FOOD PRODUCTION POTENTIAL AND ASSESSMENT OF POPULATION SUPPORTING CAPACITY--METHODOLOGY AND APPLICATION

M.M. Shah & G.Fischer, IIASA
G.M. Higgins & A.H. Kassam, FAO

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

Understanding the nature and dimension of the food problem and the policies available to alleviate it has been the focal point of the Food and Agriculture Program at the International Institute for Applied Systems Analysis (IIASA) since the program began in 1977.

In the program we are not only concerned with policies over a 5-15 year time horizon, but also with a long term perspective to obtain a comprehensive understanding of the food problems of the world.

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

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

(b) Can mankind be fed adequately by this stable, sustainable production potential?

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

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

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

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

Stability and sustainability are both desirable properties from the considerations of inter-generational equity as well as of political stability and peace.

We hold environmental considerations to be of critical importance in answering the questions posed.

This report presents the results of a case study of Kenya carried out as a part of the FAO/UNFPA Project INT/513, Land Resources for Populations of the Future, being carried out in collaboration with the Food and Agriculture Program, IIASA.

The results are preliminary and should be regarded as the first approximation. At the present time a detailed case study of Kenya (Phase 2, FAO/Kenya/IIASA Study) is being carried out. As understanding of the ecological and technological limits of food production is a critical part of agricultural development planning, this report highlights the results for Kenya and the methodology of evaluating agricultural production potential, population supporting capacity and soil degradation hazards. Policy relevance and implications for Kenya are briefly discussed.

This preliminary report in collaboration with the Land and Water Division of the FAO is the first of a series on the potential and limits of food production in developing countries.

K.S. Parikh
Acting Program Leader
Food & Agriculture Program
IIASA

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M. M. Shah and G. Fischer
Food & Agriculture Program
IIASA, Laxenburg, Austria.

G. M. Higgins and A. H. Kassam
Land and Water Division
FAO, Rome, Italy.

INTRODUCTION

"Is there sufficient land to sustain the likely world population in the year 2000?" Previous estimates of the populations that can be supported by the arable lands in the world vary from 7.5 to 40 thousand million. However, these estimates have not taken account of some crucial aspects, (Dudal, FAO, 1980) namely:

a) Quality of lands, their productive capacities and hence their varied potentials for supporting different levels of population on a degradation-free and sustained basis.

b) Alternative crops (with differing climatic and soil requirements).

c) Levels of inputs and management.

d) Socio-economic factors.

The ability of land to produce food is limited. The limits of production are set by soil and climatic conditions and the use and management applied. Any "mining" of land beyond these limits will, in the long term, only result in degradation and ever decreasing productivity. Accordingly, there are critical levels of populations that can be supported, in perpetuity, from any given land area.

Recognizing these facts within the context of a rapidly expanding world population, FAO and UNFPA, in collaboration with the International Institute of Applied Systems Analysis, initiated project INT 75/P13 to determine the limits of population supporting capacities of lands. A further objective is to compare these estimates with data on present and projected populations and so identify critical areas where land resources are insufficient to support existing and/or future populations and where action is urgently required to rectify this situation. It is hoped that the results of the study will be used as an improved physical resource base for planning future population activities and that the work will shed light on many migration/ land resource issues.

This paper describes the methodology developed for the study and the results obtained for the continent of Africa. The results represent a "first approximation" of the general situation as revealed by interpretation of a 1.5 million scale land inventory and need to be interpreted with due caution. More detailed country studies are required and will be the object of a Phase II of the project. The reported work has been guided by international expert consultations held under the auspices of FAO and UNFPA (FAO, 1978, 1980).

METHODOLOGY

Land Suitability and Productivity

The methodology developed, to assess the potential population supporting capacity of land, uses six principles which are fundamental to any sound evaluation of land namely:

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;

ii) the evaluation of production potential is made in respect of specified input levels, e.g., whether fertilizers are applied, if pest control is effected, if machinery or hand tools are being used;

iii) suitability refers to use on a sustained basis, that is the envisaged use of land must not result in its depletion, e.g., through wind erosion, water erosion, salination or other degradation processes;

iv) evaluation involves comparison of more than one alternative type of land use, e.g. suitability for millet or sorghum or maize, and not just for a single crop;

v) different kinds of land use are compared at least on a simple economic basis, i.e., suitability for each use is assessed by comparing the value of the produce to the cost of production;

vi) an interdisciplinary approach is adopted, the evaluation being based on inputs from crop ecologists, agronomists, climatologists and economists, in addition to those from pedologists.

These priciples are described in a "Framework for Land Evaluation" (FAO, 1976) and are as formulated over the past years through international cooperation.

Figure 1 illustrates, in a simplified form, the methodology developed to assess land suitability, the numbers in the cells of the figure relating to the step descriptions in the present section. The methodology is applied for each of the three levels of input circumstances shown in Table 1. Each of the assessments considers 16 crops to ascertain maximum potential calorie production. The 16 crops considered are listed in Table 2, in comparison with the twenty most widely grown crops of the world. The sixteenth crop, grassland, is used for the estimation of livestock potential and its associated population supporting capacity.

Basic to the assessment is the soil and climatic inventory shown at the head of the flow chart, Figure 1, step (1). This inventory comprises overlay of a specially compiled climatic inventory onto the 1.5 million FAO/UNESCO Soil Map of the World (FAP, 1971-79). The Soil Map records the composition, location and extent of some 5000 mapping units which are associations of soil units. The legend to the map is based on 26 major soil units, 106 soil units and 12 phases important to production management. The climatic inventory differentiates major climates (e.g. warm tropics) and lengths of growing periods zones at 30 days intervals (e.g. 120 -150 days). Measurements of the unique agro-ecological zones resulting from this combination allows quantification of the land resources of all developing countries in terms of soil and climatic conditions matched to the soil and climatic requirements of crops.

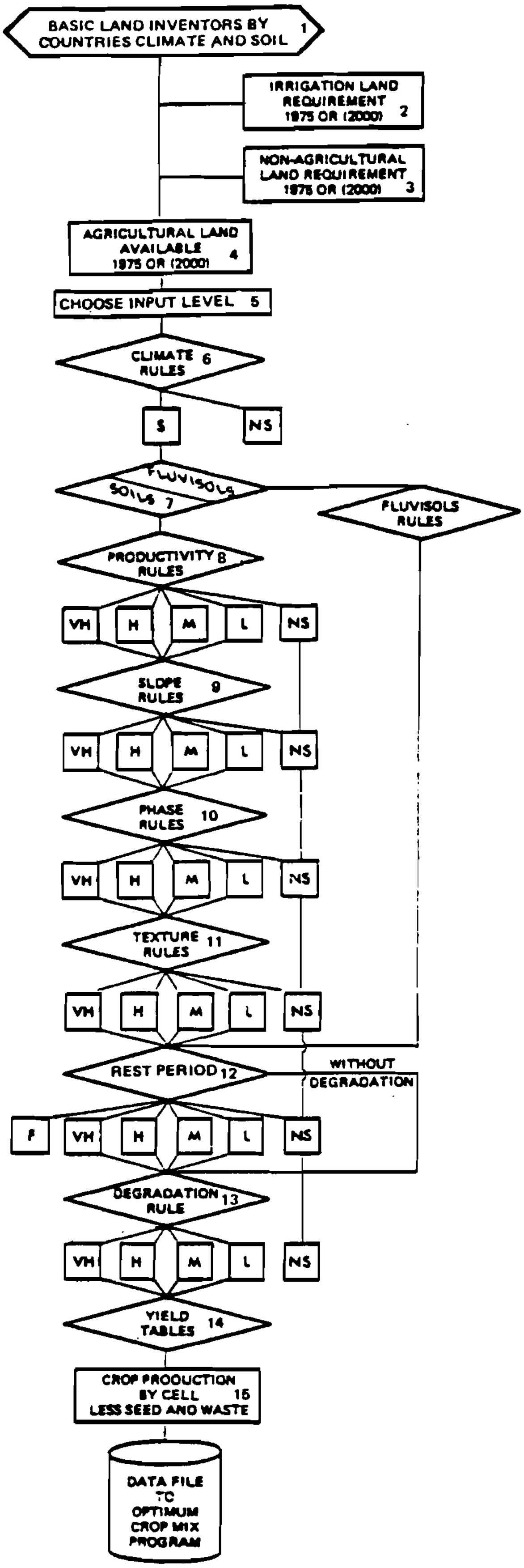
This is achieved by first applying major climate/crop temperature requirement rules to ascertain "suitable crops" i.e. which crops can be considered further (6). The main features of the climatic inventory created by the study for the assessment of agro-climatic crop suitability (Kassam et al, 1977 and Kassam 1979) are:

a) classification of crops into climatic adaptability groups according to their fairly district photosynthesis characteristics.

b) classification of temperature and moisture requirements of crops. The quantification of heat attributes and moisture conditions is based on the actual temperature regime during the growing period and a water balance model comparing precipitation with potential evapotranspiration.

The data utilized for the calculation of the water balance and for further climate-related calculations, comprise meteorological records from 850 stations where extended data on rainfall, maximum and minimum temperatures, vapour pressure, wind speed and sunshine duration is available on a monthly and yearly basis.

Individual crop productivity values, (Kassam, 1979 et. al) as determined for each major climate and each length of growing period zone, are then applied (8). The agro-climatic productivity is modified by soil suitability rules (9) to (11), (Sys and Riquier, 1979). The 1.5 million FAO/UNESCO Soil Map of the World



VH: Very high Productivity
H: High Productivity
M: Moderate Productivity
L: Low Productivity
NS: Not Suitable
F: Fallow

Fig. 1 Land suitability and productivity assessment
- Three levels of input
- With and without degradation hazards
- Country level results
- Results for 1975 or (2000)

Table 1 DEFINITION OF LEVELS OF INPUTS ASSUMED

ATTRIBUTE	LOW INPUT LEVEL	INTERMEDIATE INPUT LEVEL	HIGH INPUT LEVEL
Produce and production	Rainfed cultivation of pearl millet, sorghum, maize, rice, wheat, sweet potato, white potato cassava, phaseolus bean, soybean, barley, oil palm, groundnut, banana/plantain, sugarcane, grassland. According to presently grown mixture of crops	With part change to optimum mixture of crops	According to optimum mixture of crops
Market orientation	Subsistence production	Subsistence production plus commercial sale of surplus	Commercial production
Capital intensity	Low	Intermediate with credit on accessible terms	High
Labour intensity	High, including un-costed family labour	High, including part costed family labour	Low, family labour costed if used
Power sources	Manual labour with hand tools	Manual labour with hand tools and/or animal traction with improved implements	Complete mechanization including harvesting
Technology employed	Local cultivars. No fertilizer or chemical pest, disease and weed control. Rest (fallow) periods. No long-term soil conservation measures	Improved cultivars as available. Limited fertilizer application. Simple extension packages including some chemical pest, disease and weed control. Some rest (fallow) period. Some simple long-term conservation measures	High yielding cultivars. Optimum fertilizer application. Chemical pest, disease and weed control. Minimum rest (fallow) periods. Complete conservation measures
Infrastructure requirements	Market accessibility not necessary. Inadequate advisory services	Some market accessibility necessary with access to demonstration plots and services	Market accessibility essential. High level of advisory services and application of research findings
Land holdings	Small, sometimes fragmented	Small, sometimes consolidated	Large, consolidated

Table 2 CROPS OF THE ASSESSMENT CF. MAIN CROPS OF THE WORLD

Main World Crops (in decreasing order of importance with regard to area cultivated)	Area 1/ Harvested (000 ha)	Crops of the Assessment
Wheat	232 076	Spring wheat, Winter wheat
Rice	145 130	Bunded rice, Upland rice
Maize	117 767	Maize
Barley	94 324	Winter barley
Millet	55 019	Pearl millet
Soybean	52 859	Soybean
Sorghum	51 911	Sorghum
Cotton	32 980	
Phaseolus bean	29 615	Phaseolus bean
Oat	27 895	
Groundnut	18 919	Groundnut
White potato	18 167	White potato
Rye	16 365	
Sugarcane	13 881	Sugarcane
Drypea	13 231	
Cassava	13 132	Cassava
Sweet potato	11 934	Sweet potato
Rapeseed	11 104	
Chickpea	10 481	
Grape	10 040	
		Banana/Plantain
		Oil palm
		Grassland

1/ FAO, 1979. Production Yearbook 1978. Vol. 32, FAO, Rome.

(FAO, 1971-79) has been used for the provision of essential soil, slope, texture and phase data. The next step in the methodology is the application of rest period rules, (12), (Young and Wright, 1979). The extent of the necessary rest period is dependent on the level of input, soil and climatic conditions and crops. Many soils of the tropical and sub-tropical regions cannot be continuously cultivated, in their natural state, with annual food crops without undergoing degration and hence it is important to incorporate the relevant rest periods.

In addition to the effects of climatic and soil factors on yield and production potentials, these two factors also need to be considered in respect of their effects on degradation of land and resultant reduced yield and production potentials. Degradation of land takes place in many ways, water erosion and wind erosion being the most obvious in rainfed crop production. Computations of the rate of soil loss under various climatic, soil and land use circumstances reveal the severity of the degradation hazard in the various agro-ecological zones (Arnoldus, 1980, FAO/UNEP/UNESCO, 1979). In the present study degradation hazard input (13) is taken into account after the other physical factors influencing productivity have been considered, and is applicable only to those tracts of land found to be at least marginally productive.

The final step in the estimation of crop production potential in terms of caloric value is the application of crop-wise calorie/protein yield levels with appropriate reductions for seed and waste, (FAO, 1980).

LAND PRODUCTIVITY AND CROP MIX

Figure 2 shows the steps in the assessment of optimal crop mix choice. This assessment uses the results of the land suitability and productivity, Figure 1, and determines for each agro-ecological zone a crop mix subject to certain constraints depending on the mode under which the land productivity is evaluated, (Fischer and Shah, 1979).

Three modes of evaluation are considered, namely:

Mode 1: Selects for each zone a crop mix in order to maximize calorie production.

Mode 2: Maximizes zonal calorie production subject to a calorie/protein ratio constraint.

Mode 3: Maximizes zonal calorie production subject to a given cropping pattern. (Present Crop Mix Constraint)

In the following, the three modes will be described in a more formal way. Let X_{ij} denotes the share of crop i, i=1,...,NCOM in the land use of cell j, j=1,...,NCELL, in a particular agro-ecological zone. Similarly, let CAL_{ij} and PRT_{ij} denote the potential calorie and protein production of crop i in cell j. On the zone level, we define CALIR and PRTIR to be the calorie and protein production from irrigation whereas CALREQ and PRTREQ denote country-specific calorie and protein requirement. Finally, β_i, i=1,..., NCOM, is the share of each crop in the present cultivation practice. Using the above notation, the different modes can be described in the following way:

MODE 1:

$$\max_{X_{ij}} \sum_{j=1}^{NCELL} \sum_{i=1}^{NCOM} X_{ij} \cdot CAL_{ij}$$

$$\text{s.t.} \sum_{i=1}^{NCOM} X_{ij} \leq 1 \qquad j = 1,\ldots,NCELL$$

$$X_{ij} \geq \emptyset \qquad i = 1,\ldots,NCOM \; ; \; j = 1,\ldots,NCELL$$

MODE 2:

$$\max_{X_{ij}} \sum_{j=1}^{NCELL} \sum_{i=1}^{NCOM} X_{ij} \cdot CAL_{ij}$$

$$\text{s.t.} \sum_{i=1}^{NCOM} X_{ij} \leq 1 \qquad j = 1,\ldots,NCELL$$

$$CALIR + \sum_{j=1}^{NCELL} \sum_{i=1}^{NCOM} X_{ij} \, CAL_{ij} \leq \frac{CALREQ}{PRTREQ} \cdot \left(PRTIR + \sum_{j=1}^{NCELL} \sum_{i=1}^{NCOM} X_{ij} \cdot PRT_{ij} \right)$$

$$X_{ij} \geq 0 \qquad i=1,\ldots,NCOM \; ; \; j=1,\ldots,NCELL$$

<u>Remark</u>: Because of the calorie and protein production from irrigation, the mode 2 problem might be infeasible. In this case, CALIR and PRTIR are ignored in the protein constraint.

Mode 3:

$$\max_{X_{ij}} \sum_{j=1}^{NCELL} \sum_{i=1}^{NCOM} X_{ij} \cdot CAL_{ij}$$

$$\text{s.t.} \sum_{i=1}^{NCOM} X_{ij} \leq 1 \qquad j=1,\ldots,NCELL$$

$$\sum_{j=1}^{NCELL} X_{ij} \cdot \frac{CAREA_j}{TAREA} \leq \beta \cdot \lambda \quad i=1,\ldots,NCOM$$

where

$CAREA_j$, j=1,...,NCELL, denotes the extent of crop land area in cell j and TAREA the total zonal crop land area, i.e.

$$TAREA = \sum_{j=1}^{NCELL} CAREA_j \quad .$$

The scalar λ may be used to specify which portion of the land is to be allocated according to the present cultivation practice. Any land left after solving problem (3) is allocated as under MODE 1.

Although all three problems have been posed in the form of a linear program, the mode 1 case has a very simple solution. The algorithm just picks the most productive crop (in terms of calories) in each cell. If this solution together with production from irrigation satisfies the calorie/protein constraint in the zone, then this crop mix is also optimal for mode 2. In practice, we have found that this applies to a considerable number of zones in Africa.

The choice of crop mix depends on, for example at a country-level, the food and non-food crop requirements for domestic use and for trade. These are basically determined by the traditional diet as well as prices and relative profitability of each crop. For example a strategy for a particular country crop mix could take the form of satisfying (100% or less) the domestic food requirements and maximizing the export earnings of the surplus. In the present project phase the aim was to evaluate the maximum food production potential and in this context the non-food crops were not explicitly considered in the case of rainfed production. The food - equivalent value of irrigated nonfood crops have been included in the quantification of the caloric/protein value of irrigated crops, (FAO, 1979, Wood, 1979).

In the second phase of the project, for particular country case studies, the methodology will take account of the aspects such as non-food crops, domestic and trade requirements of all crops, input and infrastructure requirements, etc.

As shown in Figure 2, once the maximum potential calorie-protein production for each length of growing period zone is ascertained (rainfed and irrigated), application of country specific per capita calorie-protein requirements (15) allow computation of the potential population supporting capacity in each zone in each country. This data is computed as potential population densities (persons per ha.) and is compared with present population density data (17) to identify critical zones where, according to the level of input envisaged, potential sustained production from land resources is insufficient to meet the food needs of the populations already living in these areas. Country population projections for the year 2000 - U.N. medium variant projections, are also compared with country potential population densities to identify critical zones, i.e. zones which will be critical with regard to food production for their future populations. At the scale of the assessment, it has not been possible to take into account existing or projected trade of food supplies between countries. The results for Africa, with the "no trade" assumption, are presented in the present contribution.

For any particular country (or region), the number of alternative evaluations, summarized in Fig. 3, are 18 for the year 1975 and another 18 for the year 2000.

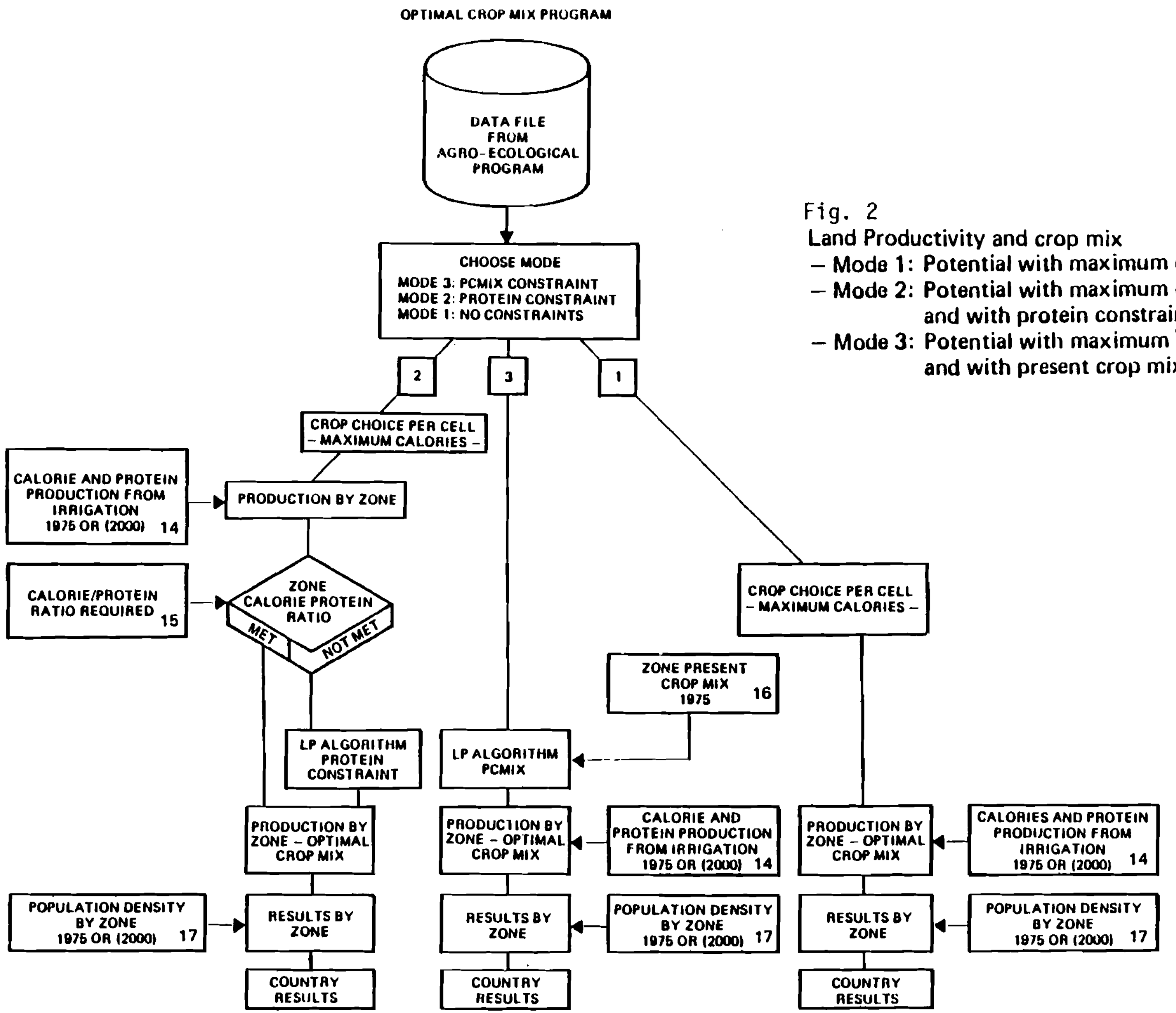


Fig. 2
Land Productivity and crop mix
– Mode 1: Potential with maximum calorie production
– Mode 2: Potential with maximum calorie production and with protein constraint
– Mode 3: Potential with maximum calorie production and with present crop mix constraint

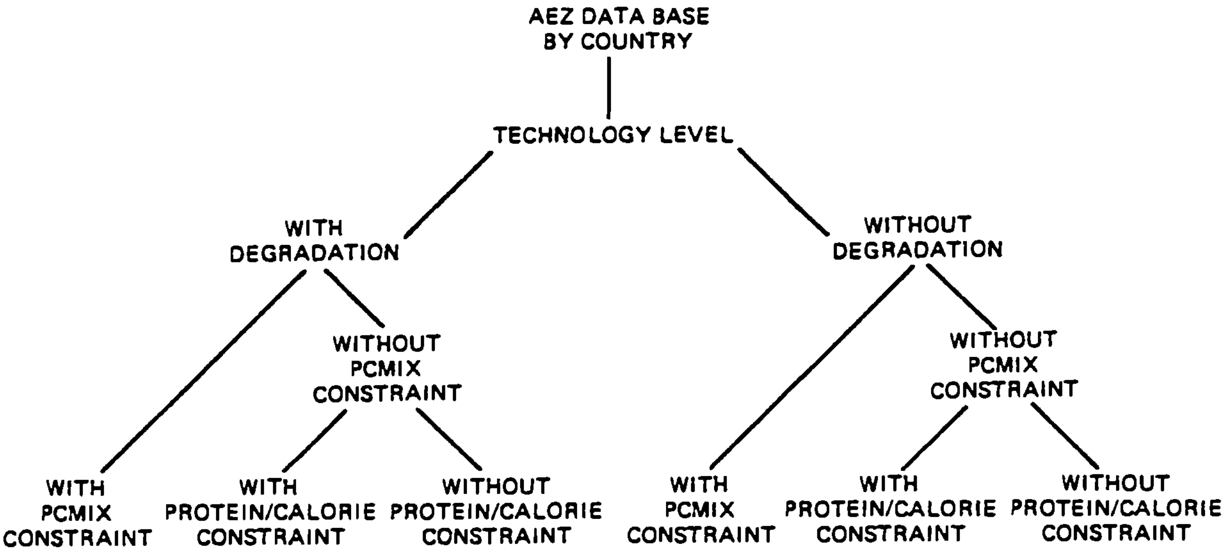


Fig.3 Alternative runs for assessment of population supporting capacity
– Year 1975 or (2000)
– Three levels of technology: low, intermediate or high
(1975: Total number runs for one country = 18)
(2000: Total number runs for one country = 18)

RESULTS

In this paper the results for three alternative scenarios will be discussed, namely,

<u>High Level of Inputs</u>: The potential population supporting capacity if all rainfed cultivable land were put to optimal use through an application of high level of inputs including complete mechanization, complete installation of all necessary soil conservation measures and cultivation of only the most calorie-protein productive crops.

<u>Intermediate Level of Inputs</u> The potential population supporting capacity if all rainfed cultivable land were utilized under an intermediate level of inputs, with crop optimization confined to presently unused (but potentially cultivable) areas and with application of simple conservation measures to lessen land degradation.

<u>Low Level of Inputs</u> The potential population supporting capacity, assuming only hand labour (no fertilizers, pesticides, insecticides) and extending the presently grown mixture of crops to all rainfed potentially cultivable lands but without conservation measures and hence with productivity losses due to land degradation.

These estimates are compared with data on present population in the length of growing period zones to identify critical zones where land resources are insufficient to meet present food needs.

While there is no simple methodology to undertake population projections on a zone basis, projections are available on a country level data, appropriate zone potential population supporting capacities are aggregated to arrive at the potential for each zone as a whole, these zone potentials are compared with zone projections (year 2000 medium variant), as well as with present populations. This allows identification of critical zones where land resources are (or will be) insufficient to supply the food needs of present and/or projected populations.

The present population data employed in this comparison is based on the most recent country census data for administrative areas. The zone totals are derived from this by map overlays and approximation, according to the extents of the various zones occurring in each administrative area. For these computations, the census data (various years) were brought forward to 1975 and the country totals adjusted to correspond with current UN estimates.

The results of these comparisons, for Africa, are as follows:

Africa Zone Results Compared With Present Population.

Results of the assessment for each length of growing period zone in Africa, combined for all countries, are presented by major climates in Table 3. The zones occurring in each major climate are listed on the left hand side of the table. Column 2 records the total extent of the zone; column 3 the present population in the zone and column 4 is the present population density in the zone expressed as persons per hectare. The remaining six columns of the table (5 to 10) show the results of the assessments of potential populations supporting capacities of the zones under the three levels of input envisaged. Column 5, 7 and 9 show the potential density and columns 6, 8 and 10 show the ratio of potential to present population (year, 1975). Ratios of less than 1.0 indicate that the potential population supporting capacity of a zone is less than the present population in that zone. Such situations are underlined, to indicate zones where the envisaged use of the land resources cannot meet the food needs of the existing population. In considering the results, the reader is again cautioned that the assessment represents a "first approximation" of the situation and that the results need to be interpreted with due caution particularly as no account is taken of trade between surplus and deficient zones.

Over the vast area of the tropics, the highest population densities are generally found in the moderately cool and cool (highland) areas. Maximum densities of more than 0.4 persons per hectare occur in most of the wetter parts of these climates (more than 240 days length of growing period zones), decreasing to 0.3 and 0.2 persons per hectare as the length of growing period shortens and conditions become less suitable for crop growth. Only in the extremely arid areas (less than 75 days growing period zones) do present population densities decrease below 0.2 persons per hectare.

This present situation does not accord with the potential population supporting capacities of zones in these major climates which contain a considerable number of large cities. Under low input conditions the majority of zones in the cool tropics contain more people than the land can support (11 critical zones) and the situation is no better in the moderately cool tropics (12 critical zones). Even under intermediate and high levels of inputs, some zones still remain critical.

The situation in the vast areas of the warm tropics (lowlands) in Africa is not, in general, critical. This climatic area could support more than three (3.397) times the present population even under a low level of inputs. Present population densities range from 0.319 persons per hectare in the wetter areas (365 days growing period zone) to 0.026 persons per hectare in the driest areas (0 days growing period zone).

However, within this overall picture of the warm tropics, critical areas do occur. Under low level of input conditions, the entire area of the Sahelian zone is critical. On the average, all lengths of growing period zones of less than 150 days already

Table 3 POTENTIAL POPULATION SUPPORTING CAPACITIES OF LENGTH OF GROWING PERIOD (LGP) ZONES IN AFRICA COMPARED WITH PRESENT POPULATIONS (DENSITIES-PERSONS/HA)

LGP ZONE (days)	TOTAL LAND (000 HA)	PRESENT POPULATION (000)	PRESENT DENSITY	LOW INPUTS		INTERMEDIATE INPUTS		HIGH INPUTS	
				POTENTIAL DENSITY	RATIO	POTENTIAL DENSITY	RATIO	POTENTIAL DENSITY	RATIO
WARM TROPICS									
365- N	19 791	1 367	0.069	1.434	20.783	6.333	91.783	8.986	130.232
365- N	127 585	40 636	0.319	1.610	5.054	4.689	15.351	12.546	39.390
330-364 N	75 016	16 189	0.216	1.373	6.364	5.333	24.711	11.168	51.749
300-329 N	73 264	16 555	0.226	1.440	6.374	6.068	26.855	13.431	59.435
270-299 N	127 820	29 556	0.231	0.876	3.788	4.698	20.317	10.209	44.152
240-269 N	133 423	25 157	0.189	0.919	4.876	4.427	23.481	11.577	61.400
210-239 N	129 920	20 416	0.157	0.659	4.194	2.891	18.399	10.535	67.030
180-209 N	225 745	36 794	0.163	0.492	3.017	2.149	13.185	8.368	51.341
150-179 N	175 044	29 814	0.170	0.503	2.952	2.327	13.660	9.027	53.002
120-149 N	114 190	24 917	0.218	0.135	0.619	0.759	3.478	5.214	23.896
90-119 N	72 051	12 661	0.176	0.075	0.426	0.247	1.404	3.179	18.092
75-89 N	58 436	7 661	0.131	0.059	0.452	0.144	1.100	1.557	11.875
1-74 N	370 809	23 825	0.064	0.034	0.529	0.043	0.673	0.058	0.903
0 (dry)	180 563	4 620	0.026	0.000	0.005	0.000	0.005	0.000	0.005
1-74 I	64 808	1 299	0.020	0.007	0.344	0.015	0.727	0.027	1.332
75-89 I	22 707	1 134	0.050	0.033	0.656	0.106	2.118	0.919	18.397
90-119 I	49 590	3 229	0.065	0.030	0.454	0.152	2.335	2.013	30.923
120-149 I	43	11	0.250	0.107	0.429	0.507	2.026	2.355	9.421
Sub-total	2 020 797	295 841	0.146	0.496	3.397	2.075	14.212	6.110	41.849
MODERATELY COOL TROPICS									
365- N	1 446	398	0.275	0.011	0.041	0.056	0.205	0.873	3.171
330-364 N	1 568	693	0.442	0.052	0.118	0.273	0.618	2.265	5.128
300-329 N	2 138	1 022	0.478	0.166	0.347	0.648	1.355	3.269	6.843
270-299 N	7 293	3 223	0.442	0.252	0.570	0.854	1.933	4.770	10.795
240-269 N	10 570	4 754	0.450	0.334	0.743	1.049	2.333	5.343	11.882
210-239 N	9 586	2 855	0.298	0.360	1.209	1.392	4.674	5.741	19.275
180-209 N	8 775	2 400	0.273	0.316	1.154	1.259	4.603	5.073	18.552
150-179 N	4 225	1 657	0.392	0.251	0.641	0.852	2.172	3.704	9.444
120-149 N	3 887	1 158	0.298	0.138	0.464	0.502	1.685	2.195	7.367
90-119 N	4 709	1 029	0.219	0.025	0.114	0.057	0.259	0.124	0.569
75-89 N	2 551	702	0.275	0.022	0.078	0.051	0.184	0.115	0.419
1-74 N	1 466	246	0.168	0.047	0.281	0.061	0.362	0.078	0.468
0 (dry)	2 750	0	0.0	0.036		0.036		0.036	
1-74 I	2 453	20	0.008	0.008	0.956	0.017	1.947	0.024	2.818
75-89 I	131	0	0.008	0.004	0.536	0.011	1.521	0.026	3.476
90-120 I	64	0	0.0	0.004		0.011		0.025	
Sub-total	63 612	20 157	0.317	0.220	0.695	0.783	2.470	3.584	11.309
COOL TROPICS									
365- N	697	193	0.276	0.008	0.030	0.042	0.152	0.280	1.014
330-364 N	749	317	0.424	0.027	0.063	0.178	0.420	0.612	1.445
300-329 N	1 010	470	0.466	0.040	0.086	0.183	0.392	0.636	1.365
279-299 N	3 534	1 420	0.402	0.084	0.210	0.306	0.763	0.905	2.251
240-269 N	5 084	2 276	0.448	0.167	0.373	0.681	1.522	3.532	7.888
210-239 N	4 607	1 357	0.295	0.283	0.960	1.001	3.400	3.529	11.985
180-209 N	4 226	1 143	0.271	0.375	1.387	1.399	5.169	4.875	18.016
150-179 N	1 985	749	0.377	0.239	0.632	0.833	2.206	3.517	9.319
120-149 N	1 807	539	0.298	0.137	0.460	0.509	1.707	2.099	7.042
90-119 N	2 044	431	0.211	0.028	0.134	0.066	0.313	0.127	0.605
75-89 N	1 185	335	0.283	0.022	0.079	0.053	0.198	0.116	0.412
1-74 N	678	109	0.161	0.010	0.064	0.024	0.152	0.041	0.257
0 (dry)	1 359	0	0.0	0.0		0.0		0.0	
1-74 I	1 223	9	0.007	0.008	1.114	0.017	2.269	0.024	3.281
75-89 I	64	0	0.0	0.005		0.011		0.025	
90-119 I	31	0	0.0	0.004		0.010		0.023	
Sub-total	30 283	9 348	0.309	0.163	0.527	0.602	1.950	2.329	7.546
COLD TROPICS									
0 (cold)	2 905	1 070	0.368	0.0	0.0	0.0	0.0	0.0	0.0
Sub-total	2 905	1 070	0.368	0.0	0.0	0.0	0.0	0.0	0.0

Ratio = ratio of potential to present populations.

Table 3 (cont.)

LGP ZONE (days)	TOTAL LAND (000 HA)	PRESENT POPULATION (000)	PRESENT DENSITY	LOW INPUTS POTENTIAL DENSITY	LOW INPUTS RATIO	INTERMEDIATE INPUTS POTENTIAL DENSITY	INTERMEDIATE INPUTS RATIO	HIGH INPTUS POTENTIAL DENSITY	HIGH INPTUS RATIO
WARM SUB-TROPICS WITH SUMMER RAINFALL									
270-299 N	48	17	0.357	0.054	0.152	3.677	10.296	4.270	11.957
240-269 N	28	9	0.333	0.070	0.211	1.560	4.681	4.063	12.190
210-239 N	30	10	0.333	0.077	0.232	0.649	1.948	3.993	11.979
180-209 N	593	192	0.324	1.138	3.517	3.796	11.733	6.118	18.909
0 (dry)	227 611	1 509	0.007	0.000	0.025	0.000	0.025	0.000	0.025
1-74 I	8 849	108	0.012	0.007	0.547	0.013	1.094	0.020	1.603
75-89 I	684	23	0.034	0.047	1.374	0.207	6.078	1.207	35.394
90-119 I	1 456	110	0.075	0.141	1.869	0.456	6.036	2.051	27.175
120-149 I	260	66	0.254	0.651	2.566	2.178	8.581	4.753	18.725
150-179 I	282	86	0.307	0.705	2.299	2.193	7.149	3.945	12.863
Sub-total	239 840	2 130	0.009	0.006	0.649	0.019	2.176	0.044	4.898
MODERATELY COOL SUB-TROPICS WITH SUMMER RAINFALL									
240-269 N	25	4	0.154	0.344	2.234	0.794	5.160	2.044	13.283
210-239 N	25	4	0.154	0.372	2.419	0.992	6.447	2.142	13.925
180-209 N	371	104	0.282	0.303	1.074	1.073	3.808	2.651	9.407
0 (dry)	3 992	11	0.003	0.0	0.0	0.0	0.0	0.0	0.0
1-74 I	730	172	0.236	0.008	0.033	0.016	0.067	0.020	0.084
75-89 I	80	37	0.459	0.005	0.012	0.012	0.026	0.018	0.040
90-119 I	194	90	0.464	0.136	0.293	0.014	0.030	0.234	0.504
120-149 I	261	130	0.500	0.165	0.330	0.291	0.583	0.593	1.187
150-179 I	654	297	0.455	0.293	0.644	0.563	1.238	1.265	2.782
Sub-total	6 332	849	0.134	0.063	0.468	0.142	1.061	0.337	2.509
COOL SUB-TROPICS WITH SUMMER RAINFALL									
240-269 N	10	3	0.308	0.009	0.028	0.029	0.096	0.153	0.498
210-239 N	10	1	0.154	0.020	0.128	0.033	0.215	0.135	0.879
180-209 N	185	50	0.271	0.362	1.336	0.958	3.538	2.657	9.811
0 (dry)	1 984	5	0.003	0.0	0.0	0.0	0.0	0.0	0.0
1-74 I	292	51	0.176	0.008	0.045	0.016	0.089	0.018	0.100
75-89 I	34	16	0.460	0.005	0.012	0.012	0.026	0.019	0.041
90-119 I	91	42	0.458	0.006	0.014	0.014	0.030	0.221	0.482
120-149 I	126	63	0.500	0.083	0.167	0.211	0.421	0.522	1.044
150-179 I	324	147	0.455	0.189	0.416	0.484	1.062	1.239	2.723
Sub-total	3 506	378	0.124	0.047	0.375	0.120	0.969	0.323	2.607
COLD SUB-TROPICS WITH SUMMER RAINFALL									
0 (cold)	185	37	0.201	0.0	0.0	0.0	0.0	0.0	0.0
Sub-total	185	37	0.201	0.0	0.0	0.0	0.0	0.0	0.0
COOL SUB-TROPICS WITH WINTER RAINFALL									
240-269 N	84	31	0.368	0.204	0.554	0.770	2.090	2.838	7.703
210-239 N	7 589	7 735	1.019	0.261	0.256	1.208	1.185	2.782	2.729
180-209 N	7 167	7 469	1.042	0.421	0.404	1.963	1.883	4.016	3.854
150-179 N	5 635	3 297	0.585	0.647	1.106	1.919	3.279	3.449	5.894
120-149 N	5 819	2 829	0.486	0.409	0.842	1.323	2.720	2.515	5.173
90-119 N	7 751	2 644	0.341	0.411	1.205	0.808	2.370	1.337	3.919
0 (dry)	431 366	42 619	0.099	0.140	1.413	0.140	1.413	0.140	1.413
1-74 I	38 515	5 215	0.135	0.138	1.022	0.160	1.185	0.189	1.392
75-89 I	7 491	1 508	0.201	0.516	2.562	0.539	2.677	0.568	2.820
90-119 I	1 538	1 136	0.738	0.581	0.787	0.728	0.985	0.945	1.280
Sub-total	512 955	74 483	0.145	0.165	1.135	0.233	1.606	0.327	2.252
COLD SUB-TROPICS WITH WINTER RAINFALL									
0 (cold)	5 967	2 636	0.442	0.0	0.0	0.0	0.0	0.0	0.0
Sub-total	5 967	2 636	0.442	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL 1/	2 885 911	406 929	0.141	0.385	2.730	1.510	10.780	4.463	31.652

UNDERLINING INDICATES POTENTIAL POPULATION SUPPORTING CAPACITY < PRESENT POPULATION

1/ excludes South Africa

carry twice the number of people (potential to present population ratios 0.005 to 0.656) that can be supported under low inputs. Even under intermediate input conditions, all zones of less than 75 days length of growing period are critical and cannot meet the food needs of the existing populations.

Similar findings generally hold true for the relatively small areas of sub-tropics with summer rainfall. A summary of the number of critical zones in these climates of Africa is shown below.

Major Climate and (Number of Zones)	Number of Critical Zones Low Inputs	Intermediate Inputs	High Inputs
Warm Tropics (18)	9	2	2
Moderately Cool Tropics (16)	12	5	3
Cool Tropics (16)	11	7	3
Cold Tropics (1)	1	1	1
Warm Sub-tropics, Summer Rainfall (10)	5	1	1
Moderately Cool Sub-tropics, Summer Rainfall (9)	6	5	4
Cool Sub-tropics, Summer Rainfall (9)	8	7	6
Cold Sub-tropics Summer Rainfall (11)	1	1	1
Total (80)	53	29	21

In contrast with the above results covering Africa south of the Sahara, the results for sub-tropics with winter rainfall are not so critical under an intermediate level of inputs.

In areas of sub-tropics with winter rainfall in North Africa, present population densities range from more than 1.0 persons per hectare in wetter areas (more than 210 day length of growing period zones) to less than 0.1 persons per hectare in the driest areas (0 days length of growing period zone). Under low level of input circumstances, 5 out of 10 zones in this major climate are critical. Under such input circumstances the worst situation would occur in the highly populated coastal zone of 210 days to 240 days length of growing period where the potential/present population ratio is 0.256.

Under the intermediate level of input circumstances only one zone (90-120 days) is critical and even in this case, the potential/present population ratio is very close to 1.0 (i.e. 0.985). Under high levels of input circumstances, all length of growing period zones in the sub-tropics with winter rainfall are not critical with the exception of the cold (mountain) areas. The number of critical zones in Africa is shown below.

Major Climate and (Total Number of Zones)	Number of Critical Zones Low Inputs	Int. Inputs	High Inputs
Cool Sub-tropics, Winter Rainfall (10)	5	1	0
Cold Sub-tropics, Winter Rainfall (1)	1	1	1
Total (11)	6	2	1

SUMMING-UP

The ability of land to produce food is limited and the limits of production are set by soil and climatic conditions and by the use and management employed. Any "mining" of land beyond these limits leads to land degradation and reduced productivity. Accordingly, there are critical levels of populations that can be supported from any specific land area. Any attempts to produce food for populations in excess of these critical levels will, in the long term, result in failure. Degradation of land, hunger and eventual reduction in population are the outcome of such practices.

Estimates of the potential population supporting capacities of lands at a global level, are being made to identify critical areas where land resources are insufficient to meet the food needs of the people living in them. Results for Africa show that the continent as a whole has sufficient cultivable land for food self sufficiency. Under an assumption of a low level of inputs, the combined potential productivity from all 51 countries could feed 50 percent more people than the estimated year 2000 population. At an intermediate input level, the land resources could adequately provide for more than 5 times the projected population. Such however is only the overall situation assuming massive and unlimited movement of food between and within countries and a major movement of people and infra-structure building in areas which are as yet under-utilized.

At the individual zone level, the situation changes markedly due to very large differences in land resource endowment. While it is not yet possible to satisfactorily effect population projections at the zone level, comparisons of zone potential population supporting capacities with present populations indicate the present situation. In large areas of the warm tropics (lowlands), present population densities are generally less than the potential population supporting capacities.

One major exception is however apparent, namely the drier lands comprising length of growing period zones of less than 150 days which, on average, are already carrying twice the number of people that can be supported at the low level of input. The present population of such zones is 79.4 million and the land area 933.2 million ha., a density of 0.08 persons per ha. The potential population supporting capacity of these lands is 0.04 persons per ha. Even at the intermediate input conditions, some of these zones in specific countries remain critical, as do all zones with less than 75 days growing period. The present populations in such zones is 29.7 million and the land area 616.2 million ha., a density of 0.04 persons per ha. The potential population supporting capacity is 0.02 persons per ha.

Another, but less well recognized and publicized major critical area occurs in Africa, namely in the highland areas with benign moderately cool and cool climates. The potential population supporting capacity of these zones is 0.20 persons per ha. at the low level of inputs management. Even with attainment of the intermediate level of inputs, many zones in these climates remain critical and, in specific areas, some zones remain critical even at the high level of inputs management.

Three solutions only are possible in the later circumstance where the situation is critical at the high level of inputs and four solutions in the in the former circumstance where the situation is critical at the intermediate level of inputs. For those areas that already carry more people than the land resources can support at the high input level, solutions involving population planning, food importation and major land improvements (singly or in combination) are the only long-term remedies. Continuation of the present situation in critical areas can only lead to accelerated worsening conditions through land degradation, declining productivity and malnutrition.

In areas where the situation is critical at the intermediate input level, a further possibility is apparent, namely raising the input level to attain additional production. The economics of this and of major land improvements however, require careful investigation.

The present recognition of critical areas identifies locations where more detailed work, incorporating aspects outside the scope of this first general study, is required to adequately plan for the wellbeing of present and future populations.

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