralosols	N2	N1	S2/N1
Orthic Acrisols	S2	S2	S1/S2
Cambic Arenosols	N2	S2/N2	S2
Calvic Luvisols	S2	S1/S2	S1/S2
Calcaric Regosols	S2	S1/S2	S1/S2
Eutric Cambisols	S1	S1	S1
Eutric Gleysols	N2	N2	N1/N2

S1: very suitable
S2: marginally suitable
N1: not suitable but can be improved
N2: not suitable
e.g. "S2/N2" means 50% of area is of class S2 and 50% of area is of class N2

period requirements and soil conservation are taken into account.

Many soils cannot be continuously cultivated with annual food crops without undergoing some degradation. Such degradation is marked by a decrease in crop yields and a deterioration in soil structure, nutrient status and other physical, chemical and biological attributes. Accordingly, account must be taken of the fallow period requirement in estimating land productivity. On the basis of regional survey data, fallow period requirements for each of the farming technology levels have been estimated by major climate, length of growing period zone and major soils (Young and Wright, 1980). The application of these fallow period requirements (Table 8) according to the climatic and soil attributes of the agro-ecological cell enables modification of the attainable crop yield.

In addition to the effect of crop fallow period requirements on sustainability of production, the climatic and soil conditions also greatly influence the rate of soil loss by erosion. Such soil loss results in decreased productivity and

Table 8. Fallow Period Requirements (Cultivation Factors)* for Some Major Soils in the Tropics According to Level of Farming Technology.

Soil	Low Level		Intermediate Level		High Level	
	Humid** Tropics	Semi-Arid† Tropics	Humid Tropics	Semi-Arid Tropics	Humid Tropics	Semi-Arid Tropics
Arenosols	10	20	30	45	50	50
Ferralsols	15	20	35	40	70	75
Acrisols	15	20	40	60	65	75
Luvisols	25	35	50	55	70	75
Cambisols	35	40	65	60	85	80
Nitosols	40	75	55	70	90	90
Vertisols	40	45	70	75	90	90
Gleysols	60	80	80	90	90	90

* The cultivation factor is the number of years in wich it is possible to cultivate the land as a percentage of the total cultivation and non-cultivation cycle.

** Humid: more than 269 days of growing period

† Semi-arid: less than 120 days of growing period

these reductions (in productivity) must be taken into account in reliable assessments of sustainable production potentials at various levels of farming technology. In the present study, the effects of water and wind erosion on soil loss are explicitly considered. This has been achieved by developing and applying a methodology for estimating rates of soil and productivity loss under the specific climatic, soil, crop and level of farming technology (FAO/UNEP/UNESCO, 1979).

The methodology used for estimating rates of soil loss is a parametric approach using climatic (rainfall and wind erosivity indices), soil, topograhic, texture and vegetation/land use factors. Prior to the present study, regional assessments of soil loss were not possible because of the lack of a suitable climatic, soil, slope, texture and land use quantification on which to base the assessment.

The calculated rates of soil loss were translated into decreases in potential productivity according to the relationships shown in Table 9.

Table 9: Relationships between soil loss and decreases in productivity

Rate of Soil Loss (metric tons per ha per annum)	Anticipated Long-Term Productivity Losses
less than 12	No change in land productivity
12 - 50	50 percent of the area of productive land downgrades by one class; the remainder remains unchanged
51 - 100	All productive land downgrades by one productivity class
101 - 200	50 percent of all productive land downgrades to not suitable (non-productive land); the remainder downgrades by one productivity class
above 200	All productive land downgrades to not suitable (non-productive land)

Note that in the present study, soil loss and the resultant productivity losses are directly related to the level of farming technology:

Low Level: No conservation measures (full rate of soil loss)

Intermediate Level: Some conservation measures (50% rate of soil loss)

High Level: Complete conservation measures (acceptable rate of soil loss).

2.6.4. Input Requirements

Crop-specific yield-input relationships for various land types from the Global Technology Matrix (GTM) of the AT2000 Study (FAO, 1981) have been used to quantify input requirements for seed - traditional and improved, fertilizer N-P-K, pesticides and power - human, animal and mechanical. The GTM for a particular crop, Table 10, gives the yield-input relation at four discrete yield levels; for yield in between these levels a linear interpolation procedure has been used to estimate the input requirements (Fig. 2, Step 14), (Fischer and Shah, 1984).

Table 10 . **GLOBAL TECHNOLOGY MATRIX FOR MAIZE**

		lgra				llra				prob			
		ulow	low	high	uhigh	ulow	low	high	uhigh	ulow	low	high	uhigh
Seed Traditional	kg/ha	22.00	22.06	2.20	0.0	15.00	15.23	1.50	0.0	27.50	27.39	2.75	0.0
Seed Improved	kg/ha	0.0	1.25	22.27	25.00	0.0	1.00	17.91	20.00	0.0	1.02	18.12	20.41
Power	Man Day Equivalent	55.10	85.56	98.94	122.53	49.24	72.02	73.49	80.42	60.23	91.65	106.22	138.95
Fertilizer Nitrogenous	kg/ha	0.0	2.09	44.24	183.30	0.0	0.31	6.92	31.80	0.0	1.99	42.26	179.98
Fertilizer Phosphatic	kg/ha	0.0	1.36	28.89	119.71	0.0	0.21	4.61	21.20	0.0	1.30	27.75	118.20
Fertilizer Potassium	kg/ha	0.0	0.15	3.23	13.36	0.0	0.0	0.0	0.0	0.0	0.15	3.15	13.43
Pesticides	$ 1975	0.0	3.17	6.25	17.02	0.0	1.21	1.54	2.69	0.0	0.29	6.22	28.58
Yield	MT/ha	0.40	1.70	2.30	4.50	0.30	0.70	1.00	1.50	0.30	1.10	1.50	3.70

SOURCE Global Technology Matrix for Maize, Agriculture Towards Year 2000, FAO, Rome, Italy, 1979.

NOTES

lgra: 120—270 days length of growing period· zone and very suitable/suitable soil
llra: 75—120 days, length of growing period and marginally suitable soil
prob: 75—120 days, length of growing period zone
ulow: Ultralow Technology
low: Low Technology
high: High Technology
uhigh: Ultrahigh Technology

2.6.5. Land Productivity Potential

The application of the crop production models to the characteristics of the agro-ecological cells results in an estimate of land agronomic potential production (Fig.2, step 15) of each crop that can be grown in a particular cell. Not all this production, however, is available for human consumption.

Certain quantities are required for seed and planting material for future cultivation. Complete crop specific allowance for seed and planting material requirements is included in the assessment (FAO, 1978-80). Additionally, harvest and post-harvest losses need to be taken into account. Complete crop specific estimates of these losses in each country are not available. In the present study, an overall 10 percent wastage has been assumed.

Deductions for the seed requirements (Fig.2, Step 16) and harvest/post-harvest losses (Fig.2, Step 17) results in the quantification of the crop-wise agronomic potential production available for human consumption.

2.7. Crop Choice

The application of the crop production models (Figure 3) to the characteristics of the agro-ecological cells in the land inventory results in an estimate of land agronomic potential production (Figure 2, Step 17) of each crop that can be grown in a particular cell. The comparative advantage of growing a particular crop depends on the criterion of crop choice. For example, criterion of crop choice in the context of:

A Food Strategy: Maximize calorie production in each agro-ecological cell, i.e. the crop yielding the highest calorie production in a particular cell would be chosen as the crop to be grown in that cell. Additionally constraints of minimum protein availbility, present crop-mix etc., may also be introduced.

An Income Strategy: Maximize net* revenue in each agro-ecological cell, i.e. the crop yielding the highest net revenue in a particular cell would be chosen as the crop to be grown in that cell. Additionally constraints of minimum protein availability, present crop-mix, inputs availability etc., may also be introduced.

Since the aim of the present study was to estimate the human population that could be supported from the soil and climate resources, the choice of which crop to grow in a particular cell was made on the basis of maximizing calories (Fig.2, Step 19).

An example showing the comparative advantage of production of rainfed wheat in Africa, Shah et al (1985a), on the basis of a food strategy and an income strategy is given in Annex 1.

*Net revenue is defined, Value of Production - Production Costs.

Corresponding to the three alternative levels of farming technology, the following constraints at the length of growing period zone level on the crop choice have been incorporated through linear programming models, Shah and Fischer (1980):

Low Level: Presently grown mixture of crops only (Fig.2, Step 20)

Intermediate Level: Combination of presently grown mixture of crops and crops producing maximum calories while maintaning the minimum protein requirement (Fig.2, Steps 20 and 21).

High Level: Crops producing maximum calories while maintaining the minimum protein requirement (Fig.2, Step 21).

The results of these alternative assessments are presented and discussed in the next section.

3. POPULATION SUPPORTING POTENTIALS

The rainfed crop and livestock (from grassland) and irrigated production in calorie and protein equivalent in each length of growng period zone together with country level recommended calorie and protein requirements (Fig.2, Step 23) for human consumption per capita were applied to determine the population (Fig.2, Step 24) that could be fed from this potential production (Fig.2, Step 22). These requirements were based on sex and age distribution of the population and on the scales recommended by a FAO/WHO Expert Committee (FAO, 1973). The results corresponding to the three levels of farming technology were assessed for two time periods, namely, present (year 1975) and future (year 2000). The year 1975 population in a particular length of growing period zone was compared to the population that may be supported by the potential food production from that zone. Similarly for the future, the assumed year 2000 population in a zone (i.e. year 2000 projected national population distributed according to the 1975 population distribution) was compared to the population that could be supported by the potential food production in that zone. The individual length of growing period zone results for the year 2000 are not "real" since population distribution will change through migration. The "deficiency" of not being able to project zonal migrations is in fact an advantage in the sense that from a policy maker's point of view the need is to know "where will the food surplus and food deficit areas be if food is not moved and/or people don't move?" This information could provide the basis for food and population distribution policies in relation to the productive capacity of the agricultural resources in different parts of a country. under the assumption of three alternative levels of farming technology. It should be noted that in essence the study maps out the land productivity potentials corresponding to each of the three farming technology levels and the year 2000 results provide a frame within which a country's present situation can be assessed and levels for farming technology required in the future identified.

4. RESULTS

As already mentioned the crop production potential, input requirements and soil erosion/productivity losses have been computed for each of the agro-ecological cells within length of growing period zones and major climates in each country. The results for the years 1975 and 2000 have been aggregated as follows:

- Regional results for Africa, Southwest Asia, Southeast Asia, Central America and South America (Table 11).
- Country results (Figs.4 and 5 and Tables 14 to 18).
- Individual-country length of growing period zones results presented in map form. Altogether fifteen maps corresponding to the three levels of farming technology and five developing regions are available. These maps illustrate those areas that could not support their 1975 populations as well as those areas that have surplus population supporting capacity. The ranges of the population supporting capacity are shown in color in the maps (FAO/IIASA/UNFPA, 1983).

In the following we will mainly focus on the regional and country results for the year 2000.

4.1. Regional Results

The overall results (Table 11) show that the five developing regions, using all cultivatable land resources for food production (with only grassland used for livestock feed), could supply the minimum food requirements of more than one and a half, four and nine times the year 2000 projected population at respectively the low, intermediate and high levels of farming technology.

These reassuring results illustrate that the land resources in the developing countries would be sufficient for third world self-sufficiency in food. In

Table 11. Year 2000 Population Supporting Potentials and Inputs Required by Region

	Africa	Southwest Asia	Southeast Asia	Central America	South America	Total
Number of Countries	51	16	16	21	13	117
Total Land (Mill.Ha)	2878	677	898	272	1770	6495
Non-Agriculture Land (Mill.Ha)	39	13	97	11	20	180
Projected Population (Mill.)*	780	265	1937	215	393	3590
Rainfed Potential Population (Mill.)						
Low	1003	20	666	105	1231	3028
Intermediate	4238	80	2560	370	5104	12352
High	12617	165	4536	1106	12191	30615
Irrigated Potential Population (Mill.)	251	160	1798	187	184	2580
INPUTS:						
Irrigated Crop Land (Mill.Ha)**	12	19	97	9	12	149
Rainfed Cropland (Mill.Ha)						
Low Level:						
VH	10	-	32	3	27	72
H	96	3	68	10	121	298
M	162	5	64	13	209	453
L	177	10	60	18	182	447
Intermediate Level:						
VH	41	2	38	6	57	144
H	147	6	98	14	179	444
M	180	9	77	14	223	503
L	243	6	54	16	250	569
High Level:						
VH	177	4	58	16	185	440
H	268	12	102	26	257	665
M	183	1	51	13	205	453
L	140	4	35	6	149	334
Range Land (Mill.Ha)						
Low Level	451	50	22	54	168	745
Intermediate Level	438	49	25	55	163	730
High Level	291	34	21	27	135	508
Rainfed Inputs:						
Fertilizers-NPK (Mill.MT)						
Low	2	<1	1	<1	2	5
Intermediate	64	2	26	6	71	169
High	126	4	47	11	156	344
Power (Billion MDE)***						
Low	58	1	31	6	62	158
Intermediate	106	1	50	11	125	293
High	213	2	68	18	261	562

* U.N.Medium Variant
** FAO AT2000 Study
MDE = Man Day Equivalent
VH: Very High Productivity Land, i.e.>80% of Maximum Yield that can be produced
H : High Productivity Land, i.e.40 to 80% of Maximum Yield that can be produced
M : Moderate Productivity Land, i.e.20 to 40% of Maximum Yield that can be produced
L : Low Productivity Land, i.e.<20% of Maximum Yield that can be produced

reality, there will certainly be trade with the developed countries, especially for crops which have an ecological comparative advantage; for example, wheat in the latter countries and tropical crops in the former countries.

It is interesting to analyze the results in terms of relative changes in acreage and production of various crops in each of these levels of farming technologies. A comparison of these results for the three levels of farming technology at the regional level, Annex Tables A1-A5, shows that for millet, sweet potato, white potato, groundnut and phaselous bean there is generally an increase in the relative acreage under these crops, whereas for sorghum, phaselous beans, spring wheat and winter wheat there is a decrease in the relative acreage under these crops. It should also be noted that with improvements in farming technology the production of all crops increases substantially except for sorghum in Africa and Southeast Asia, phaselous beans in all five regions, spring wheat in all regions except Africa, winter wheat in Central America and winter barley in Southeast Asia.

The results of the study, on the one hand, understate the potential because fish production, other water-based food production and livestock production from crop residues and crop-byproducts have not been considered. For example, livestock production would be considerably enhanced if crop residues and crop-byproducts are also utilized as feed, Fischer et al (1984), Table 12. These results show that in Africa, Southwest Asia and South America, feed comprising of grassland, crop residue and crop-byproducts, would be comfortably able to support future livestock production. In the case of Southeast Asia and Central America, livestock feed will have to include crops (e.g. grains, roots, etc.) also. On the other hand, the results of the study, overstate the potential because of land resources for the growing of non-food crops (e.g. cotton, tobacco, etc.), other food crops (e.g. vegetables, beverage crops, etc.) and forest areas* for

*Steep areas (more than 30 percent slope) that would need to remain under protection and conservation forestry have been considered in the study.

Table 12. Livestock Supporting Potential (Millions of reference LSU*)

		Farming Technology		
	1980**	Low Level	Intermediate Level	High Level
Rangeland (Grassland)				
Africa		89.9	193.4	287.3
Southwest Asia		22.1	46.5	80.1
Southeast Asia		7.4	16.3	27.9
Central America		5.0	12.2	13.6
South America		26.0	53.8	101.7
Crop Residues and Crop-byproducts				
Africa		22.6	98.9	376.7
Southwest Asia		.8	3.4	5.8
Southeast Asia		20.9	64.9	115.2
Central America		4.1	15.0	29.5
South America		41.3	132.0	361.1
TOTAL				
Africa	90.7	112.5	292.3	664.0
Southwest Asia	25.2	22.9	49.9	85.9
Southeast Asia	160.2	28.3	81.2	143.1
Central America	22.6	9.1	27.2	43.1
South America	92.3	67.3	185.8	462.8

* The reference LSU has been defined, Gartner and Hallam (1983), as:

- A 500kg mature cow, with a calving interval of 13 months, producing 3500kg of milk per lactation.

Full details of assumptions and methodologies of estimating livestock supporting potential from crop residues and crop-byproducts are given in Fischer et al (1984).

** Estimates derived from FAO Production Yearbook 1981.

timber, fuel, etc., have not been considered in the study. These other food and non-food crop areas ranged from 20.2 percent of total cultivated land in Africa to 29.7 percent in South America, Table 13. As a conservative estimate, if we assume that one-third of the cultivatable land resource base is required for other food and non-food crops and forest areas, then it may be concluded that the five developing regions as a whole have the land resources to support the populations of the year 2000 even at the lowest technology level. However, there are wide differences in the land resource endowments among and within the five regions.

Table 13. Cultivated Land Under Main Food* Crops and All Other** Crops in Year 1975.

	Africa	Southwest Asia	Southeast Asia	Central America	South America	Total
Rainfed Land (Mill.Ha)						
Food* crops	88.9	27.5	148.6	15.0	54.0	334.0
All other crops	19.8	4.6	33.3	3.8	22.1	83.6
Irrigated Land (Mill.Ha)						
Food* crops	5.3	5.5	44.4	3.1	4.2	62.5
All other crops	4.1	4.3	9.8	1.1	2.7	22.0
Total Cultivated Land (Mill.Ha)						
Food* crops	94.2	33.0	193.0	18.1	58.2	396.5
All other crops	23.9	8.9	43.1	4.9	24.8	105.6
Land under "all other crops" as percentage of total cultivated land						
Rainfed	18.2	14.6	18.3	20.3	29.0	20.0
Irrigated	43.1	43.9	18.2	26.1	38.3	26.9
Total	20.2	21.4	18.2	21.4	29.7	21.0

* Food crops include the following crops explicitly considered in the FAO/IIASA/UNFPA study: pearl millet, sorghum, maize, winter wheat, spring wheat, upland rice, paddy rice, winter barley, soyabean, phaselous bean, sweet potato, cassava, white potato, groundnut, banana/plantain, sugarcane, oil palm and livestock (from grassland).

** All other crops: land under other food crops (e.g. vegetables, beverage crops, etc.) and non-food crops (e.g. cotton, tobacco, etc.).

Source: Data derived from AT2000 Study (FAO, 1981) and FAO Production Yearbook 1983.

At the low and intermediate levels of inputs all regions except Southwest Asia, could produce the basic food needs of their year 2000 populations. If the assumption of one third of land resource base being required for additional crops and forest areas is considered, then at the low level of farming technology the land resources of Central America and Southeast Asia would not be able to support their year 2000 projected populations. At the high level, land resources of all regions except Southwest Asia could produce all the food and agricultural needs of the year 2000 projected populations.

Much of the land resource base of Southwest Asia is unsuitable for rainfed agriculture; in fact, most of the population supporting potential in this region originates from irrigated production. However, this region of the world is also generally endowed with rich oil resources and hence has the ability to import additional food and agricultural commodities as well as to further develop its irrigation potential, though long-term availability of water may set ceilings before full food requirements are reached.

The above regional results, assume completely free movement of food from surplus to deficit areas within each of the five regions. Examining the results at the country level, the situation in many countries is less promising.

4.2. Country Results

The country results, showing the population supporting potential from both rainfed and planned irrigated production, for the year 2000, are presented in Tables 14 to 18 and in map-form in Figs.4 and 5 as follows:

- "***Critical***" countries defined as those that do not have the land resources (all arable rainfed land areas together with planned year 2000 irrigated areas) to meet the basic food needs of their populations.
- Countries with "***limited***" land resource base being defined as those countries that do not have the land resources (all arable land areas together with planned year 2000 irrigated areas) to satisfy the basic food needs as well as additional requirements of "other" food and non-food crops and forest areas (it should be noted that this "additional" requirement is assumed to amount to one-third of the cultivatable rainfed land resource base).
- Countries with sufficient and "***surplus***" land resources to meet all the food and agriculture needs of the year 2000 populations (the degree of surplus capacity in particular countries is shown in Fig.5).

Figure 4.

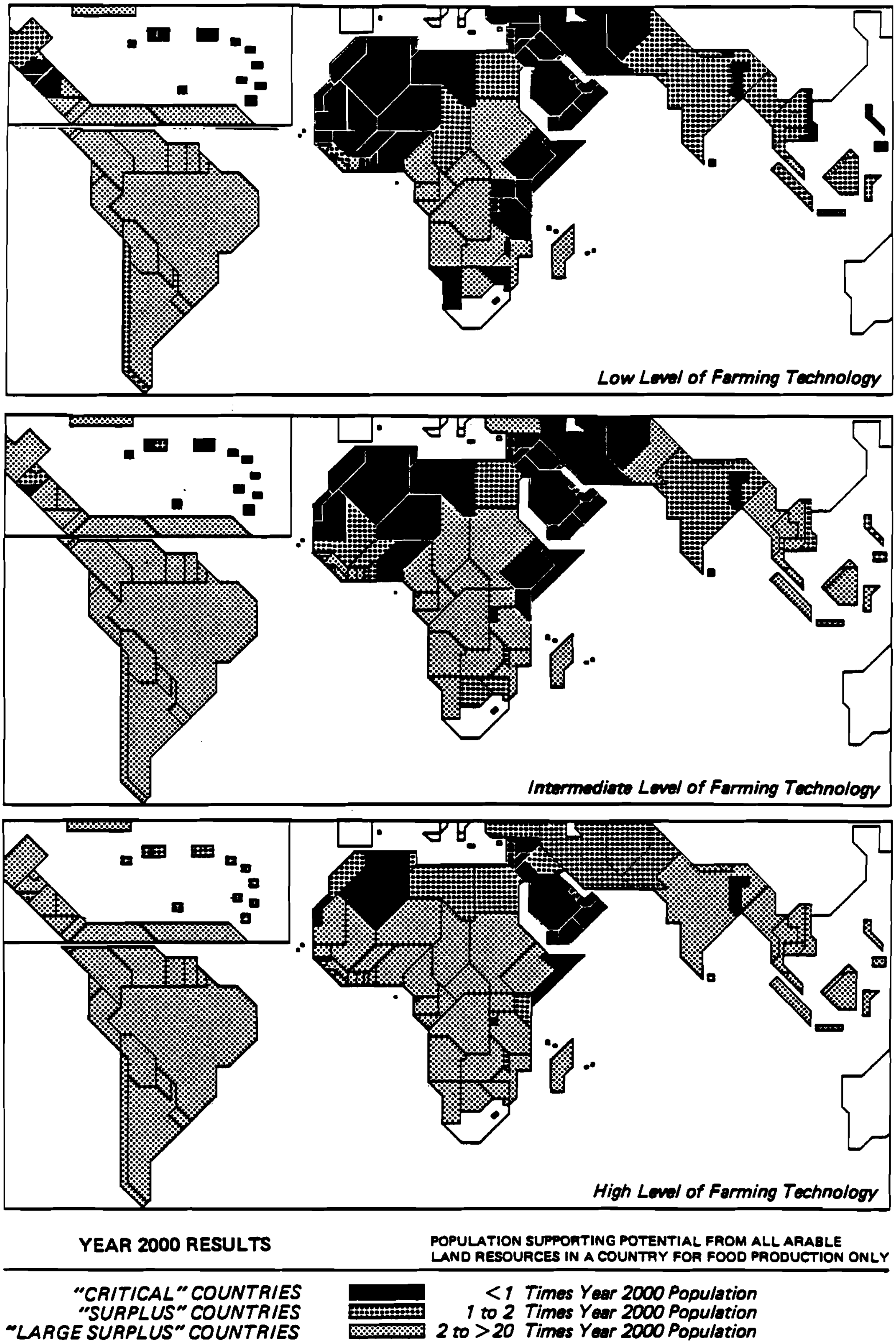
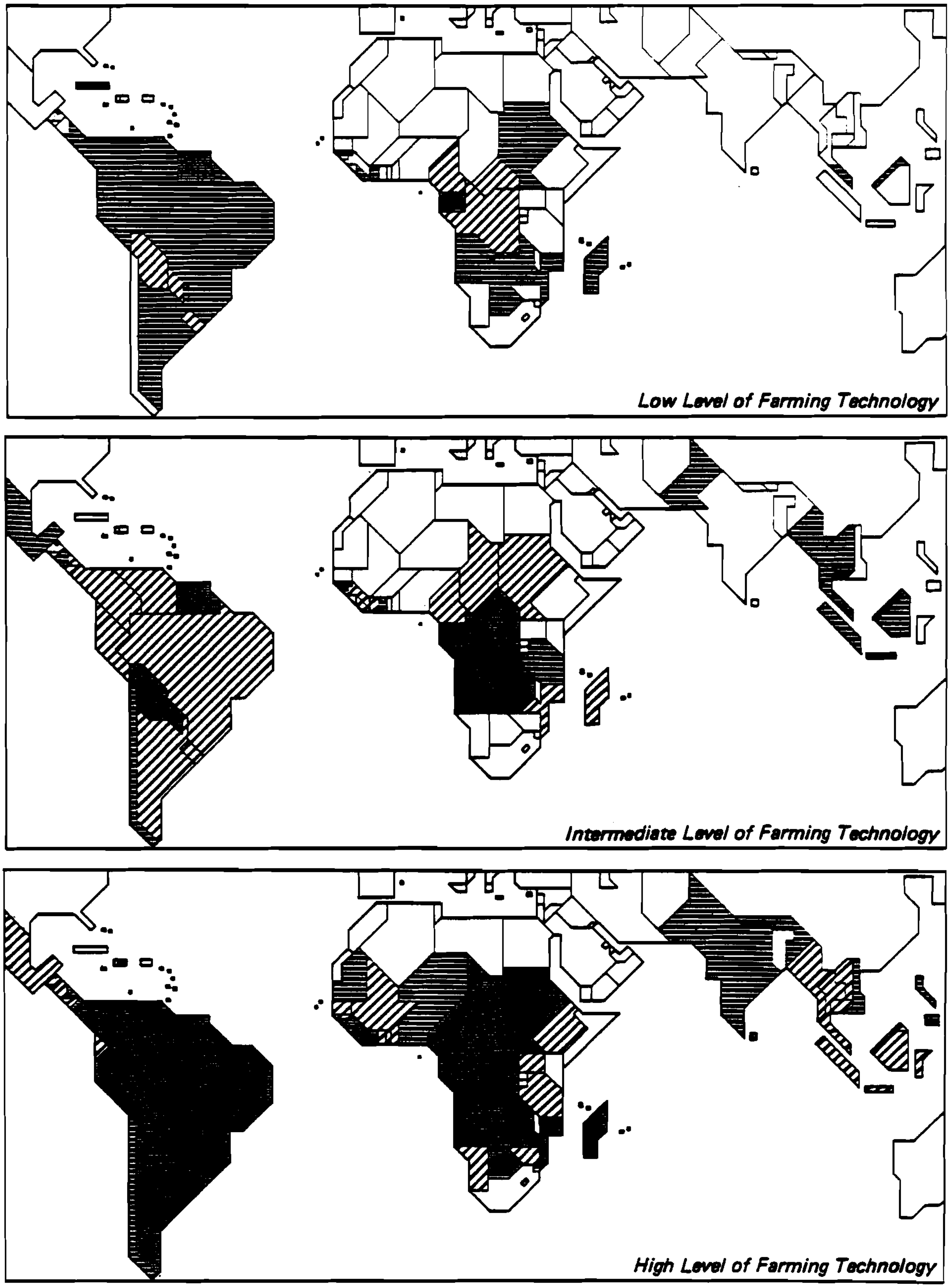

Low Level of Farming Technology
Intermediate Level of Farming Technology
High Level of Farming Technology
YEAR 2000 RESULTS
POPULATION SUPPORTING POTENTIAL FROM ALL ARABLE LAND RESOURCES IN A COUNTRY FOR FOOD PRODUCTION ONLY
"CRITICAL" COUNTRIES
"SURPLUS" COUNTRIES
"LARGE SURPLUS" COUNTRIES
< 1 Times Year 2000 Population
1 to 2 Times Year 2000 Population
2 to > 20 Times Year 2000 Population

FIGURE 5



YEAR 2000 RESULTS

POPULATION SUPPORTING POTENTIAL FROM ALL ARABLE LAND RESOURCES IN A COUNTRY FOR FOOD PRODUCTION ONLY

"LARGE SURPLUS" COUNTRIES

2 to 5 Times Year 2000 Population
5 to 20 Times Year 2000 Population
>20 Times Year 2000 Population

In considering these results, it is again emphasized that although the study is a comprehensive one, it does have a number of limitations which for some countries might distort the results. An example is the assumed (year 2000) rate of development of irrigation production. Should, as in the case of Saudi Arabia, this assumed expansion be exceeded through massive investment, the envisaged rates of expansion need to be revised to provide for updating of results. Within this context the country results are considered.

4.2.1. Africa: "Critical" Countries

At the *low level of farming technology*, by the year 2000, twenty-nine African countries do not appear to have the rainfed land resources to feed their future populations. The deficit of these "critical" countries equals the food needs of 257 million people representing 55% of the total population of these critical countries.

At present, the level of farming technology utilized in many countries in Africa corresponds closely to the low level assumed in the study. In the next two decades it is realistic to assume that these countries could move well towards the intermediate level. At this level of farming technology and using all arable land resources, twelve African countries would still be "critical" and the estimated calorie deficit would amount to the food needs of 48 million people, i.e. 44% of the total population of these twelve countries. In these twelve countries, except for Western Sahara, Cape Verde, Rwanda and Mauritius, food self-sufficiency from domestic land resources could be reached by moving to the high level of farming technology. However, widespread adoption of this high level is unlikely to be practically feasible within a period of two decades and hence a viable alternative for these eight countries (Burundi, Lesotho, Algeria, Somalia, Niger, Reunion, Kenya and Mauritania) apart from improving farming technology would be to expand irrigated production if feasible and import any

Table 14. "Critical", "Limited" Land Resource and "Surplus" Countries in AFRICA: Year 2000 Results

	Farming Technology		
	Low Level	Intermediate Level	High Level
"Critical" Countries	Cape Verde Western Sahara Rwanda Mauritius Burundi Lesotho Algeria Somalia Niger Reunion Kenya Mauritania Comoros Ethiopia Nigeria Namibia Tunisia Morocco Uganda Upper Volta Malawi Botswana Senegal Togo Sierra Leone Swaziland Mali Benin Zimbabwe	Cape Verde Western Sahara Rwanda Mauritius Burundi Lesotho Algeria Somalia Niger Reunion Kenya Mauritania	Cape Verde Western Sahara Rwanda Mauritius
Projected Year 2000 Population (Mill.)	466	110	11
Potential Population (Mill.)	209	62	9
Deficit Population (Mill.)	257	48	2
"Limited" Land Resources Countries	Libya Ghana Tanzania Gambia	Libya Comoros Ethiopia Nigeria Namibia Tunisia Morocco	Burundi Lesotho Algeria Somalia
Projected Year 2000 Population (Mill.)	62	258	52
Potential Population (Mill.)	68	340	70
Deficit Population (Mill.)	17	31	5

Table 14 cont.

"Surplus" Countries	Egypt	Egypt	Egypt
	Chad	Chad	Chad
	Sao Tome etc.	Sao Tome etc.	Sao Tome etc.
	Guinea	Guinea	Guinea
	Mozambique	Mozambique	Mozambique
	Sudan	Sudan	Sudan
	Guin Bissau	Guin Bissau	Guin Bissau
	Liberia	Liberia	Liberia
	Ivory Coast	Ivory Coast	Ivory Coast
	Madagascar	Madagascar	Madagascar
	Angola	Angola	Angola
	Zambia	Zambia	Zambia
	Cameroon	Cameroon	Cameroon
	Zaire	Zaire	Zaire
	Eq.Guinea	Eq.Guinea	Eq.Guinea
	Central Afr.Emp.	Central Afr.Emp.	Central Afr.Emp.
	Congo	Congo	Congo
	Gabon	Gabon	Gabon
		Uganda	Uganda
		Upper Volta	Upper Volta
		Malawi	Malawi
		Botswana	Botswana
		Senegal	Senegal
		Togo	Togo
		Sierra Leone	Sierra Leone
		Swaziland	Swaziland
		Mali	Mali
		Benin	Benin
		Zimbabwe	Zimbabwe
		Ghana	Ghana
		Tanzania	Tanzania
		Gambia	Gambia
			Libya
			Morocco
			Tunisia
			Mauritania
			Namibia
			Nigeria
			Ethiopia
			Comoros
			Kenya
			Reunion
			Niger
Projected Year 2000 Population (Mill.)	252	412	717
Potential Population (Mill.)	977	4087	12789
Surplus Population (Mill.)	725	3675	12072

additional food. The extent of planned (year 2000) irrigated areas in African countries is generally small (average of less than 3% of arable land in Africa) and there is undoubtedly considerable scope for further irrigation development. However, it should be noted that the possibility of irrigated area expansion in a particular country will very much depend on the availability of easily accessbile ground water or feasible river diversions. Among the core group of 12 "critical" countries at the intermediate level of farming technology, the results of the study show for Mauritius, Algeria, Somalia, Niger, Kenya and Mauritania, that more than a fifth of the population supportung potential in the year 2000 would originate from irrigated production. The possibility of further irrigation expansion in Somalia, Algeria and Mauritania may be somewhat limited due to limitation on accessible water sources.

4.2.2. Africa: "Limited" Land Resources Countries

Libya, Ghana, Tanzania and Gambia would be close to the land resource limit at the low level of farming technology and taking into account the one-third land resource requirement for "other" food and non-food crops and forests, the deficit would be equivalent to the food and agricultural needs of 17 million people out of a total projected year 2000 population of 62 million. At the intermediate level, seven "limited" resource countries, namely, Libya, Comoros, Ethiopia, Nigeria, Namibia, Tunisia and Morocco, would altogether have a deficit equivalent to the food and agricultural needs of a population of 31 million. At the high level of farming technology four "limited" land resource countries -- Burundi, Lesotho, Algeria and Somalia -- with a projected population of 52 million in year 2000 would have a deficit equivalent to a popultion of 5 million.

4.2.3. Africa: "Surplus" Countries

Among the eighteen "surplus" countries shown in Table 9, seven African countries (Zaire, Sudan, Cameroon, Angola, Madagascar, Central African Empire and Mozambique) accounting for 18% of the year 2000 population of this region have the highest potential for food and agriculture production (Fig.5). The population supporting potential of these seven countries accounts for more than half of the total potential of Africa. It should also be noted that in Egypt there are no rainfed lands and all the production is obtained from irrigated areas; Egypt could be "surplus" only if all irrigated areas are given over to food production only.

4.2.4. Africa: Summary

Many of the "critical and "limited" land resource countries in Africa are also among the low income (per capita GNP below US-$550 in 1981) and least developed countries of the world. At the low level of farming technology, the exceptions are the oil exporters (Nigeria, Libya and Algeria) and lower medium income (per capita GNP US-Dollars 550 to US-Dollars 1630 in 1981) countries: Tunisia, Morocco, Senegal, Swaziland, Mauritania, Botswana, Mauritius, Kenya, Lesotho, Ghana, Zimbabwe and Reunion* The latter six countries are basically agricultural exporters whereas the former six countries also export minerals and metals. As mentioned previously, it should also be noted that most of the thirty-three "critical" and "limited" resources countries, Table 9, are presently using farming technology equivalent to the low level; the exceptions being Mauritius, Reunion and Zimbabwe which are on average using intermediate level of farming technology.

The "critical" situation in many of the low income and least developed

*Upper middle income (US-Dollars 2481 per capita GNP in 1981) countries is alarming and needs urgent national and international measures (OAU, 1980; IBRD, 1981) to bring about economic and agricultural development. In particular, improvements in the level of farming technology will be essential if food production is to keep pace with the increasing consumption demand in many countries in Africa.

4.2.5. Southwest Asia: "Critical" Countries

In this region, all countries except Turkey, Iran, Iraq, and Syria, are "critical" at all three levels of farming technology; the latter three countries being not "critical" only at the high level of farming technology. At the low level of farming technology, the food deficit in the 15 "critical" countries, with a projected year 2000 population of 195 million, amounts to the food needs of 108 million people. If intermediate level of farming technology were practiced, then this deficit would be reduced to the food needs of 79 million people. Even at the high level of farming technology, in the 12 "critical" countries the food needs of 42 million out of a projected year 2000 population of 89 million would not be met.

4.2.6. Southwest Asia: "Limited" Land Resources Countries

At the low level of technology, Turkey falls in this group. At the present time, the level of farming technology attained in Turkey is between low and intermediate levels and hence Turkey would not be a "limited" resource country. At the high level of farming technology, Iran, Iraq, and Syria together could support (only the basic food needs) 118 million and their year 2000 population is projected to be 116 million. Considering the assumption of one-third land resource requirement for other food and non-food crops, these countries would not have sufficient land resources to meet all the food and agricultural needs from domestic production; here the deficit would be the food and agriculture

Table 15. "Critical", "Limited" Land Resource and "Surplus" Countries in SOUTHWEST ASIA: Year 2000 Results

	Farming Technology		
	Low Level	Intermediate Level	High Level
"Critical" Countries Countries	Bahrain Qatar Oman Kuwait United Arab Emir. Jordan Saudi Arabia Lebanon Yemen Dem. Yemen Arab Rep. Afghanistan Iraq Syria Iran	Bahrain Qatar Oman Kuwait United Arab Emir. Jordan Saudi Arabia Lebanon Yemen Dem. Yemen Arab Rep. Afghanistan Iraq Syria Iran	Bahrain Qatar Oman Kuwait United Arab Emir. Jordan Saudi Arabia Lebanon Yemen Dem. Yemen Arab Rep. Afghanistan
Projected Year 2000 Population (Mill.)	195	195	89
Potential Population (Mill.)	87	116	47
Deficit Population (Mill.)	108	79	42
"Limited" Land Resource Countries	Turkey		Iraq Iran Syria
Projected Year 2000 Population (Mill.)	69		106
Potential Population (Mill.)	93		118
Deficit Population (Mill.)	7		27
"Surplus" Countries		Turkey	Turkey
Projected Year 2000 Population (Mill.)		69	69
Potential Population (Mill.)		121	159
Surplus Population (Mill.)		52	90

needs of 37 million people.

4.2.7. Southwest Asia: "Surplus" Countries

One country -- Turkey -- would have "surplus" production capacity in this region at intermediate and high levels. This country accounting for 26% of the regional population represents about half the total regional population supporting potential at all three levels of farming technology.

4.2.8. Southwest Asia: Summary

Productive rainfed land resources are very limited in Southwest Asia and in fact most of the population supporting potential in this region orginates from irrigated production. In recent years there has been considerable expansion of irrigated areas in the countries of the Southwest Asia region. However, during the next decade the irrigation reserves in two major areas, namely, Iran and the Tigris-Euphrates region, are likely to be fully used. In some of the other countries in the region there is some scope for further irrigation development. Many countries in the region are also endowed with rich oil resources and hence have the ability to finance the imports of necessary food and agricultural requirements. The exception to this possibility are Jordan, Lebanon, Yemen Democratic Republic, Yemen Arab Republic and Afghanistan. The critical situation in the latter three countries, falling within the group of low income and least developed countries and with limited access to foreign exchange earning opportunities, will need international attention for improvement.

4.2.9. Southeast Asia: "Critical" Countries

The sixteen countries of this region account for more than half of the present and projected population of the five developing regions included in the study. Irrigation is well developed and Southeast Asia accounts for over 60% of irrigated acreage in the developing world. As far as rainfed land resources are concerned, Southeast Asia has only about 15% of cultivatable rainfed lands of the developing world.

At the low level of farming technology, the total deficit of the six "critical" countries amounts to a basic food need of 71 million people out of a projected year 2000 population of 341 million. If intermediate level of farming technology were to prevail, then in the two "critical" countries – Bangladesh and Singapore

Table 16. "Critical", "Limited" Land Resource and "Surplus" Countries in SOUTHEAST ASIA: Year 2000 Results

	Farming Technology		
	Low Level	Intermediate Level	High Level
"Critical" Countries	Singapore Bangladesh Vietnam Bhutan Sri Lanka Phillipines	Singapore Bangladesh	Singapore
Projected Year 2000 Population (Mill.)	341	156	3
Potential Population (Mill.)	270	148	
Deficit Population (Mill.)	71	8	3
"Limited" Land Resource Countries Countries	India Nepal Burma Thailand		Bangladesh
Projected Year 2000 Population (Mill.)	1190		153
Potential Population (Mill.)	1492		185
Deficit Population (Mill.)	195		62
"Surplus" Countries	Kampuchea Lao Indonesia Pakistan Brunei Malaysia	Kampuchea Lao Indonesia Pakistan Brunei Malaysia Vietnam Bhutan Sri Lanka Phillipines India Nepal Burma Thailand	Kampuchea Lao Indonesia Pakistan Brunei Malaysia Vietnam Bhutan Sri Lanka Phillipines India Nepal Burma Thailand
Projected Year 2000 Population (Mill.)	407	1782	1782
Potential Population (Mill.)	702	4210	6149
Surplus Population (Mill.)	295	2428	4367

-- the food deficit wold be equivalent to food needs of 8 million people. At the high level of farming technology, only Singapore would remain critical.

4.2.10. Southeast Asia: "Limited" Land Resources Countries

Four countries -- India, Nepal, Burma and Thailand -- fall into this group at the low level of farming technology. These countries, with an expected year

2000 population of 1190 million, would have a deficit equivalent to meeting all the food and agriculture requirements of 195 million people. At the intermediate level none of the countries in the Southeast Asia region fall in this group, and at the high level of inputs only Bangladesh would have "limited" land resources with a deficit equivalent to a population of 30 million, i.e. 20% of the projected year 2000 population of Bangladesh.

4.2.11. Southeast Asia: "Surplus" Countries

At the low level of technology among the six "surplus" countries shown in Table 11, Indonesia and Malaysia, relative to their year 2000 population, would have the highest "surplus" potential based on the use of all arable rainfed land areas together with the planned year 2000 irrigated production. At the intermediate and high levels, additional "surplus" countries would be Burma, India, Pakistan and Thailand. These six countries with a total year 2000 population of 1554 million would account for more than 80% of the population supporting potential of Southeast Asia at all three levels of farming technology.

4.2.12. Southeast Asia: Summary

At present the level of farming technology in Southeast Asia is in between the low and intermediate levels. By reaching at least the intermediate level by the year 2000, all countries in the region except Bangladesh and Singapore could achieve self-sufficiency in agricultural production. In the case of Bangladesh -- a low income, most seriously affected and least developed country -- further expansion of irrigation and flood control and some food imports appears to be the only option. Singapore does not basically have any land resources for agriculture production and as a prosperous free trade centre has the ability to cover, by import, all its food and agricultural needs.

4.2.13. Central America: "Critical" Countries

The total population of the twenty-one countries in this region is projected to be 272 million in the year 2000. At the low level of farming technology, fourteen countries would be "critical" and the food deficit amounts to the food need of 18 million people out of a projected year 2000 population of 52 million. With the adoption of intermediate level of farming technology, the excess population would amount to 7 million people out of a projected population of 24 million in seven "critical" countries. At the high level of farming technology, only Barbados and Netherland Antilles would be "critical".

4.2.14. Central America: "Limited" Land Resources Countries

The countries falling into this group are Mexico and Honduras at the low level and Haiti even at the high level of farming technology. For Mexico and Honduras the total deficit amounts to the food and agricultural needs of a population of 10 million. In Haiti the deficit is equivalent to the needs of 2 million people.

4.2.15. Central America: "Surplus" Countries

Cuba, Nicaragua, and Panama have the highest relative potentials in this region. Mexico also has a large "surplus" potential at the intermediate and high levels. These four countries with an expected year 2000 population of 153 million account for more than 75% of the population supporting potential of this region.

4.2.16. Central America: Summary

As in the case of Southeast Asia, most countries in Central America could comfortably aim to reach an intermediate level of farming technology by the year 2000. Under this assumption, five of the remaining seven critical coun-

Table 17. "Critical", "Limited" Land Resource and "Surplus" Countries in CENTRAL AMERICA: Year 2000 Results

	Farming Technology		
	Low Level	Intermediate Level	High Level
"Critical" Countries	Neth.Antilles Barbados Martinique Antigua El Salvador Haiti Puerto Rico Windward Is. Trinidad & Tobago Jamaica Bahamas Guatemala Dominican Rep. Guadeloupe	Neth.Antilles Barbados Martinique Antigua El Salvador Haiti Puerto Rico	Neth.Antilles Barbados
Projected Year 2000 Population (Mill.)	52	24	2
Potential Population (Mill.)	34	17	1
Deficit Population (Mill.)	18	7	1
"Limited" Land Resource Countries	Mexico Honduras		Haiti
Projected Year 2000 Population (Mill.)	139		10
Potential Population (Mill.)	194		11
Deficit Population (Mill.)	10		3
"Surplus" Countries	Cuba Costa Rica Panama Nicaragua Belize	Cuba Costa Rica Panama Nicaragua Belize Mexico Honduras Trinidad & Tobago Jamaica Bahamas Guatemala Dominican Rep. Windward Is. Guadeloupe	Cuba Costa Rica Panama Nicaragua Belize Mexico Honduras Trinidad & Tobago Jamaica Bahamas Guatemala Dominican Rep. Windward Is. Guadeloupe Puerto Rico Martinique Antigua El Salvador
Projected Year 2000 Population (Mill.)	24	191	203
Potential Population (Mill.)	64	540	1281
Surplus Population (Mill.)	40	349	1078

tries have the option to expand irrigation and/or adopt high level of farming technology. For Barbados, expansion of irrigated production and for Netherland Antilles, food imports are the main possibilities.

4.2.17. South America: "Critical" and "Limited" Land Resources Countries

No countries in this region fall into these categories.

Table 18. "Surplus" Countries in SOUTH AMERICA*: Year 2000 Results

	Farming Technology		
	Low Level	Intermediate Level	High Level
"Surplus" Countries	Chile Ecuador Brazil Peru Colombia Venezuela Argentina Uruguay Paraguay Bolivia Guyana Surinam French Guyana	Chile Ecuador Brazil Peru Colombia Venezuela Argentina Uruguay Paraguay Bolivia Guyana Surinam French Guyana	Chile Ecuador Brazil Peru Colombia Venezuela Argentina Uruguay Paraguay Bolivia Guyana Surinam French Guyana
Projected Year 2000 Population (Mill.)	393	393	393
Potential Population (Mill.)	1418	5288	12375
Surplus Population (Mill.)	1025	4895	11982

* No critical or limited land resource countries in this region.

4.2.18. South America: "Surplus" Countries

All the thirteen countries in this region have the land resources to provide all the food and agricultural needs of the projected year 2000 populations at all three levels of farming technology. Brazil, Argentina and Colombia account for almost 70% of the production potential of South America. The extent of planned year 2000 irrigation areas in all the countries of this region is low(less than 3% of total arable crop land for the region as a whole) and with the possibility of further irrigation development, most of the countries in South America have very extensive land resources for food and agriculture production for all domestic needs and also substantial exports.

4.2.19. Country Results: Concluding Remarks

In summary the above results reveal that populations are unevenly distributed in relation to land resources for food and agricultural production both between and within the different countries and regions. Out of the one hundred and seventeen developing countries considered in the study, at the low, intermediate and high levels of farming technology, respectively, seventy-five, forty-three and twenty-eight countries would not have rainfed and planned (year 2000) irrigated land resources to meet all the food and agriculture needs of the year 2000 population from domestic production. It is reasonable to assume that most countries could feasibly reach an intermediate level of farming technology within the next two decades. In this case, of the remaining forty-three "critical" and "limited" land resource countries, fifteen would have the option to become self-sufficient in food and agriculture by moving towards a high level of farming technology as well as expanding irrigation production. For the twenty-eight countries which would be "critical" or "limited" even at the high level of farming technology, irrigation expansion, if feasible, as well as food imports will be essential. It would be stressed that the required levels of irrigation expansion (generally being more expensive than improvements in farming technology) in the "critical" and "limited" resource countries may be difficult to realize in a time span of about decades. Also successful adoption of higher levels of farming technology will call for appropriate planning and extension effort to ensure that practical constraints (social, economic as well as technological) are overcome.

The methodology and results obtained on the basis of ecological and technological considerations represent a first approximation of the potential production and population supporting capacity in the developing world. The study provides a framework for the incorporation of economic and social considerations leading to inter-disciplinary information for the formulation and identification of long-term policies required to bring about a rational and timely development of food and agriculture in the developing world.

5. POLICY RELEVANCE AND IMPLICATIONS

In the long term mankind on earth will eventually be forced to face the issue of an equitable sharing of the world resources. There are wide differences in the resource endowments between and within the different countries and regions of the world. These differences become more accentuated when the high levels of population growth in some countries is taken into account. This study has been concerned with land resources for food production. A sustainable and equity oriented development of these resources has a number of policy implications in relation to population planning, agricultural technological development, environmental conservation, agricultural research and extension, and international cooperation and aid.

5.1. Population Distribution

Historically, man has migrated when the need arose. For example, more than 60 million Europeans had the opportunities to migrate to the Americas and Australia during the last hundred years. Most of the earlier migrants originated from rural areas and were lured to the new colonies by the availability and abundance of land resources for agriculture. Such international migration opportunities are no longer open.

The possibility of migration within groups of developing countries is also becoming more constrained. In the Sahelian region, Eastern and Central Africa, etc., seasonal or longer term migration in search of food, across the present national boundaries in the region, was a common phenomenon in the past. Today such free movements are becoming more and more restricted.

In many developing countries, the situation within countries is no better. In some instances there are large inequities in the standards of living among and between the agricultural, rural and urban populations in different parts of a country. Within countries, there is at least the opportunity to formulate policies to equitably share national resources.

The study quantifies the potential production (in terms of food quantities, calorie equivalent, value equivalent) and population supporting capacity of each length of growing period zone in each of the countries of the study. Country level population census data was utilized to derive the 1975 population distribution among the various lengths of growing period zones in a country. This same distribution was assumed for the year 2000. Bearing this in mind, the results of the study determine the ability of different areas in a country to supply the food needs of the resident population.

Table 19 shows the regional results for populations living on land areas where the food production is insufficient to meet the food needs of the resident populations. In the year 1975 the populations were actually living on these "deficit" land areas and their food needs were met by food transfers. Levels of required food transfers to deficit areas, measured in wheat equivalent, are shown in Table 19. In reality during the next two decades, people will certainly migrate from one area to another and also food movements among different areas will occur.

In countries where a major share of national population derive their livelihood from agriculture, formulation of policies to bring about a distribution of population in relation to agricultural land resource endowment in different parts of the country is important. The quantified results of the study, for example, the total potential production and data on the per capita and per hectare value of potential production, Table 20, would enable a formulation of such equity-oriented policies (Shah and Fischer, 1982a). Additionally, if land resources in particular areas cannot provide sufficient income for the resident population, then the need for development of alternative sources of income (e.g.

Table 19. Land Areas, Population Affected and Potential Food Transfers of Critical Length of Growing Period Zones (Year 1975 and Year 2000)

	Africa	Southwest Asia	Southeast Asia	Central America	South America	Total
Total Extent* of all LGP Zones	2878	677	898	272	1770	6495
YEAR 1975						
Extents* of Critical LGP Zone Areas at:						
Low Level**	1355	506	313	67	213	2453
Interm.Level	1029	456	62	22	139	1707
High Level	881	428	45	2	77	1434
Total Population† of All LGP Zones	380	136	1118	107	216	1957
Total Population† of Critical LGP Zone Areas at:						
Low Level	184	99	767	59	56	1165
Interm.Level	74	73	176	29	37	387
High Level	44	61	82	9	15	211
Size of Population† Exceeding Potential Supporting Capacity in Critical LGP Areas at:						
Low Level	105	66	316	40	37	563
Interm.Level	43	42	56	14	22	176
High Level	27	26	31	8	10	102
Food Transfer Requirement in Wheat Equivalent (Mill.MT) for Population Exceeding Supporting Capacity in Critical LGP Zone Areas at:						
Low Level	26	18	74	10	10	138
Interm.Level	11	11	13	4	6	45
High Level	7	7	7	2	3	26
YEAR 2000						
Extents* of Critical LGP Zone Areas at:						
Low Level	1474	546	325	85	233	2663
Interm.Level	1119	530	129	58	134	1970
High Level	960	485	49	6	81	1581
Total Population† of All LGP Zones	780	265	1938	215	393	3590
Total Population† of Critical LGP Zone Areas at:						
Low Level	458	216	1099	135	112	2020
Interm.Level	213	203	597	102	65	1180
High Level	116	173	235	28	31	583
Size of Population† Exceeding Potential Supporting Capacity in Critical LGP Areas at:						
Low Level	317	156	454	94	73	1094
Interm.Level	131	123	167	57	42	520
High Level	64	93	80	21	18	276
Food Transfer Requirements in Wheat Equivalent (Mill.MT) for Population Exceeding Supporting Capacity in Critical LGP Zone Areas at:						
Low Level	79	42	106	24	20	271
Interm.Level	33	33	39	14	11	130
High Level	16	25	19	5	5	70

* Million Hectares

** Level of farming technology

† Million persons

non-agricultural development) to provide for incomes can also be assessed. In this context the problems of very rapid urbanization in many developing countries could be policy-guided to develop and locate new urban growth centres (e.g. agricultural processing industries) nearer areas with large potential for agricultural production.

The study results also show that the present population densities tend to be highest in the cooler and non-humid areas. Such areas, generally, have lower rainfed agricultural potential in comparison to warmer humid tropical areas. The main reasons for the aversion of people to reside in the latter areas are related to the difficulties and problems of working in very humid environments, such as greater prevalence of human, animal and plant diseases, higher incidence of pests, rapid growth of weeds, etc. These problems and difficulties will have to be overcome if sustainable agricultural development is to occur in the humid areas.

One example of the disease issue is the Tsetse infestation in African countries. A special study (Fischer et al, 1984) was carried out by IIASA for FAO to assess the potential production in terms of income generation and population supporting capacities of all Tsetse habitable areas where animal (and human) trypanosomiasis is an important constraint to development. Results for 37 African countries, together with information on related costs of Tsetse control and eradication provide the basis for the identification of priority areas for the implementation of Tsetse control measures. Given the recent development in the food situation in a number of African countries, population migration into and development of Tsetse cleared areas will be important to reverse recent declining food production trends in Africa.

The above mentioned policies of population distribution in relation to land resources would further enable the planning and development of spatially

Table 20. Total Net Revenue, Income per Capita and Income per Hectare by Major Climate and Length of Growing Period Zone – Kenya Year 2000.

	Scenario A No Resource Constraint Full Soil Conservation			Scenario D Resource Constraints 50% Soil Conservation		
	1	2	3	1	2	3
Warm Tropics: Length of Growing Period (Days)						
240-270	162	176	1246	108	117	831
210-239	317	178	1910	289	162	1624
180-209	422	387	1648	374	343	1461
150-179	359	292	1408	287	233	1125
120-149	678	631	1132	457	425	768
90-119	582	283	507	418	203	373
75-89	595	486	385	489	399	317
Subtotal	3116	332	760	2421	258	594
Moderately Cool Tropics: Length of Growing Period (Days)						
330-365	3	71	3000	2	48	400
300-329	43	211	2389	23	113	920
270-299	153	291	2068	87	165	1160
240-269	131	279	1845	86	183	1147
210-239	202	430	1663	156	332	1279
180-209	607	816	1236	492	661	932
150-179	136	156	1236	96	110	800
120-149	225	273	1355	130	158	681
Subtotal	1500	361	1426	1021	258	938

1 = Net Revenue Million KShs 1975 (1 US-Dollar = 10 KShs)
2 = Income per Capita in KShs
3 = Income per Hectare in KShs

Note:
In this Kenya case study the criterion of crop choice for each agro-ecological cell was on the basis of maximizing net revenue subject to commodity specific year 2000 production targets and resource (fertilizer and power) constraints. The year 2000 population distribution by length of growing period zones has been assumed to be the same as the actual distribution in year 1975, i.e. no migration between length of growing period zones. Here the estimated per capita and per hectare incomes in the various length of growing period zones provide information for equity-oriented land, income and population distribution policies.

Source: Shah and Fischer (1982a).

relevant facilities such as transportation, communications, habitation, processing and storage industries, etc.

5.2. Population Size

Much has been written and argued about the need for reduction in population growth. On one hand, there are those who feel that development itself will lead to reduction in population growth—this has been the case in the present-day developed countries. On the other hand, there are others who feel that we cannot afford (and that we do not have the time left) to wait for development to solve the population problem. The low and lower middle income countries identified in the study as able to meet their food needs in the year 2000 only at the high level of farming technology as well as countries which would be "critical" even at this level of input are a particular cause of concern.

Table 21. Population Supporting Potential and Future Populations: Some Demographic Data for Low Income and Lower Middle Income Critical Countries

Low and Lower Middle Countries able to meet Food and Agricultural Needs at	Year 2000 Projected Population (Million)	Year 2000 Potential Population High Level of Farming Technology (Million)	1981 Fertility Rate*	Hypothetical Size of Stationary Population* (Million)	Year of Reaching Stationary Population*
High Level of Farming Technology					
Ethiopia	55	307	6.5	244	2050
Niger	10	43	7.0	41	2045
Kenya	34	52	8.0	157	2035
Mauritania	3	9	6.0	8	2040
Nigeria	149	701	6.9	623	2040
Tunisia	10	16	5.1	20	2020
Morocco	36	60	6.9	113	2030
El Salvador	9	16	5.6	16	2020
Not Even High Level of Farming Technology					
Rwanda	9	8	8.3	44	2045
Burundi†	8	10	6.5	26	2045
Somalia†	6	8	6.5	23	2050
Afghanistan	37	24	6.9	82	2045
Bangladesh†	153	185	6.4	430	2035
Haiti†	10	11	4.7	15	2030
Lesotho†	2	3	5.8	7	2035
Jordan	6	2	7.3	18	2025
Yemen Democratic	3	2	7.0	12	2040
Yemen Arab Rep.	10	9	6.8	39	2040
Syria†	16	22	7.4	48	2020

* IBRD (1983)

† These countries would be self-sufficient in basic food but if the land resource requirements of "other" food and non-food crops and forests are considered then these countries do not have the rainfed land resources to be self-sufficient.

Table 21 presents some demographic data on these countries. Most of these countries have a fertility rate (1981) of above 6.5 and are not expected to reach stationary population levels until the years 2035 to 2045.

It is also interesting to examine the long term prospects of the potential "surplus" countries identified in the study. Table 22 classifies these countries according to the minimum level of farming technology that will be required in cultivating all their arable lands to meet the food needs of the hypothetical size of their stationary population. The year of reaching this population level for each country is also shown in the table.

In the long term, countries will have to squarely face and tackle the issues of fertility reduction and lower population growth rates, as a number have already done, especially for those countries that may not have either the land resources to produce the domestic food and agricultural requirement nor other resources to secure stable and long-term foreign exchange for food and agricultural imports.

5.3. Agricultural Investment

The development of the food and agricultural sector in many countries will require a mix of land-extensive and input-intensive investment strategies. The food production and population supporting potential results, obtained in the study on the basis of using available land resources at each of the three levels of farming technology, provide information to assess the investment mix required for rainfed land expansion, soil conservation, improvement of farming technology and further expansion of planned (year 2000) irrigated areas to meet the food and agricultural needs of future populations. This will require allocation and commitment of investment funds for agricultural development. It should be noted that the ability of the non-agricultural sector to rapidly absorb an increasing share of the growing population is often limited and hence

Table 22. Classification of Surplus Countries According to the Minimum Level of Farming Technology Required to Meet Food Needs of Stationary* Populations

LEVEL OF FARMING TECHNOLOGY			
Low	Low to Intermediate	Intermediate to High	Not Even High
AFRICA			
Gabon (2040) Eq.Guinea (2040) Madagascar (2040) Angola (2045) Zambia (2035) Cameroon (2035) Zaire (2035) Centr.Af.Emp.(2045) Congo (2030)	Sao Tome etc.(2035) Chad (2045) Guinea Bissau (2040) Guinea (2040) Mozambique (2040) Sudan (2040) Liberia (2035) Ivory Coast (2040) Togo (2035) Sierra Leone (2040) Benin (2040) Ghana (2035) Tanzania (2035)	Botswana (2035) Uganda (2040) Swaziland (2045) Upper Volta (2040) Gambia (2040) Malawi (2045) Namibia (2040) Senegal (2045) Mali (2045) Zimbabwe (2035)	Egypt (2020)
SOUTHWEST ASIA			
	Turkey (2015)		
SOUTHEAST ASIA			
Malaysia (2010) Brunei (2015)	Kampuchea (2020) Lao (2045) Indonesia (2020) Sri Lanka (2005) Phillipines (2015) Burma (2030) Thailand (2005)	Vietnam (2015) India (2020)	Pakistan (2035) Bhutan (2040) Nepal (2045)
CENTRAL AMERICA			
Cuba (2000) Costa Rica (2005) Panama (2010) Nicaragua (2030) Belize (2015)	Mexico (2015) Honduras (2030) Trinidad & Tob.(2000) Bahamas (2015) Guatemala (2025)	Jamaica (2005) Dominican Rep.(2015) Windward Is.(2015) Guadeloupe (2015)	
SOUTH AMERICA			
Chile (2010) Ecuador (2025) Brazil (2015) Peru (2020) Colombia (2010) Venezuela (2010) Argentina (2010) Uruguay (2010) Paraguay (2020) Bolivia (2035)			

* Year of reaching the stationary population in each country is shown in brackets, IBRD (1983).

it will be essential to efficiently channel agricultural investments according to the needs and development possibilities of various agricultural areas and rural populations in a country. In a number of developing countries, the development of agricultural resources and the provision of employment opportunities, incomes and an acceptable standard of living in the rural reas, is essential to curtail the ever increasing rural-urban migration and thereby solve the problem of urban unemployment and poverty that is so rampant and increasing.

Tables 23 and 24 show a classification of countries according to the lowest farming technology at which they would be able to meet the minimum food and agricultural needs from domestic production in the year 2000. Investments in land development (bringing "new" rainfed land into production and expanding irrigation), farming technology (fertilizer production, imports and distribution, animal traction equipment and tractors, etc.) can be assessed on the basis of the individual country results taking into account each country's particular situation.

As mentioned previously, most countries could comfortably reach an intermediate level of farming technology by the year 2000. Some of the countries underlined in Table 24 that can be self-sufficient in food and agriculture at the low or intermedate level of farming technology also are endowed with other natural resources that could continue to facilitate foreign exchange earnings in the future. Among the countries that would require a high level of farming technolgy to be self-sufficient in food and agriculture as well as countries that do not have the land resources to be self-sufficient even at the high level of farming technology, Table 24 shows the countries that may be able to finance future food imports through the exports of non-agricultural products. For the remaining core group of countries, investments in non-agricultural development with the aim of earning foreign exchange to finance food imports will need priority attention. It should be noted that for all other countries (not underlined in Table 24), the food and agriculture sector was the main source of foreign exchange earnings (UNCTAD, 1983).

Table 23. Number of Countries: Classified by Lowest Farming Technology at which they are able to meet Food and Agricultural* Needs from Domestic Production in Year 2000

	Africa	Southwest Asia	Southeast Asia	Central America	South America	Total
EVEN AT LOW LEVEL	**18**	-	**8**	**5**	**13**	**42**
Low Income	6	-	3	-	-	9
Lower Middle Income	11	-	1	4	6	22
Upper Middle/ High Income	1	-	2	1	7	11
ONLY AT INTERM. LEVEL	**14**	**1**	**8**	**9**	-	**32**
Low Income	9	-	6	-	-	15
Lower Middle Income	5	1	2	5	-	13
Upper Middle/ High Income	-	-	-	4	-	4
ONLY AT HIGH LEVEL	**11**	-	-	**4**	-	**15**
Low Income	4	-	-	-	-	4
Lower Middle Income	5	-	-	2	-	7
Upper Middle/ High Income	2	-	-	2	-	4
NOT EVEN AT HIGH LEVEL	**8**	**15**	**2**	**3**	-	**28**
Low Income	4	1	1	1	-	7
Lower Middle Income	3	4	-	-	-	9
Upper Middle/ High Income	1	10	1	2	-	14

Income levels defined in 1981 U.S.$, IBRD (1983):
Low Income < 550 U.S.$
Lower Middle Income < 550 to 1630 U.S.$
Upper Middle Income/High Income > 1630 U.S.$

*Here the assumption of one-third of the cultivatable land resources being required for other food and non-food commodities has been used.

5.4. Agricultural Technology

For all lengths of growing period zones in each country, the study quantifies the volume of potential food production, related crop-mix and production levels (Annex 2, Tables A1-A5), and inputs (land, fertilizers, and power, Table 11) required. What farming technological options are necessary and real-

Table 24. Countries† Classified by Lowest Level of Farming Technology at which they are able to meet Food and Agricultural* Needs from Domestic Production in Year 2000

	EVEN AT LOW LEVEL
	Low Income Countries
Africa:	Chad, Guinea, Sudan, Madagascar, **Zaire**, **Central African Empire**
Southeast Asia:	Kampuchea, Lao, Pakistan
	Lower Middle Income Countries
Africa:	**Egypt**, Sao Tome etc., Mozambique, Guinea Bissau, **Liberia**, Ivory Coast, **Angola**, **Zambia**, Cameroon, Eq. Guinea, **Congo**
Southeast Asia:	**Indonesia**
Central America:	Cuba, Costa Rica, Nicaragua, Belize
South America:	**Ecuador**, **Peru**, Colombia, **Bolivia**, **Guyana**, French Guyana
	Upper Middle/High Income Countries
Africa:	**Gabon**
Southeast Asia:	**Brunei**, **Malaysia**
Central America:	Panama
South America:	**Chile**, Brazil, **Venezuela**, Argentina, Uruguay, Paraguay, **Surinam**
	ONLY AT INTERMEDIATE LEVEL
	Low Income Countries
Africa:	Uganda, Upper Volta, Malawi, **Togo**, **Sierra Leone**, Mali, Benin, Tanzania, Gambia
Southeast Asia:	Vietnam, Bhutan, Sri Lanka, India, Nepal, Burma
	Lower Middle Income Countries
Africa:	**Botswana**, **Senegal**, Swaziland, Zimbabwe, Ghana
Southwest Asia:	Turkey
Southeast Asia:	Philippines, Thailand
Central America:	**Jamaica**, Guatemala, Dominican Republic, Honduras, Windward islands
	Upper Middle/High Income Countries
Central America:	**Trinidad and Tobago**, Bahamas, Guadeloupe, **Mexico**
	ONLY AT HIGH LEVEL
	Lower Income Countries
Africa:	Comoros, Ethiopia, Namibia, **Niger**
	Lower Middle Income Countries
Africa:	Kenya, Mauritius, **Nigeria**, **Tunisia**, **Morocco**
Central America:	Antigua, El Salvador
	Upper Middle/High Income Countries
Africa:	Reunion, **Libya**
Central America:	Puerto Rico, Martinique
	NOT EVEN AT HIGH LEVEL
	Lower Income Countries
Africa:	Rwanda, Western Sahara, Burundi, Somalia
Southwest Asia:	Afghanistan
Southeast Asia:	Bangladesh
Central America:	Haiti
	Lower Middle Income Countries
Africa:	Cape Verde, Mauritius, Lesotho
Southwest Asia:	Jordan, Yemen Democratic, Yeman Arab Republic, **Syria**
	Upper Middle/High Income Countries
Africa:	**Algeria**
Southwest Asia:	**Bahrain**, **Quatar**, **Kuwait**, **United Arab Emirates**, **Saudi Arabia**, Lebanon, **Israel**, **Iraq**, **Iran**, **Oman**
Southeast Asia:	**Singapore**
Central America:	**Netherland Antilles**, Barbados

* Here the assumption of one-third of the cultivatable land resources being required for other food and non-food commodities has been used.

† Countries in bold earned a major share of foreign exchange earnings from the export of non-agricultural products in 1980 (UNCTAD, 1983), and if this trend continues, could possibly continue to finance food imports in the future. Most of these countries are petroleum exporters except for Central African Empire (pearls and semi-precious stones), Zambia (copper), Zaire (copper, non-ferrous metals), Liberia (iron ore, rubber), Peru (copper, non-ferrous metals and petroleum), Bolivia (non-ferrous metals, precious metals and gas), Guyana (non-ferrous metals), Malaysia (petroleum, rubber), Chile (copper), Surinam (inorganic elements - oxides and non-ferrous metals), Togo (fertilizers and petroleum), Sierra Leone (pearls and semi-precious stones), Jamaica (inorganic elements - oxides and non-ferrous metals), Senegal (petroleum and fertilizers), Niger (uranium), Botswana (pearls and semi-precious stones), Morocco (fertilizers), Israel (pearls, precious stones and manufactured goods), Singapore (manufactured goods).

istically feasible in various countries (see Tables 23 and 24) during the next two decades?

Data on the quantity and mix of crop production, as well as the levels of input required and practically feasible, in each country provides the information for the location and development of infrastructure for crop storage and processing facilities, fertilizer distribution and production (perhaps viable on a regional basis for groups of countries), power-mix (human power from the resident population to be supplemented by appropriate levels of additional migrant population, animal and/or mechanical power), location and expansion of irrigated areas, etc. Note that the important contribution of the study is the provision of spatial and geographical information to enable an assessment of farming technology needs of particular areas and accordingly the planning of appropriate and feasible future agricultural development.

The criterion of crop choice corresponding to the three levels of assessment in the study results in different crop production mix (Annex 2, Tables A1-A5). It is interesting to note from Tables A1-A5 in Annex 2 that there is considerable potential for the production of certain crops. For example, oil palm accounted for 20 to 30% of the total calorie production in Africa, Central and South America and Southeast Asia. Although at first sight this relatively large share of calorie intake originating from oil palm appears unreasonable, it should be recognized that at present between 30 and 40% of average calorie intakes in the developed countries originate from direct and indirect consumption of oils and fats, FAO Provisional Indicative World Plan (1970) and FAO Food Balance Sheets (1980); for the developing countries the corresponding share of oil and fats in average calorie intake is in the range 10 to 20%.

If the production crop-mix does not match the food consumption-mix of the population then policies would be required to change the production crop-mix or bring about changes in dietary preference or import the necessary food items. For example, in some African countries, according to the study results, there is generally a large land and productivity potential for rainfed sorghum and millet. In recent years there has been a shift away from the consumption (and production) of these coarse cereals in favor of consumption of wheat. The rainfed production of the latter crop is ecologically and economically nonviable in most parts of the warm tropics of Africa (see Annex 1) and consumption needs in recent years have increasingly been satisfied by imports from overseas, Shah et al (1984). Can appropriate technologies be developed to turn sorghum and millet (perhaps together with some wheat) into "acceptable and palatable" bread or can African countries export sorghum and millet and import wheat? Such issues are important in terms of comparative advantage and ecological suitability.

5.5. Environmental Conservation

The issues of environmental preservation and conservation is especially important in ensuring sustainability of agricultural production. Soil erosion losses are quantified in the study on the basis of the FAO/UNEP/UNESCO (1981) land degradation methodology. The results of the study (Table 25) show that rainfed land degradation may depress food production in the long run by an average of between 15% to 30% according to the region. The lands of Central America and Southeast Asia are particularly susceptible in that the average losses in these regions would be higher. The study results, available at individual length of growing period zones in each country, provide quantified data on the effect of unchecked land degradation on food production. This information is important for governments and farmers in justifying and applying soil erosion conservation measures (Shah, 1982b).

Table 25. Effects of Land Degradation (Soil Erosion) on Production Potential -- Year 2000 Results

	Africa	Southwest Asia	Southeast Asia	Central America	South America	Total
Rainfed Land Degradation Productivity Loss (%):						
Low	29	35	39	45	23	29
Intermediate	27	19	31	36	23	24
High	22	14	20	21	14	15

The preliminary functional relationships between soil erosion and crop productivity losses (Table 9) have recently been improved on the basis of theoretical and empirical considerations (Higgins and Kassam, 1981). The latter comprised almost 160 sets of experimental data from various countries in the world. A report on the methodology of this soil erosion-productivity loss study and the detailed results for the countries of the five developing regions is presently under preparation (Shah et al, 1985a).

5.6. Agricultural Research and Extension

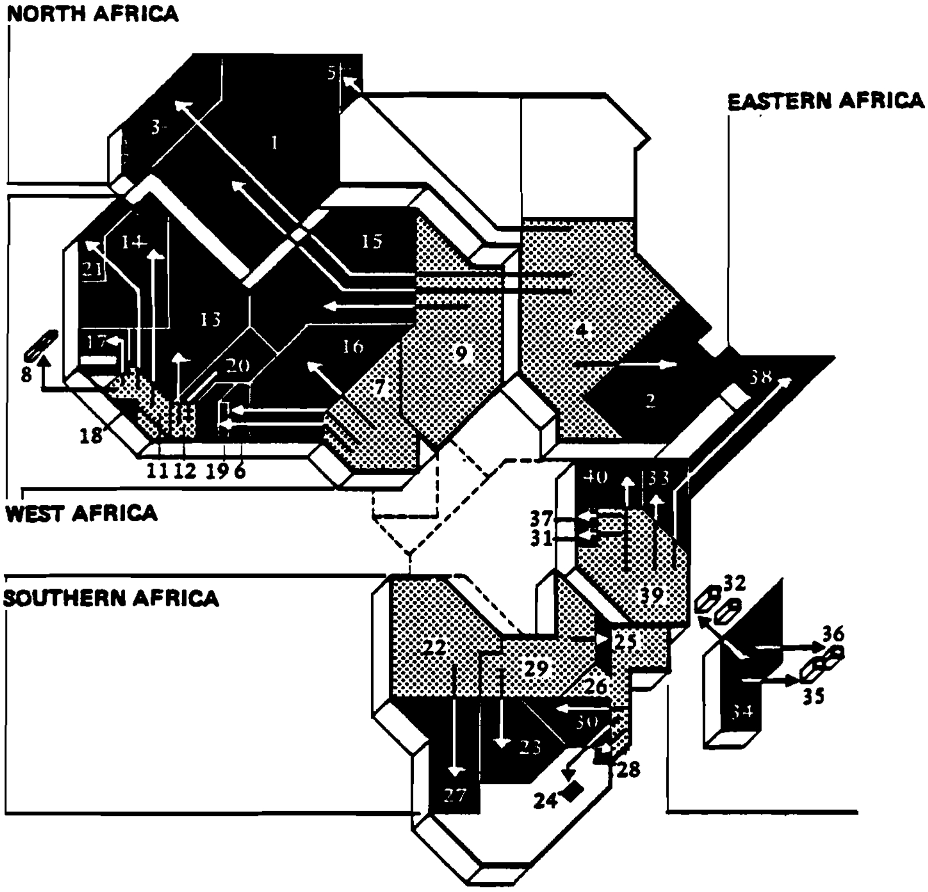
In relation to the policies and priorities for agricultural research in the developing countries, the study identifies and assesses the food production potentials and the likely increases in production of specific ecologically suitable crops. These results provide information that may be useful for the focussing and planning of agricultural research for particular crops and environments. Examples of this are the need for agricultural research focussed on sorghum and millet production in the drier areas and root crops in the wetter areas.

The study results corresponding to the three levels of farming technology provide a benchmark against which the desirable and feasible levels of food self-sufficiency and the necessary farming technology level in particular areas can be assessed. This in turn would enable effective planning and operation of agricultural extension services.

5.7. Regional Cooperation

Historically, there has been limited agricultural trade among the developing countries. There is considerable scope, necessity and interest among the developing countries to develop regional trade and economic cooperation. The results of the study show that there is potential for greatly increased self-reliance in food on a regional basis in Africa, Central America and Southeast Asia. In these regions potentially "critical" countries are generally adjacent to countries that could produce considerable surpluses. Utilizing this potenial would stimulate intra-regional trade, and increase food security by reducing dependence (as at present) on food imports from one or two overseas sources. Depending on crop demand-mix of potentially "critical" countries and the production-mix of potentially "surplus" countries (Tables 14 to 18), these countries may be grouped into food self-reliant regions.

A hypothetical example of the grouping of potentially food-surplus and food-deficit countries in Africa is shown in Fig.6. This grouping of "critical" and surplus" countries was derived on the basis of the results for the year 1975 at low level of farming technology. In this derivation the availability of "surplus" cereal production for trade from the potentially "surplus" countries was taken into account. However, transport and financial infrastructure for trade between many of these countries is lacking at present. It should also be noted that the situation in the year 2000 will be different. For example Malawi and Tanzania, both "surplus" countries at the low level of farming technology in the year 1975 will respectively be "limited" land resource and "critical" countries and hence would not be able to have surplus production for trade in the year



NORTH AFRICA
1. ALGERIA
2. ETHIOPIA
3. MOROCCO
4. SUDAN
5. TUNISIA

WEST AFRICA
6. BENIN
7. CAMEROON
8. CAP VERDE
9. CHAD
10. GHANA
11. GUINEA
12. IVORY COAST
13. MALI
14. MAURETANIA
15. NIGER
16. NIGERIA
17. SENEGAL
18. SIERRA LEONE
19. TOGO
20. UPPER VOLTA
21. WESTERN SAHARA

SOUTHERN AFRICA
22. ANGOLA
23. BOTSWANA
24. LESOTHO
25. MALAWI
26. MOZAMBIQUE
27. NAMIBIA
28. SWAZILAND
29. ZAMBIA
30. ZIMBABWE

EASTERN AFRICA
31. BURUNDI
32. COMOROS
33. KENYA
34. MADAGASCAR
35. MAURITIUS
36. REUNION
37. RWANDA
38. SOMALIA
39. TANZANIA
40. UGANDA

"DEFICIT" COUNTRIES
"SURPLUS" COUNTRIES

Figure 6 : *GEOGRAPHICAL GROUPING OF AFRICAN COUNTRIES FOR REGIONAL FOOD-SELSUFFICIENCY*

2000.

The overall results of the study suggest that there is scope for developing food and agricultural trade links between developing countries. Numerous constraints (for example, transport infrastructure) will need to be overcome in developing such trade links but the advantage (for example, regional food security and self-reliance) would be attractive in the long run. Note that in addition to possibilities of intra-regional trade, surplus countries with low levels of population (and hence power bottlenecks for increased production) may also be able to use any surplus labour available in the adjacent "critical" countries.

5.8. International Assistance

In relation to development assistance from international agencies and developed countries, the study results may provide the opportunities to assess levels and type of assistance required. For example, typically a assistance to a group of developing countries is faced with the issue of who to give assistance to and in what form to ensure maximum utility? The study identifies countries (Table 24) and within-country areas according to the ability of their respective land resources to be self-sufficient in food and agriculture. A number of countries and areas could achieve greater food self-sufficiency levels through a combination of improving farming technology, developing irrigation and implementing soil conservation measures. For such countries it is important to receive assistance in terms of inputs, capital and know-how. There are also a number of countries with limited agricultural potential to produce future food and agriculture needs due to a poor natural land resource base. For such countries assistance might more properly be focussed on non-agricultural investments to facilitate the foreign exchange for food and agricultural imports. Finally there may be a small group of countries that have very limited possibilities, and for these countries sustained direct international food and agricultural assistance will be required.

The above type of considerations would help to identify assistance projects and with additional feasibility studies ensure that assistance is better channeled, focussed and efficiently utilized.

6. CONCLUDING REMARKS

The study's major contribution is the development of a methodology and land resource data base for the ecological and technological assessment of food production potentials and population supporting capacities.

This information is suitable for the design and analysis of crop and region-specific agricultural development policies. In particular the approach allows an explicit consideration of environmental and technological aspects which together with economic and demographic issues provide the basis for medium and long-term planning of sustainable agricultural development.

The most fruitful avenue for further work and application of the methodology developed in this study is in relation to detailed country food and agricultural planning studies based on further refinements and improvements of the methodology and resources data base, and taking into account other food and non-food crops, the overall national economy as well as the linkages to the international economy. A first such case study of Kenya is presently being carried out by FAO and IIASA in collaboration with the Government of Kenya.

The coming two decades and beyond will see an ever increasing number of mouths to be fed in the developing world and only with integrated ecological and socio-economic studies will it be possible to adequately plan and provide for the well-being of future populations in the developing world on a sound environmental basis.

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ANNEX 1

Ecological and Economic Rationality of Wheat Production in Africa, Shah et al (1984)

Food production in many African countries has in recent years not expanded fast enough to keep up with population growth. there is great concern at the diminishing self-sufficiency and food security and the consequent increase in food imports of many African countries. Among all food items, wheat stands out as the one commodity whose influence in consumption, mainly through imports, seems to be rapidly growing. What is the ecological and economic potential and comparative advantage of wheat production in Africa?

The ecological and economic rationality of growing wheat vis-a-vis other food crops has been estimated on the basis of the Agro-ecological Zone (AEZ) methodology and the soil and climate resources data base. The computerized land resources (climate and soil) data comprise a mosaic of unique land units (10000 ha) with particular combination of soil and climatic conditions by location in each African country.

The maximum area agroclimatically suitable for growing wheat under rainfed conditions in each country is first identified. All this land is, however, not likely to be devoted to wheat cultivation. Monocropping with wheat of such large areas would not be a technically feasible proposal. However, it gives an idea of the maximum rainfed wheat production potential in Africa (column 2, Table A1.1).

Economically viable production (column 3, Table A1.1) depends on relative prices and on alternative crop potentials on the same land. 1975 world prices for food crops and inputs have been used to determine potential wheat production under revenue maximization ("Income Strategy"). In assessing the comparative advantage of growing wheat also maximum production in terms of calories ("Food Strategy") has been considered a meaningful criterion for crop choice (column 3, Table A1.1).

In Table A1.1 below, the first column contains historical data including irrigated wheat production. About 15 and 25 percent of the acreage shown have been under irrigation in North and Subsahara Africa respectively in 1978-80.

Table A1.1. Summary of Potential Rainfed Wheat Production at Intermediate Level of Technology

	1978-80 average	AEZ-Wheat only	AEZ-Income Strategy	AEZ-Food Strategy
	Acreage 1000 hectares			
North Africa	5430	10639	7009	5364
Subsahara Africa	1069	17704	1040	2546
Total Africa	6499	28343	8049	7910
	Production 1000 metric tons			
North Africa	5767	17931	14573	11119
Subsahara Africa	1279	28700	3027	5150
Total Africa	7046	46631	17600	16269

For North Africa, about two thirds of the land potentially suitable for wheat production would be devoted to growing wheat under revenue maximization yielding about 80 percent of the potential wheat production. This shows that soil and climate conditions are generally suitable for wheat production the only competing crop being barley in North Africa. However note that this level of competitive wheat production may be further reduced if additional important competing crops, namely citrus and olive, were also to be considered.

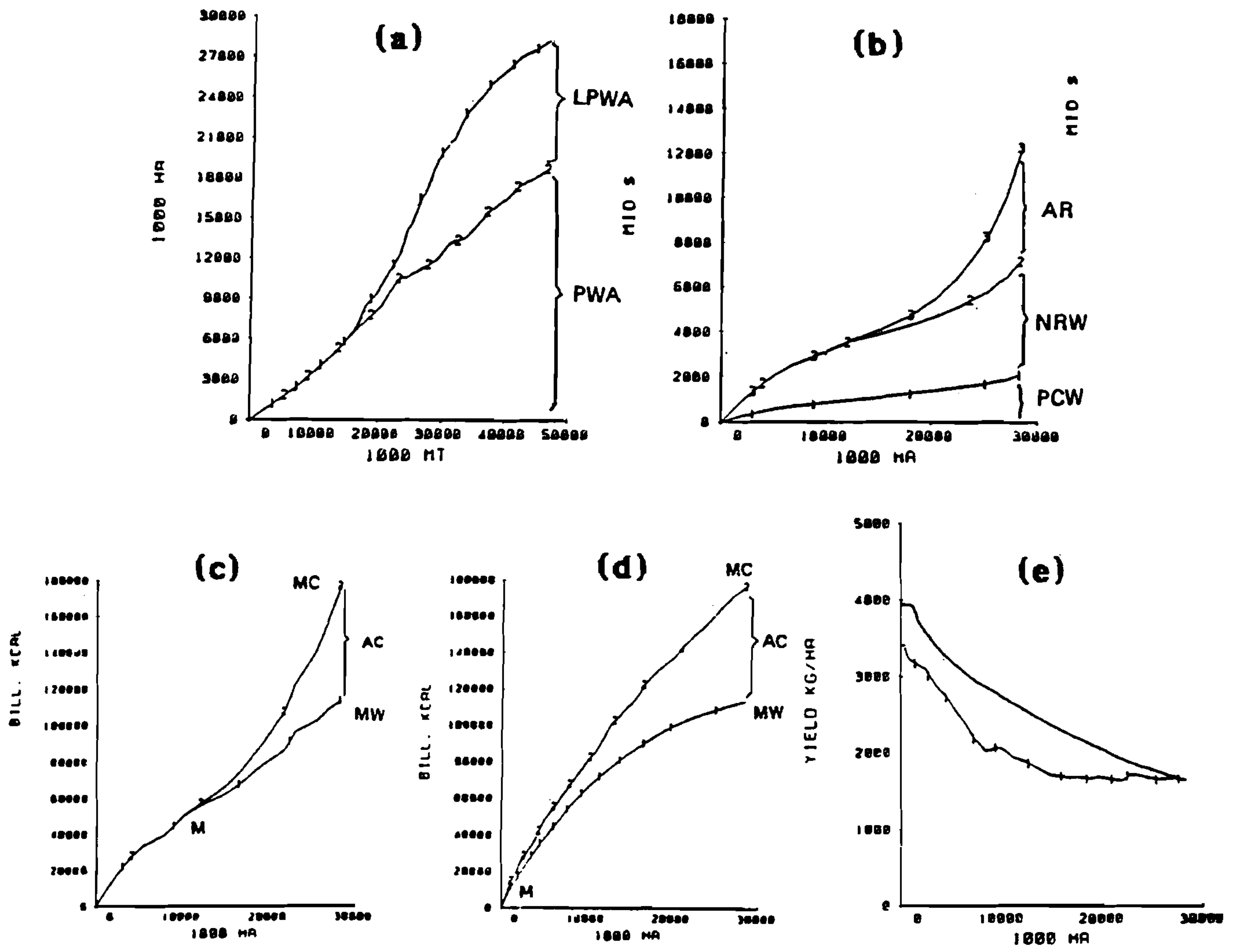
The agroclimatic suitability for wheat is much poorer in Subsahara Africa. Under intermediate technology less than 6 percent of potentially suitable land gets allocated to wheat under "Income Strategy" resulting in an economically viable production of 3 million mT, i.e. about 11 percent of potential production.

Though theoretically with intermediate technology, Africa could produce 46.6 million mT of rainfed wheat (under monocropping) and be selfsufficient for this commodity, this would be at substantial opportunity costs. Economically viable rainfed wheat potential under "Income Strategy" is only 17.6 million mT using intermediate technology. Trying to push production above these limits, under intermediate level of farming technology, would cause a loss of potential income to African economies.

When a "Food Strategy" is persued to further food security through calorie maximization, rainfed wheat output even reduces to 16.3 million mT, however, with a 70 percent increase of rainfed wheat production in Subsahara Africa to 5.1 million mT. Here again selfsufficienc.y in wheat (in year 2000) would be expensive for Africa. If wheat production is pushed beyond the "Food Strategy" limits, imports of other foods (instead of wheat) would probably have to be increased.

The comparative advantage of wheat production is presented in the form of supply and cost curves. In relation to different levels of wheat area, Fig.A1 shows (for Africa as a whole) wheat production, costs of wheat production, average obtainable yields and opportunity costs in terms of food (calories) foregone as a consequence of producing wheat instead of the optimally suited crop. The curves are of considerable theoretical interest and one can briefly point out some thought-provoking observations:

Figure A1. **Acreage, yield, production cost and net revenue of wheat production in Africa at intermediate level of inputs**



AC: Additional calorie production,ie.difference of calories produced from wheat and competitive crops and calories produced from mono cropping of wheat on all land areas where wheat can be grown.

MC: Total maximum calories production from mono cropping of wheat

MW: Total maximum calories production from mono cropping of wheat

M: Calorie production and average up to which wheat would be most productive crop.

AR: Additional revenue ie. difference of revenue produced from wheat and competitive crops and revenue produced from mono cropping of wheat on all land areas where wheat can be grown.

NRW: Net revenue from wheat production.

PCW: Production costs of wheat.

LPWA: Low productivity wheat area.

PWA: Very high to moderate productivity wheat area.

(a) Wheat production and land use
(b) Wheat production under 'Income Strategy'
(c) Wheat production under 'Food Strategy'
(d) Wheat production using most productive land first
(e) Average obtainable yields using most productive land first and under 'Income Strategy'

- Yields do not fall monotonically with area when net revenues are maximized. This is understandable, as high yield land which is better suited for crop production other than wheat may be selected at a later stage.
- Similarly, cost per unit of output does not change monotonically when production is increased.

These observations derived in the context of competing food crops question some of the assumptions traditionally made in econometric estimations of yield and cost functions. A more complete analysis covering the production potential of the major food crops in Africa is presented in a detailed report, Fischer and Shah (1985).

Annex 2: Crop Area and Production Mix: 1974-76 Average and Year 2000
Results of Alternative Assessments

Table A1. Africa: Crop acreage and production. Year 2000 results and 1974-76 average.**

	Area in '000 Ha			Production in '000 mt			1974-76 Average	
	Low Level	Intermediate Level	High Level	Low Level	Intermediate Level	High Level	Area '000 Ha	Production '000 mT
Pearl Millet	14051	23870	45941	4023.	24702.	77377.	15165	9558
Sorghum	22934	28704	1294	9371.	40441.	3663.	13452	9315
Maize	43276	62782	106205	27616.	120805.	416903.	14599	18412
Soyabean	27	425	30809	2.	198.	23023.	222	120
Phaselous Bean	3121	10217	412	415.	7404.	291.	2148	1414
Sweet Potato	3663	6282	58970	4989	17302.	448000.	691	4007
Cassava	34772	46728	59179	26175.	125498.	427245.	6754	43002
Paddy Rice	151240	167044	138467	55475.	206234.	379277.	4419†	7952†
Spring Wheat	2972	4013	1085	1274.	5206.	4192.	7017*	7671*
White Potato	912	1160	6768	574.	2380.	29601.	447	3298
Winter Wheat	5735	6403	5406	2314.	8884.	16222.		
Winter Barley	2368	5886	6651	512.	5312.	14024.	4485	4185
Upland Rice	2211	7375	80358	538.	5270.	408724.		
Groundnut	17322	34824	99023	4791.	32379.	242205.	6563	5161
Banana/Plantain	35024	40839	59593	26268.	93077.	256325.	14500E	15234
Sugar	3328	8203	12736	1962.	11237.	50654.	573	3566
Oil Palm	101557	155133	53649	30072.	123446.	78603.	3100E	1290
Total	444513	609888	768543				94135	

† Includes Upland Rice
* Includes Winter Wheat
E: Estimated since acreage data not reported in FAO Production Yearbooks
** Rainfed and irrigated acreage and production

Table A2. Central America: Crop acreage and production. Year 2000 results and 1974-76 average

	Area in '000 Ha			Production in '000 mt			1974-76 Average	
	Low Level	Intermediate Level	High Level	Low Level	Intermediate Level	High Level	Area '000 Ha	Production '000 mT
Pearl Millet	31	48	190	18.	60.	331.		
Sorghum	3349	2672	2083	1152.	2798.	4042.	1718	4278
Maize	11792	15998	9679	8991.	34744.	50552.	8569	10411
Soyabean	63	171	1402	9.	237.	2133.	272	464
Phaselous Bean	2721	1874	49	482.	1346.	7.	2124	1324
Sweet Potato	984	1096	6706	810.	3015.	56393.	147	758
Cassava	265	283	2012	305.	908.	17412.	153	865
Paddy Rice	7622	9016	13223	4225.	14465.	46572.	800†	1911†
Spring Wheat	604	737	75	242.	652.	173.	856*	3032*
White Potato	1420	1686	10803	691.	2240.	48904.	87	920
Winter Wheat	169	172	-	19.	56.	-		
Winter Barley	104	155	327	13.	51.	257.	274	413
Upland Rice	1304	1064	1410	877.	2618.	8665.		
Groundnut	306	1251	4038	73.	1481.	10794.	145	149
Banana/Plantain	2315	1658	4358	1360.	2758.	16774.	500E	7886
Sugar	3550	5293	564	1435.	8329.	2851.	2420	15087
Oil Palm	7575	7163	4377	2143.	6485.	6647.	35E	43
Total	44173	50337	61298				18100	

† Includes Upland Rice
* Includes Winter Wheat
E: Estimated since acreage data not reported in FAO Production Yearbooks
** Rainfed and irrigated acreage and production

Table A3. South America: Crop acreage and crop production. Year 2000 results and 1974-76 average.**

	Area in '000 Ha			Production in '000 mt			1974-76 Average	
	Low Level	Intermediate Level	High Level	Low Level	Intermediate Level	High Level	Area '000 Ha	Production '000 mT
Pearl Millet	2348	4203	11371	447.	3197.	15576.	211	241
Sorghum	19381	12872	6040	7732.	16562.	9519.	2509	6245
Maize	74903	88282	66140	69545.	163110.	194594.	16394	28003
Soyabean	12538	17927	13350	3186.	25310.	12179.	6412	10613
Phaselous Bean	20275	25398	15	2575.	10673.	2.	4761	2575
Sweet Potato	2636	16112	40377	2858.	38922.	204790.	232	2255
Cassava	16338	32244	53350	22681	112191.	452914.	2549	30587
Paddy Rice	147796	156809	197676	69979.	217498.	705812.	6661†	11966†
Spring Wheat	50166	39186	412	17569.	46929.	906.	9751*	12895*
White Potato	5195	30800	76606	3495.	58280.	271797.	959	8737
Winter Wheat	4000	4415	2199	824.	3360.	4430.		
Winter Barley	842	3489	6673	109.	1953.	6372.	973	1149
Upland Rice	26015	25917	102385	15815.	61667.	591253.		
Groundnut	1263	5844	42685	249.	7539.	98247.	77	880
Banana/Plantain	41086	21617	91421	25079	45901.	349615.	2760E	1429
Sugar Cane	21112	20175	3861	13736.	48452.	16468.	3002	16228
Oil Palm	93173	204086	80112	31157.	198513.	116838.	250E	70
Total	539066	709375	794670				58200	

† Includes Upland Rice
* Includes Winter Wheat
E: Estimated since acreage data not reported in FAO Production Yearbooks
** Rainfed and irrigated acreage and production

Table A4. Southwest Asia: Crop acreage and production. Year 2000 results and 1974-76 average.**

	Area in '000 Ha			Production in '000 mt			1974-76 Average	
	Low Level	Intermediate Level	High Level	Low Level	Intermediate Level	High Level	Area '000 Ha	Production '000 mT
Pearl Millet	200	303	949	32.	117.	579	191	193
Sorghum	326	466	1306	44.	186.	912	1398	1011
Maize	140	143	443	40.	152.	935	1191	2161
Phaselous Bean	3	-	-	1.			214	253
Spring Wheat	7	19	-	1.	14.			
White Potato	89	103	167	35.	146.	389	291	3760
Winter Wheat	12307	12745	3922	3139.	12441.	12054	21933*	25803*
Winter Barley	4241	9882	15138	815.	7772.	27303	6563	7286
Soyabean							58	78
Paddy Rice							757	2218
Groundnut							44	94
Banana/Plantain							280E	148
Sugar							17	112
Total	17313	23661	21924				33000	

* Includes Spring Wheat
E: Estimated since acreage data not reported in FAO Production Yearbooks
** Rainfed and irrigated acreage and production

Table A5. Southeast Asia: Crop acreage and production. Year 2000 results and 1974-76 average.

	Area in '000 Ha			Production in '000 mt			1974-76 Average	
	Low Level	Intermediate Level	High Level	Low Level	Intermediate Level	High Level	Area '000 Ha	Production '000 mT
Pearl Millet	10533	6791	4503	7413.	11600.	10313.	19309	9528
Sorghum	10481	5738	136	7804.	12824.	308.	16656	10651
Maize	16906	28525	35022	15845.	78576.	171912.	14430	16806
Soyabean	298	394	11360	49.	330.	8645.	1037	829
Phaselous Bean	1442	1260	70	271.	1103.	72.	9327	2980
Sweet Potato	6891	11127	21348	5682.	32597.	204472.	1113	7527
Cassava	6357	8591	11014	9128.	38874	96250.	2897	30588
Paddy Rice	139513	122128	77803	69664.	198397.	252635.	82747†	158817†
Spring Wheat	1216	265	14	331.	294.	24.	25501*	33544*
White Potato	422	677	651	226.	1019.	2063.	825	8123
Winter Wheat	55	54	58	23.	102.	191.		
Winter Barley	124	55	31	25.	50.	22.	3030	3081
Upland Rice	3262	1277	4344	1040.	2256.	23104.		
Groundnut	7134	5623	20474	3042.	7653.	43545.	8556	7122
Banana/Plantain	3735	22028	38493	3495.	49377.	158833.	5300E	11842
Sugar	2281	2802	5050	1446.	5423.	20276.	469	22778
Oil Palm	12937	51008	16941	10646.	59810.	24049.	1365E	1601
Total	223585	268345	245311				193000	

† Includes Upland Rice
* Includes Winter Wheat
E: Estimated since acreage data not reported in FAO Production Yearbooks
** Rainfed and irrigated acreage and production