WORKING PAPER

ASSESSMENT OF POPULATION SUPPORTING CAPACITIES - OVERALL COMPUTER PROGRAMS

G. Fischer and M.M. Shah

March 1980
WP-80-40

Presented at the FAO/UNFPA Expert Consultation on Methodology for Assessment of Population Supporting Capacities in Rome, 4-6 December, 1979

IIASA
International Institute for Applied Systems Analysis

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PREFACE

"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, namely:

a) Different 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) Different crops (with widely differing climatic and soil requirements).

c) Different levels of inputs and technology.

d) Different socio-economic factors.

Recognizing these aspects, FAO and UNFPA have initiated a project to compute the human supporting capacities of agricultural lands and to compare these with data on existing and projected populations. The project entitled "Land Resources for Populations of the Future" commenced on 1st September, 1976.

The Food and Agriculture Program at IIASA has participated in this project since September, 1978. IIASA's contribution in conjuction with the Land and Water Division, FAO, is concerned with the development and simulation of the overall methodology for the analysis of the FAO climate/soil data base to determine optimum crop mix and estimation of population supporting capacity.

The information generated in this approach is important in that it provides data which can form the basis of the planning of the food and agricultural sector. It is recognized that the analysis is carried out on the basis of the 1:5 million FAO-UNESCO soil map. Most developing countries have not had the resources to carry out detailed soil and climate surveys. Apart from being expensive in time and money, soil surveys are useful only if carried out with a view to assessing the agricultural potential. The methodology as developed in this project is particularly relevant since it considers the most important food crops as well as the degradation hazard in relation to the environment and management practice. At a country level, the data best generated here will certainly need to be supplemented by specific and in-depth surveys.

The present and future agricultural production in various countries depends on a wide variety of factors such as ecology, technology, environment, socio-economics, international trade, etc. All these aspects cannot be investigated at the global level but for particular country studies, the data base as generated in the AEZ project provides a starting point for the integration of the wide range of factors that are crucial to the development of the food and agricultural sector in various countries.

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ASSESSMENT OF POPULATION SUPPORTING CAPACITIES - OVERALL COMPUTER PROGRAMS

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1. INTRODUCTION

The Food and Agriculture Program at the International Institute for Applied Systems Analysis (IIASA) has participated in this project since September, 1978. IIASA's contribution in conjunction with the Land and Water Division, FAO, is concerned with the computerization of the data base and development of computer programs for the simulation of the overall methodology to assess the population supporting capacities of all developing countries in Africa of present (1975) and projected (2000) populations with interzone comparisons. The methodology for this assessment was to be developed in the context of the following alternative assumptions:

1. The ultimate potential human supporting capacity, if all lands were used for an optimum (maximize calorie production) mix of food crops under the assumption of three input levels of technology, namely, low, intermediate and high.

2. As in 1. but also incorporating land degradation hazards.

3. As in 1. and 2. but also incorporating a protein constraint.

4. As in 1. and 2. but also incorporating a present land use (PLU) constraint. The PLU is concerned with the present crop mix pattern by length of growing period in agro-ecological zone (AEZ) and limited to the basic eighteen food crops.

The computer program development was completed in October 1979 and the results for a number of countries were discussed with the Land and Water Division, F.A.O. The final programs were implemented on the F.A.O. IBM computer in early November 1979.

2. STRUCTURE OF THE COMPUTER PROGRAM

In developing the overall computer program[†] the central feature was the incorporation and coordination of a large data base, in such a way that a computationally efficient (computer storage requirement and computing time) program is obtained. The data base is composed of:

1. Land inventory: 51[*] countries, total number of records = 36,868[**]

2. Irrigation data. Area by location and corresponding calorie/protein production: 37 countries, total number of records (1975) = 368, (2000) = 539.

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[*] Two countries have been left out (Djibuti, South Africa).

[**] After elimination of double and zero entries in the land inventory.

[†] "Computer Programs for Assessment of Food Production and Human Supporting Capacities . G. Fischer, B. Lopuch, M.M. Shah. FAO/IIASA, 1979, forthcoming.

3. Climate, Productivity, Slope, Phase, Texture, Fluvisol, Degradation, Fallow and Yield Tables: approximately 1347 records.

4. Present Crop Mix by AEZ, Population (1975) by AEZ, Agricultural Land by AEZ and Protein/Calorie Requirement for 51 countries. For the year (2000) we have assumed* that the population in each AEZ grows proportional to total population increase, i.e., relative population densities remain constant.

The overall computer program has been structured in two parts, namely,

A. Land Productivity Program

B. Optimal Crop Mix Program.

The program has been set up such that results can be obtained for any one country or a region (a number of neighbouring countries, all developing countries in Africa, etc.).

2.1. Land Productivity Program

The structure and sequence of operation of this program is shown in Figure 1. The main steps in the program are:

*Alternatives are linear share extrapolation, exponential share extrapolation, etc.

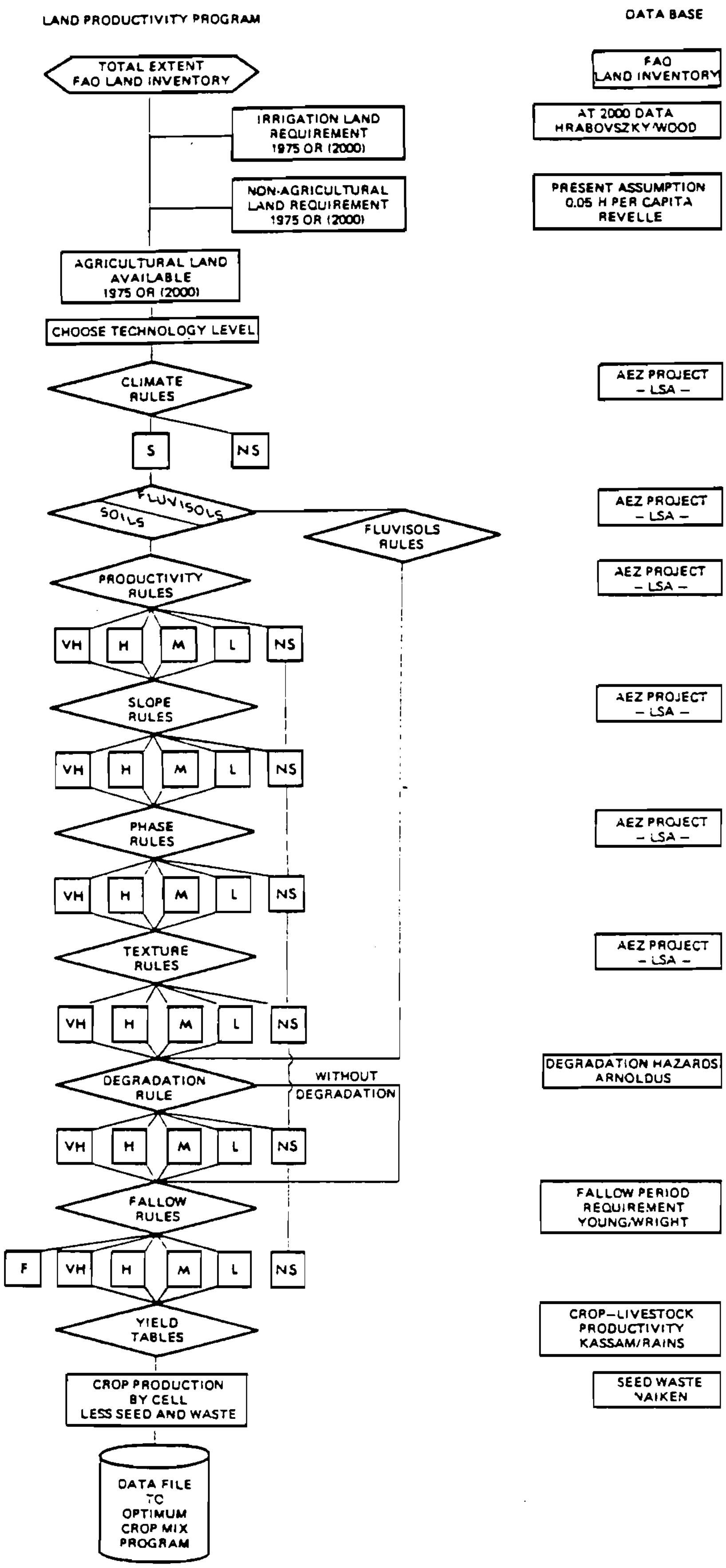

Figure 1. Agro-ecological program and data base for crop and livestock production assessment
- Three levels of technology
- With and without degradation hazards
- Country level results
- Simulation for 1975 or (2000)

Step 1. From the total extent of land, the available agricultural land is derived after making appropriate allowance for non-agricultural and irrigation land requirement.

Step 2. The climate, productivity, slope, phase, texture, and fluvisol rules are applied to each cell of information in the land inventory. The application of the climate rules results in two sets of information, i.e., whether a crop is suitable or not suitable for consideration within a particular climate. The application of all other rules at each stage allocates land within five classes, namely, Very High productivity (VH), High productivity (H), Moderate productivity (M), Low productivity (L), and Not Suitable (NS). Note that if at any stage a particular piece of land falls in the NS class, then this land* is not considered further in the analysis.

Step 3. The program has the facility to include or exclude the land degradation rules, i.e., with or without land conservation measures.

Step 4. Fallow (rest period) land rules are applied and this results in an additional class of land labeled F (fallow).

Step 5. Finally the yield tables (by crop, by AEZ and by climate) are applied to the land areas in the four classes (VH, H, M and L) which are suitable for crop productivity.

It should be emphasized that the total number of computer runs by program A for a particular country (or region) comprises of a total of 6 runs for 1975 under the assumption of three technology levels and with and without degradation rules. A similar number of runs is necessary for the year (2000).

*This aspect has been modified and the NS land, if suitable, is reallocated to livestock production.

A data file for each of the six runs of Program A is created and this forms the input file for Program B where alternative assumptions for optimal crop mix and assessment of human supporting capacities are considered.

2.2. Optimal Crop Mix Program

Figure 2 shows the structure of this computer program. The Optimal Crop Mix Program uses the results of the Land Productivity Program and determines for each agro-ecological zone an optimal crop mix subject to certain constraints depending on the mode under which the program is operated. The relevant file produced by the Land Productivity Program contains three kinds of records referring to zones, cells within zones and crop production within a particular cell.

A zone is determined by four characteristics, the region, the country, the major climate and the length of the growing period. A zone is further subdivided into cells characterized by soil type, slope, phase and texture. Accordingly, zone records contain the necessary code information and data on total zone area, irrigated zone area, zone population, calories and protein from irrigation, and present crop mix shares. Cell records consist of coding information and the cell extent. Furthermore, for each suitable crop,a crop record describes the potential calorie and protein production from that particular crop in the cell under consideration. In addition, the crop record gives also the splitting of the cell extent into the different productivity classes.

A small control file contains country codes and country specific calorie and protein requirements and selects the run mode. The OCM Program can be operated under three modes:

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.

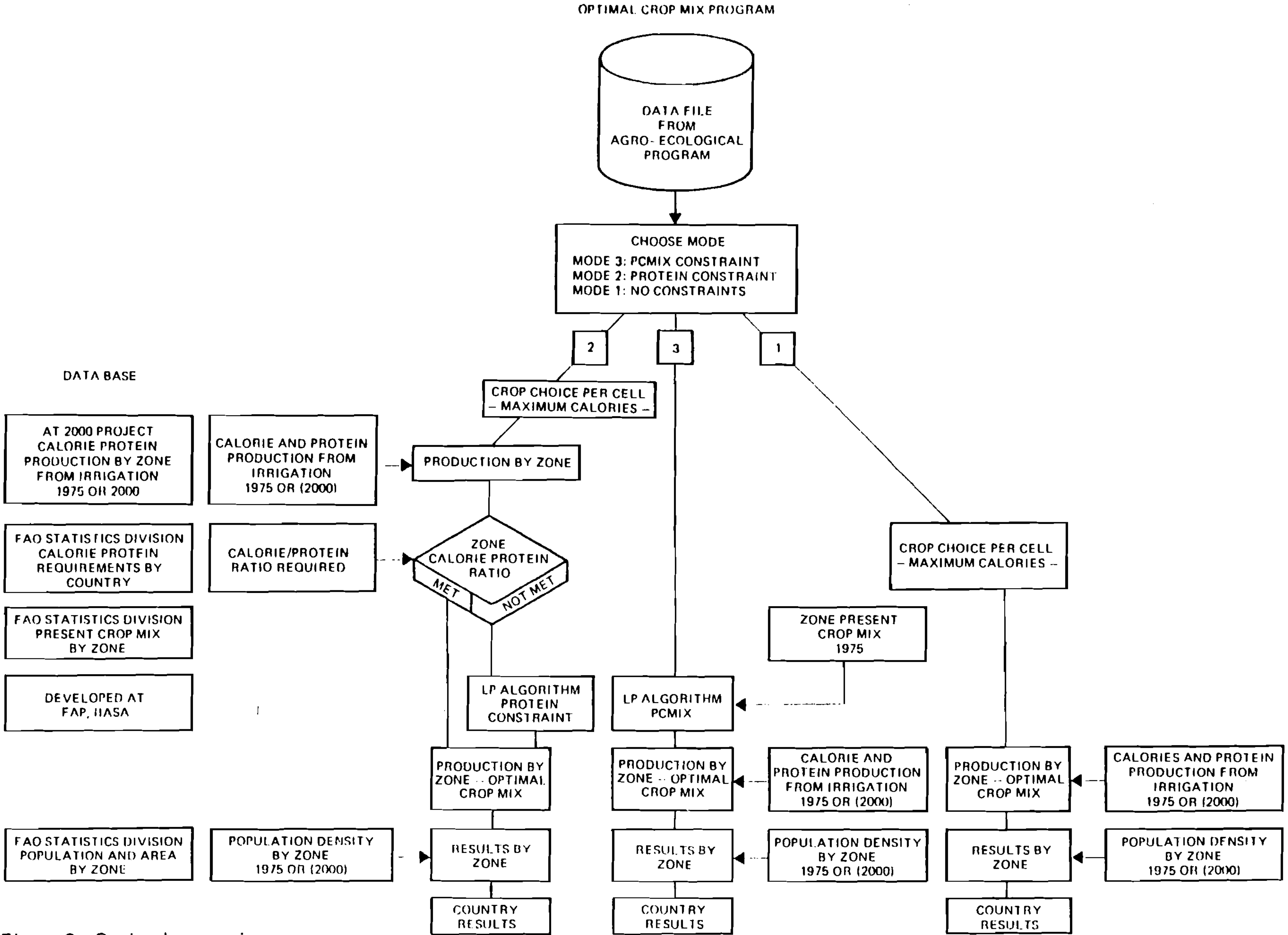

Figure 2. Optimal crop mix program
– Mode 1: Potential with maximum calorie production
– Mode 2: Potential with maximum calorie production and with protein constraint
– Mode 3: Potential with maximum calorie production and with present crop mix constraint

In the following, three modes will be described in a more formal way. Let X_{ij} denote the share of crop $i, i=1,\ldots,$ NCOM in the land use of cell $j, j=1,\ldots,$ 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, $\beta_i, i=1,\ldots,$ 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:

(1) MODE=1 :

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

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

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

(2) MODE=2 :

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

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

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

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

<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.

(3) <u>MODE=3</u> :

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

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

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

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 most expensive problem in terms of CPU and storage requirements is mode 3, since for each zone the corresponding LP has to be solved.

For each of the six computer runs for 1975 (and similarly for the year (2000)) carried out in Program A, the application of Program B yields three computer runs. Hence, for any particular country (or region), the number of alternative computer runs, summarized in Figure 3, is 18 for the year 1975 and another 18 for the year (2000).

Program A, as well as Program B has the facility to give results for any country (or region) at the following levels of information:

(i) Information by cell
(ii) " " zone
(iii) " " country
(iv) " " region.

To facilitate the understanding, the operation of computer programs A and B, numerical examples of the results for one cell, two zones and a country (reference country Kenya) are given in Appendix 1.

3. COMPUTER REQUIREMENTS

The computer (storage and computing time) requirements for a particular country run are dependent on the size of the land inventory. By this we mean the number of climates in the country, number of agro-ecological zones within each climate, and the number of cells within each zone. The overall computer program was developed on the PDP 11/70 Computer at IIASA. It whould be noted that this computing facility, much smaller than the IBM 370/148 at F.A.O., is suitable to process and produce all the results as considered in the project. The computer requirements in order to apply the computer Program A to a country depends on the size of the land inventory (number of cells) for the particular country. In the case of Program B, the major computational effort is involved in the mode 2 (protein constraint) and mode 3 (PLU constraint) where linear programming routines have to be applied.

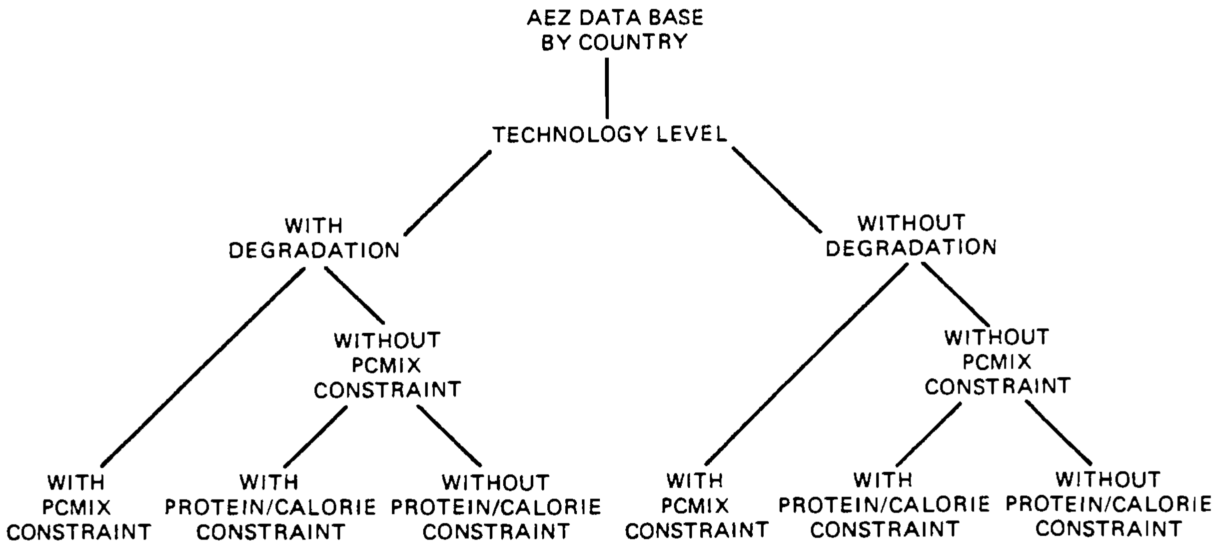

Figure 3. Alternative runs for assessment of human supporting capacity
— Year 1975 or (2000)
— Three levels of technology: low, intermediate or high
(1975: Total number runs for one country = 18)
(2000: Total number runs for one country = 18)

In the case of the Africa region:

Largest country:	Tanzania, 1678 entries in the land inventory, (maximum of 160 cells/zone).
Average country:	Nigeria, 660 entries (maximum of 86 cells/zone).
Smallest country:	Cape Verde, 18 entries (maximum of 15 cells/zone).

4. CONCLUSIONS AND FUTURE WORK

The work reported in this paper was completed in November 1979 and the resultant computer programs were implemented on the FAO computer. The results for all countries in Africa were discussed at the FAO/UNFPA Consultation Meeting, Rome, 4-6 December 1979. The final results consist of scenarios for three technology input levels, each with and without land degradation, under the assumption of:

i) continuance of the present cropping pattern;

ii) continuance of the present cropping pattern in part of the land area, the balance being allocated to crops producing the highest amount of calories;

iii) allocating the entire extent of the suitable area to crops producing the highest amount of calories;

iv) same as iii) but including a calorie/protein constraint.

The country level ecological and agricultural data base, as generated in this project, appears to be suitable for the analysis and modeling of ecological, environmental and technological systems within appropriate FAP national models. In particular, the following aspects are being investigated:

1. Comparison of the food production potential with the actual production. This "actual production" incorporates the following considerations:*

    a) Food crops as well as a number of cash crops.
    b) Different input levels (labor, fertilizer, capital, seed varieties, etc.) and management practices, corresponding to particular crops in different parts of the country.

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*not a exhaustive list

c) Crop choice depending on food requirement as well as "maximation of farmer's revenue". The present LP model is based on maximizing calories. This will be further developed to include satisfaction of food needs and other constraints, e.g., maximize foreign exchange, etc.

d) Future cropping pattern dependent on expected food and cash crop demand.

2. Choice and development of agricultural technology

3. Land conservation practice is vogue, future degradation risks corresponding to crops and management practice, and the identification of land conservation priorities.

The above aspects will be related to particular country case studies and the results used to develop simulation models that can be linked to the FAP models.

LIST OF PAPERS FOR THE FAO/UNFPA PROJECT -
RESOURCES FOR THE FUTURE

Report on the Agro-Ecological Zones Project, Vol. 1, Methodology and Results for Africa, World Soil Resource Report No. 48, FAO, Rome, 1978.

"Ratings of FAO/UNESCO Soil Units for Specific Crop Production", Consultant Paper No. 1, FAO-UNFPA Project INT/75/P13, FAO, Rome, 1979.

"Framework of a Soil Degradation Assessment Methodology", FAO-UNEP-UNESCO Report, FAO, Rome 1979.

"Rest period requirements of tropical and subtropical soils under annual crops". Consultant Paper No. 6, FAO-UNFPA Project, INT/75/P13, FAO, Rome, 1979

"Multiple cropping and rainfed crop productivity in Africa". Consultant Paper No. 5, FAO/UNFPA Project, INT/75/P13, FAO, Rome, 1979.

"Land Resources and Animal Production", Consultant Paper No. 8, FAO/UNFPA Project INT/75/P13, FAO, Rome, 1979.

A P P E N D I X

Numerical results of the land productivity program and the optimum crop mix program for three cases, namely, a cell, two zones and the national results for Kenya will be considered. A brief analysis is presented below. In considering these results, it is useful to refer to Figures 1 - 3.

EXAMPLE 1: Cell of total extent 18000 Hectares. The cell is situated in Warm Tropical Climate (01), Length of growing period: 240-269 days (05) and the soil (Fx), slope (B), texture (1), and phase (20) of the land in this cell are as follows:

Soil:	Fx ,	Xanthia Ferrasols
Slope:	B ,	Slope of 8-30 cms (soil rules apply)
Texture:	1 ,	Light Texture Limitations (texture rules apply)
Phase:	20,	No phase (phase rules do not apply)

Two crops, namely, maize and beans will be considered in detail for this cell.

Table 1a: Evaluation of Maize as a potential crop in cell (0105 Fx 20 B1): Results from the application of Land Productivity Program.

Comments: Under low level of technology, all the available agricultural land in the cell falls in the very high productivity class. The application of the soil rule causes the total area to fall from very high to high productivity class. The phase and the slope rules have no effect on the productivity class for this crop under low technology level. The application of the texture rule causes the extent of available land to fall into the moderate productivity class. The expected calorie and protein production of maize under three technology levels and with and without land conservation measures are shown. If land degradation occurs, i.e., no conservation measures, then the total available land falls into the NS (not suitable) class and in this case there is no potential production for this crop in the cell. The results of the intermediate and high technology are similar in that after the application of all rules, 1900 hectares of land are available in the low productivity class. In the case of high technology, the slope rule eliminates two thirds of the available land from maize production whereas the relatively high rest period requirement limits the final availability of land for maize production under intermediate technology. Note that, because of the associated yield levels in the intermediate and high technology levels, the calorie and protein production, in the case of both with and without conservation measures increase as the technology changes from low to intermediate to high level.

Table 1b: Evaluation of phaseolus beans as a potential crop in cell (0105 Fx 20 B1): Results from the application of land productivity program.

Comments:

The total area available falls initially in the high productivity class. However, on application of all other rules, only 1200 ha are left in the low productivity class under low technology, 1900 ha under intermediate and high technology. In this example, the productivity, soil and texture rule as well as degradation affect land productivity in a similar way under all three technology levels. While the slope does not reduce productivity under low technology, 85% of the land has to be left uncultivated (fallow requirement). In the case of high technology, these percentages are 66% and 30% respectively.

A summary of the results after the application of all the rules for all the eighteen food crops under the assumption of low, intermediate and high technology for this cell are given in Tables 2a, 2b and 2c respectively.

TABLE 1a: Cell Example: Kenya

CELL IDENTIFICATION

Major Climate : warm tropics
Length of gr. Period : E (240-269)
Soil : FX
Phase : 20
Slope : B
Texture : 1

TOTAL EXTENT OF LAND '000H 18.0
NON-AGRICULTURAL LAND REQUIREMENT '000H 1.8
AGRICULTURAL LAND AVAILABLE '000H 16.2

Productivity Classes	LOW TECHNOLOGY						INTERMEDIATE TECHNOLOGY						HIGH TECHNOLOGY					
MAIZE (03)	VH	H	M	L	NS	F	VH	H	M	L	NS	F	VH	H	M	L	NS	F
Productivity Rule	16.2	0	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0	0
Soil Rule	0	16.2	0	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0
Phase Rule	0	16.2	0	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0
Slope Rule	0	16.2	0	0	0	0	0	0	10.8	0	5.4	0	0	0	5.4	0	10.8	0
Texture Rule	0	0	16.2	0	0	0	0	0	0	10.8	5.4	0	0	0	0	5.4	10.8	0
Degradation Rule	0	0	0	0	16.2	0	0	0	0	5.4	10.8	0	0	0	0	2.7	13.5	0
Fallow Require.	0	0	0	0	16.2	0	0	0	0	1.9	10.8	3.5	0	0	0	1.9	13.5	0.8

PRODUCTION MAIZE	CALORIES Millions		PROTEIN Millions gms		CALORIES Millions		PROTEIN Millions gms		CALORIES Millions		PROTEIN Millions gms	
	Without	With	Without	With	Without	With	Without	With	Without	With	Without	With
Total Production	4165.1	0	96.79	0	12964.9	6482.3	301.32	150.67	17876.5	8938.4	415.49	207.74
Seed and Waste	654.5	0	15.21	0	1666.9	833.4	38.74	19.38	2157.5	1078.8	50.15	25.07
Available Production	3510.6	0	81.58	0	11298.0	5648.9	262.58	131.29	15719.0	7859.6	365.34	182.67

TABLE 1b : Cell Example: Kenya

CELL IDENTIFICATION

Major Climate : warm tropics
Length of gr. Period : E (240-269)
Soil : FX
Phase : 20
Slope : B
Texture : 1

TOTAL EXTENT OF LAND '000H 18.0
NON-AGRICULTURAL LAND REQUIREMENT '000H 1.8
AGRICULTURAL LAND AVAILABLE '000H 16.2

Productivity Classes	LOW TECHNOLOGY						INTERMEDIATE TECHNOLOGY						HIGH TECHNOLOGY					
PHASEOLUS BEAN (o5)	VH	H	M	L	NS	F	VH	H	M	L	NS	F	VH	H	M	L	NS	F
Productivity Rule	0	16.2	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0	0
Soil Rule	0	0	16.2	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0
Phase Rule	0	0	16.2	0	0	0	0	0	16.2	0	0	0	0	0	16.2	0	0	0
Slope Rule	0	0	16.2	0	0	0	0	0	10.8	0	5.4	0	0	0	5.4	0	10.8	0
Texture Rule	0	0	0	16.2	0	0	0	0	0	10.8	5.4	0	0	0	0	5.4	10.8	0
Degradation Rule	0	0	0	8.1	8.1	0	0	0	0	5.4	10.8	0	0	0	0	2.7	13.5	
Fallow Require.	0	0	0	1.2	8.1	6.9	0	0	0	1.9	10.8	3.5	0	0	0	1.9	13.5	0.8

PRODUCTION PHASEOLUS BEAN	LOW TECHNOLOGY CALORIES Millions		PROTEIN Millions gms		INTERMEDIATE TECHNOLOGY CALORIES Millions		PROTEIN Millions gms		HIGH TECHNOLOGY CALORIES Millions		PROTEIN Mill gms	
	Without	With	Without	With	Without	With	Without	With	Without	With	Without	With
Total Production	1241.0	620.5	80.43	40.21	5794.2	2897.1	375.51	187.76	8678.2	4339.1	562.42	281.21
Seed and Waste	455.0	227.5	29.49	14.74	1094.5	547.2	70.92	35.46	1382.1	691.0	89.57	44.78
Available Production	786.0	393.0	50.94	25.47	4699.7	2349.9	304.59	152.30	7296.1	3648.1	472.85	236.43

Table 2 (a - c): Evaluation of the potential for all food crops in cell (0105 Fx 20 B1): Results of the land productivity program and the optimum crop mix program.

Table 2a: Low Technology Level

Comments:

Without Land Degradation, i.e. with Land Conservation Measures

In this cell, none of the eighteen food crops falls in very high or high productivity class. For maize, soybean, sweet potato, cassava and upland rice 15% of the land falls into the moderate productivity class, whereas 85% have to be left uncultivated (rest period requirement). For millet, sorghum, beans, groundnut and sugar cane 15% of the land is low productive and again 85% fallow. Spring wheat, white potato, winter wheat, and winter barley are ruled out by the climate rule. All other crops do not have rest period requirements but part of the land is classified as not suitable. For these crops the remaining percentages and productivity classes are as follows: bunded rice 33% (low), banana and plantain 100% (low), oil palm 100% (low), grass land 100% (moderate). The potential calorie and protein production is shown for each of the eighteen crops in Table 2a. In MODE 1, oil palm is picked as this choice maximizes the calorie production for this cell. Note that in MODE 1 the protein constraint is violated in the zone under consideration (warm tropics, 240 - 269 days LGP). Nevertheless, oil palm is also chosen in MODE 2. When the present crop mix constraint is imposed upon the crop choice (MODE 3), 46.6% of the land is allocated to sorghum and 53.4% to beans. Note that in terms of calorie production these crops are very much inferior to oil palm.

With Land Degradation, i.e., No Land Conservation Measures

For soybean, beans, sweet potato, cassava, upland rice and groundnut the production potential is seriously affected by degradation. Millet, sorghum and maize become not suitable without land conservation measures. Bunded rice, banana and plantain, sugar cane and oil palm, however, are not affected by land degradation. Potential grass land production drops roughly by 30%. In MODE 1, oil palm is, of course, chosen again. Banana and plantain comes in under MODE 2, while beans are allocated in MODE 3.

In Tables 2b and 2c, the corresponding results for intermediate and high technology are shown. Under both technology levels oil palm is allocated exclusively in MODE 1 and MODE 2 runs. In MODE 3 the crop choice is similar for both technology levels but markedly different when conservation is taken into account. When no land conservation measures are taken, all land is given to maize production. Assuming land conservation, however, the land allocation is 67.8% beans and 32.3% banana and plantain under intermediate technology while 46.6% sorghum, 21.2% beans and 32.3% banana and plantain are chosen for high technology.

TABLE 2a : Cell Example: Kenya

CELL IDENTIFICATION — TECHNOLOGY LEVEL: LOW

Major Climate	:	warm tropics
Length of Growth Period	:	E (240-269)
Soil	:	FX
Phase	:	20
Slope	:	B
Texture	:	1

TOTAL EXTENT OF LAND '000H 18.0

AGRICULTURAL LAND AVAILABLE '000H 16.2

CROP	LAND PRODUCTIVITY CLASSES						PRODUCTION		CROP SHARE		
	VH	H	M	L	NS	F	CAL.	PROT.	M1	M2	M3
PEARL* MILLET				2.45	16.2	13.75	1856.0 0	52.77 0			
SORGHUM				2.45	16.2	13.75	1536.9 0	45.26 0			0.466 0
MAIZE			2.45		16.2	13.75	3510.6 0	81.58 0			
SOYBEAN			2.45	1.2	8.1	13.75 6.9	1686.5 340.4	191.21 38.89			
PHASEOLUS BEAN				2.45 1.2	8.1	13.75 6.9	785.9 393.0	50.93 25.47			0.534 1.000
COTTON					16.2 16.2.		0 0	0 0			
SWEET POTATO			2.45	1.2	8.1	13.75 6.9	4143.3 787.2	46.94 8.92			
CASSAVA			2.45	1.2	8.1	13.75 6.9	4424.0 1106.0	36.48 9.12			
BUNDED RICE				5.4 5.4	10.8 10.8		2620.6 2620.6	49.30 49.30			
SPRING WHEAT					16.2 16.2		0 0	0 0			
WHITE POTATO					16.2 16.2		0 0	0 0			
WINTER WHEAT					16.2 16.2		0 0	0 0			
WINTER BARLEY					16.2 16.2		0 0	0 0			
UPLAND RICE			2.45	1.2	8.1	13.75 6.9	4262.7 1000.1	80.19 18.81			
GROUNDNUT				2.45 1.2	8.1	13.75 6.9	2174.5 1087.2	101.90 50.95			
BANANA PLANTAIN				16.2 16.2			9700.8 9700.8	110.64 110.64		0 1.000	
SUGAR CANE				2.45 2.45		13.75 13.75	72.8 72.8	0.49 0.49			
OIL PALM				16.2 16.2			38605. 38605.	0 0	1.000 1.000	1.000 0	
GRASSLAND (LIVESTOCK)			16.2 8.1	8.1			323.5 242.6	15.96 11.97			

*First row: with land conservation measures; Second row: no land conservation measures.

TABLE 2b : Cell Example: Kenya

CELL IDENTIFICATION		TECHNOLOGY LEVEL: INTERMEDIATE
Major Climate	:	warm tropics
Length of Growth Period	:	E (240-269)
Soil	:	FX
Phase	:	20
Slope	:	B
Texture	:	1

TOTAL EXTENT OF LAND '000 H 18.0

AGRICULTURAL LAND AVAILABLE '000 H 16.2

CROP	LAND PRODUCTIVITY CLASSES						PRODUCTION		CROP SHARE		
	VH	H	M	L	NS	F	CAL.	PROT.	M1	M2	M3
PEARL * MILLET				3.8 1.9	5.4 10.8	7.0 3.5	3928.5 1964.2	111.70 55.85			
SORGHUM				3.8	5.4 16.2	7.0	6592.2 0	194.12 0			
MAIZE				3.8 1.9	5.4 10.8	7.0 3.5	11298. 5648.9	262.56 131.28			0 1.000
SOYBEAN				3.8 1.9	5.4 10.8	7.0 3.5	5470.9 2735.4	620.28 310.14			
PHASEOLUS BEAN				3.8 1.9	5.4 10.8	7.0 3.5	4699.7 2349.8	304.58 152.29			0.678 0
COTTON					16.2 16.2		0 0	0 0			
SWEET POTATO			3.8	 1.9	5.4 10.8	7.0 3.5	21667. 5029.7	245.49 56.99			
CASSAVA			3.8		5.4 16.2	7.0	21715. 0	179.05 0			
BUNDED RICE				5.4 5.4	10.8 10.8		9172.0 9172.0	172.54 172.54			
SPRING WHEAT					16.2 16.2		0 0	0 0			
WHITE POTATO					16.2 16.2		0 0	0 0			
WINTER WHEAT					16.2 16.2		0 0	0 0			
WINTER BARLEY					16.2 16.2		0 0	0 0			
UPLAND RICE		1.9	1.9 0.95	 0.95	5.4 10.8	7.0 3.5	23015. 5651.8	432.94 106.32			
GROUNDNUT				3.8 1.9	5.4 10.8	7.0 3.5	9983.4 4991.7	467.83 233.91			
BANANA PLANTAIN				16.2 16.2			19402. 19402.	221.28 221.28			0.323 0
SUGAR CANE				3.8 3.8	5.4 5.4	7.0 7.0	6230.3 6230.3	41.54 41.54			
OIL PALM				16.2 16.2			102948. 102948.	0 0	1.000 1.000	1.000 1.000	
GRASSLAND LIVESTOCK)			16.2 8.1	 8.1			638.9 479.2	31.52 23.64			

*First row: with land conservation measures; Second row: no land conservation measures.

TABLE 2c : Cell Example: Kenya

CELL IDENTIFICATION — TECHNOLOGY LEVEL: HIGH

Major Climate	: warm tropics
Length of Growth Period	: E (240-269)
Soil	: FX
Phase	: 20
Slope	: B
Texture	: 1

TOTAL EXTENT OF LAND '000 H 18.0

AGRICULTURAL LAND AVAILABLE '000 H 16.2

CROP	LAND PRODUCTIVITY CLASSES						PRODUCTION		CROP SHARE		
	VH	H	M	L	NS	F	CAL.	PROT.	M1	M2	M3
PEARL * MILLET				3.8 1.9	10.8 13.5	1.6 0.8	4960.9 2480.5	133.38 70.53			
SORGHUM				3.8	10.8 16.2	1.6	9203.6 0	271.01 0			0.466 0
MAIZE				3.8 1.9	10.8 13.5	1.6 0.8	15719. 7859.6	365.30 182.65			0 1.000
SOYBEAN				3.8 1.9	10.8 13.5	1.6 0.8	7167.8 3583.9	812.68 406.34			
PHASEOLUS BEAN				3.8 1.9	10.8 13.5	1.6 0.8	7296.2 3648.1	472.86 236.43			0.212 0
COTTON					16.2 16.2		0 0	0 0			
SWEET POTATO			3.8	 1.9	10.8 13.5	1.6 0.8	32193. 7662.1	364.75 86.81			
CASSAVA		1.9 0.95	1.9 0.95		10.8 13.5	1.6 0.8	47199. 11799.	389.17 97.29			
BUNDED RICE				5.4 5.4	10.8 10.8		15287. 15287.	287.57 287.57			
SPRING WHEAT					16.2 16.2		0 0	0 0			
WHITE POTATO					16.2 16.2		0 0	0 0			
WINTER WHEAT					16.2 16.2		0 0	0 0			
WINTER BARLEY					16.2 16.2		0 0	0 0			
UPLAND RICE		3.8	 1.9		10.8 13.5	1.6 0.8	43006. 10650.	808.99 200.34			
GROUNDNUT				3.8 1.9	10.8 13.5	1.6 0.8	15037. 7518.5	704.64 352.32			
BANANA PLANTAIN				16.2 16.2			29102. 29102.	331.91 331.91			0.323 0
SUGAR CANE				3.8 3.8	10.8 10.8	1.6 1.6	12074. 12074.	80.49 80.49			
OIL PALM				16.2 16.2			154421. 154421.	0 0	1.000 1.000	1.000 1.000	
GRASSLAND (LIVESTOCK)			16.2 8.1	 8.1			1285.9 964.4	63.44 47.58			

*First row: with land conservation measures; Second row: no land conservation measures.

EXAMPLE 2: Zone Examples: Tables 3-4

Table 3: Optimum crop mix and assessment of human supporting capacity for zone: length of growing period 240-269 days, warm tropical climate, Kenya: Three levels of technology and without land conservation measures.

Comments:

This zone has about 0.4% of the agricultural land in Kenya and about 3.7% of Kenya's total population, i.e. population density of 2.028.

Mode 1: Maximize calories

In all the three technology levels the calorie-protein ratio constraint is violated (Ratio required for Kenya is 59.8). However, based on the calorie requirement, this zone can support 5% more population for the low technology case. There is a 2.66 and 4.1-fold possible increase in the potential population for the intermediate and high technology levels respectively. For the low and intermediate technology cases the crop choice is bunded rice and oil palm, and for the high technology cassava is an additional crop.

Mode 2: Protein constraint

In comparison to the Mode 1 run, the potential population supporting capacity for this zone falls considerably. Note that under the low technology assumption the present population of this zone is almost three times the supporting capacity, whereas for the intermediate and high technology, increases of 33% and 239% respectively of the present population could be accommodated in this zone.

Mode 3:

The strict imposition of present crop mix constraint in this zone would cause the following usage of the total land available in the zone:

Low Technology	(44.1%)
Medium "	(76.7%)
High "	(45.2%)

The balance of land would not be utilized at all, since it is not suitable for the present crop mix pattern as given. In reality, other food and cash crops (not included in the present crop mix data) are produced in this zone. A more realistic evaluation of the mode 3 run includes a procedure to allocate the land according to the present crop mix pattern and the balance of utilized land is reallocated to a mix of any of the eighteen food crops.

The results show that sorghum cannot be allocated for the low technology case. For the intermediate and high technology cases, millet and beans additionally are not included. The population supporting potential for this Mode 3 run is improved for the low and intermediate technology cases (potential/present population, 0.58 and 1.55 respectively) but for the high technology, this ratio is considerable less than the results for the Mode 1 and Mode 2 runs. The results show the issue of how relevant (from an agro-ecological viewpoint) the present cropping mix pattern is.

Table 3. Zone (Kenya, Warm Tropics: LGP 240-269 days)
Comparison of Mode 1 (Maximize Calories) Results for three Technology Levels and Without Land Conservation Measures.

ZONE IDENTIFICATION: WARM TROPICS, LGP: 240-269 DAYS, NUMBER OF CELLS: 15, NUMBER OF SUITABLE CELLS: 13

TOTAL EXTENT '000 H :	226
IRRIGATION LAND AREA '000 H :	1
NON-AGRICULTURAL LAND AREA '000 H :	23.8
TOTAL AGRICULTURAL AREA '000 H :	202.2
IRRIGATION CALORIE PRODUCTION (MILLIONS):	29,200
IRRIGATION PROTEIN PRODUCTION (M. GMS):	195
PRESENT POPULATION PRODUCTION :	458,400
PRESENT DENSITY:	2.028

		LOW TECHNOLOGY	INTERMEDIATE TECHNOLOGY	HIGH TECHNOLOGY
WITH DEGRADATION				
MODE 1: MAXIMIZE CALORIES				
AGRICULTURAL AREA BY CLASS	'000 H			
: VH + H PRODUCTIVITY AREA	"	2.7	2.7	21.3
: M PRODUCTIVITY AREA	"	7.2	7.2	10.6
: L PRODUCTIVITY AREA	"	149.8	148.9	107.5
: NS PRODUCTIVITY AREA	"	33.6	34.4	43.3
: FALLOW AREA	"	0	0	10.5
CALORIE PRODUCTION (MILLIONS)		379,057	1,001,644	1,563,081
PROTEIN PRODUCTION (M. GMS)		252	820	4,621
CALORIE/PROTEIN RATIO		913.5	1015.3	330.6
POTENTIAL/PRESENT POPULATION		1.05	2.66	4.10
CROPS CHOSEN *		BUNDED RICE (4) OIL PALM (41)	BUNDED RICE (12) OIL PALM (109)	BUNDED RICE (140) OIL PALM (122) CASSAVA (140)
MODE 2: PROTEIN CONSTRAINT				
AGRICULTURAL AREA BY CLASS	'000 H			
: VH + H PRODUCTIVITY AREA	"	2.8	2.2	34.9
: M PRODUCTIVITY AREA	"	20.7	28.1	19.7
: L PRODUCTIVITY AREA	"	125.5	79.6	43.3
: NS PRODUCTIVITY AREA	"	31.8	52.3	80.6
: FALLOW AREA	"	12.5	31.0	14.7
CALORIE PRODUCTION (MILLIONS)		107,402	488,096	899,699
PROTEIN PRODUCTION (M.GMS)		2,090	8,456	15,340
CALORIE/PROTEIN RATIO		59.8	59.8	59.8
POTENTIAL/PRESENT POPULATION		0.35	1.33	3.39
CROPS CHOSEN *		SOYBEAN (1) BUNDED RICE (13) GROUNDNUT (1) BANANA/PLANTAIN (15)	SOYBEAN (17) BUNDED RICE (27) OIL PALM (37)	SOYBEAN (7) BUNDED RICE (52) OIL PALM (24) UPLAND RICE (132)
MODE 3: PLU CONSTRAINT				
AGRICULTURAL AREA BY CLASS	'000 H			
: VH + H PRODUCTIVITY AREA	"	3.1	4.2	8.3
: M PRODUCTIVITY AREA	"	12.6	13.4	15.7
: L PRODUCTIVITY AREA	"	82.8	90.5	90.2
: NS PRODUCTIVITY AREA	"	44.3	48.8	63.0
: FALLOW AREA	"	50.3	36.3	16.0
CALORIE PRODUCTION (MILLIONS)		194,531	573,507	959,974
PROTEIN PRODUCTION (M. GMS)		825	3,399	6,789
CALORIE/PROTEIN RATIO		219.4	167.7	141.6
POTENTIAL/PRESENT POPULATION		0.58	1.55	2.55
CROPS CHOSEN *		MAIZE (2.5) BEANS (0.1) BANANA/PLANTAIN (0.9) BUNDED RICE (3.6) MILLET (1.2) SWEET POTATO (0.1) CASSAVA (1.7) GROUNDNUT (0.6) SUGARCANE (0.3) OIL PALM (17.7) NOT INCLUDED† SORGHUM (3.9)	MAIZE (19.9) SWEET POTATO (0.6) CASSAVA (12.7) GROUNDNUT (2.1) SUGARCANE (1.8) BANANA PLANTAIN (1.9) BUNDED RICE (11.7) OIL PALM (45.2) NOT INCLUDED† MILLET (5.1) SORGHUM (3.9) BEANS (29.0)	MAIZE (51.3) CASSAVA (55.4) SUGAR CANE (1.9) BANANA/PLANTAIN (2.8) SWEET POTATO (1.7) BUNDED RICE (13.8) GROUNDNUT (0.4) OIL PALM (61.3) NOT INCLUDED† MILLET (5.1) SORGHUM (3.9) BEANS (29.0)

*CROP IN '000 MT PRODUCTION

LIVESTOCK IN '000 HEAD: 16% OF HERD MILKED (MILK DRY: 0.4 KG/DAY/COW), 8% OFFTAKE (COW PER LIVESTOCK) UNIT, 250 KG LIVEWEIGHT), 50% OF HERD BLED (6 LITRES PER YEAR PER ANIMAL).

†(%)SHARE OF AREA IN LGP AS GIVEN IN PRESENT CROP MIX DATA.

Table 4: Optimum crop mix and assessment of human supporting capacity for zone: length of growing period 120-149 days, warm tropical climate, Kenya.

Results for three levels of technology, Mode 1 with and without land conservation measures.

Comments:

This zone contains some 2.6% of Kenya's agricultural land and 4.3% of the total population. Of the total available agricultural land, 1.459 million hectares, the most suitable land (VH + H) increases from 14,000 H for the low technology without land conservation to 353,000 H for the high technology with land conservation case. The protein calorie ratio is met in all cases except low technology with degradation and there is a large potential for agricultural production especially with conservation measures. For example, without land conservation measures, the potential/present population for low, intermediate and high technology is 0.88, 3.33 and 6.5 respectively. For the case of with conservation measures, this potential is almost doubled. Hence this zone has the potential to carry a significantly larger population. Also, the mix of crops chosen is important in the Kenyan diet, namely, maize, millet, livestock, etc. It is interesting to note that as the technology moves up, a larger range of crops is chosen for this mode 1 case. This zone, with proper management of degradation hazards and under the assumption of high technology, has the potential for supporting more than half of the present total population of Kenya.

Table 4. Zone (Kenya, Warm Tropics, LGP 120-149 days)
Comparison of Mode 1-3 Results for three Technology Levels and With/Without Land Conservation Measures.

ZONE IDENTIFICATION: WARM TROPICS LGP 120-149 DAYS, NUMBER OF CELLS: 61, NUMBER OF SUITABLE CELLS: 42

TOTAL EXTENT '000 H	1499
IRRIGATION LAND AREA '000 H :	14
NON-AGRICULTURAL AREA '000 H :	26
TOTAL AGRICULTURAL AREA '000 H :	1459
IRRIGATION CALORIE PRODUCTION (MILLIONS):	219100
IRRIGATION PROTEIN PRODUCTION (MILL. GMS):	2756
PRESENT POPULATION	535360
PRESENT DENSITY	0.357

	LOW TECHNOLOGY	INTERMEDIATE TECHNOLOGY	HIGH TECHNOLOGY
MODE 1: MAXIMIZE CALORIES			
WITHOUT LAND CONSERVATION			
AGRICULTURAL AREA BY CLASS '000 H			
: VH + H PRODUCTIVITY AREA "	14	94	28
: M PRODUCTIVITY AREA "	117	175	338
: L PRODUCTIVITY AREA "	286	213	248
: NS PRODUCTIVITY AREA "	421	424	325
: FALLOW AREA "	357	288	114
CALORIE PRODUCTION (MILLION)	176094	1282394	2737933
PROTEIN PRODUCTION (M. GMS)	3076	29094	63662
CALORIE/PROTEIN RATIO	66.3	46.8	44.3
POTENTIAL/PRESENT POPULATION	0.88	3.33	6.5
CROPS CHOSEN (PRODUCTION '000 MT (LIVESTOCK* '000 HEAD)	MAIZE (16) SWEET POTATO (21) UPLAND RICE (13) CASSAVA (3) LIVESTOCK (55)	MAIZE (309) SOYBEAN (1) UPLAND RICE (11) GROUNDNUT (8) SWEET POTATO (56) CASSAVA (2) LIVESTOCK (126)	MAIZE (665) SWEET POTATO (101) UPLAND RICE (25) GROUNDNUTS (26) LIVESTOCK (201)
WITH LAND CONSERVATION			
AGRICULTURAL AREA BY CLASS '000 H			
: VH + H PRODUCTIVITY AREA "	84	199	353
: M PRODUCTIVITY AREA "	198	142	166
: L PRODUCTIVITY AREA "	47	46	17
: NS PRODUCTIVITY AREA "	212	395	389
: FALLOW AREA "	667	426	142
CALORIE PRODUCTION (MILLION)	549764	2459952	6235665
PROTEIN PRODUCTION (M. GMS)	12317	59891	159846
CALORIE/PROTEIN RATIO	50.9	42.7	39.7
POTENTIAL/PRESENT POPULATION	1.70	5.92	14.3
CROPS CHOSEN (PRODUCTION '000 MT (LIVESTOCK* '000 HEAD)	MILLET (12) MAIZE (138) SWEET POTATO (15) CASSAVA (2) UPLAND RICE (3) LIVESTOCK (19)	MILLET (37) SORGHUM (10) MAIZE (642) SWEET POTATO (30) GROUNDNUT (20) LIVESTOCK (39)	MILLET (47) SORGHUM (86) MAIZE (1617) SWEET POTATO (3) GROUNDNUT (84) LIVESTOCK (79)
MODE 2: PROTEIN CONSTRAINT (NOT VIOLATED) : SAME AS MODE I (EXCEPT FOR LOW TECHNOLOGY WITHOUT LAND CONSERVATION)			

*LIVESTOCK '000 HEAD: 16% OF HERD MILKED (MILK DRY: 0.4 KG/DAY/COW), 8% OFFTAKE (COW PER LIVESTOCK UNIT, 250 KG LIVEWEIGHT), 50% OF HERD BLED (6 LITRES PER YEAR PER ANIMAL).

EXAMPLE 3: National (Kenya)

Table 5: Comparison of potential-present population for Kenya for 3 technology levels, with and without conservation and Mode 1-3.

Comments:

The results show that under the assumption of low technology in all agricultural production activities in Kenya, the supporting capacity of the land is well below the present population of Kenya. In reality a mix of low, intermediate and high technology is well spread in the Kenyan agricultural sector. If proper management of land degradation hazards does not occur, then even under the assumption of high technology the limit of the population supporting capacity will be reached by the year 2000, when Kenya's population is likely to double.

On the other hand, with proper land conservation measures, i.e., without degradation and under the assumption of high technology, the land has the potential to support more than four times the present population, i.e. 60-70 million people. Note that the results for PLU constraint are worse than the results for Mode 1 and Mode 2. The implication of this raises the issue of how 'optimum" (in what sense) the present crop mix pattern in Kenya is. This aspect cannot be answered completely until all the other food and cash crops relevant in Kenya under a mix of technologies are examined. However, the most important food crops are already included within the eighteen crops considered in this project and the results do suggest the necessary trend of technological development and land conservation management if food production is to meet the food demand in the next 2-3 decades.

Table 5. National Example (Kenya).
Comparison of Mode 1-3 Results (Potential/Present Population and Land Use) for three Technology Levels and With/Without Land Conservation.

NATIONAL RESULTS : KENYA

YEAR 1975

NUMBER OF CLIMATES	4
NUMBER OF ZONES	32
NUMBER OF CELLS	1213
TOTAL POPULATION	12,694,000
TOTAL AREA (H)	56,991,000
TOTAL IRRIGATED AREA (H)	43,000
TOTAL NON-AGRICULTURAL AREA (H)	633,000
TOTAL AGRICULTURAL AREA (H)	56,315,000
PRESENT POPULATION DENSITY	0.223

	LOW TECHNOLOGY	INTERMEDIATE TECHNOLOGY	HIGH TECHNOLOGY
WITHOUT DEGRADATION			
POTENTIAL/PRESENT POPULATION			
MODE 1: MAXIMIZE CALORIES	0.824	2.302	4.509
MODE 2: PROTEIN CONSTRAINT	0.799	2.255	4.439
MODE 3: PLU CONSTRAINT	0.640	1.836	3.681
WITH DEGRADATION			
POTENTIAL/PRESENT POPULATION			
MODE 1: MAXIMIZE CALORIES	0.366	1.181	2.481
MODE 2: PROTEIN CONSTRAINT	0.335	1.132	2.404
MODE 3: PLU CONSTRAINT	0.309	0.986	2.107

NOTE: CALORIE/PROTEIN RATIO AT NATIONAL LEVEL IS MET FOR ALL THE ABOVE ALTERNATIVES.