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LAND RESOURCES AND PRODUCTIVITY POTENTIAL - AGRO-ECOLOGICAL METHODOLOGY FOR AGRICULTURAL DEVELOPMENT PLANNING

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March 1985
CP-85-14

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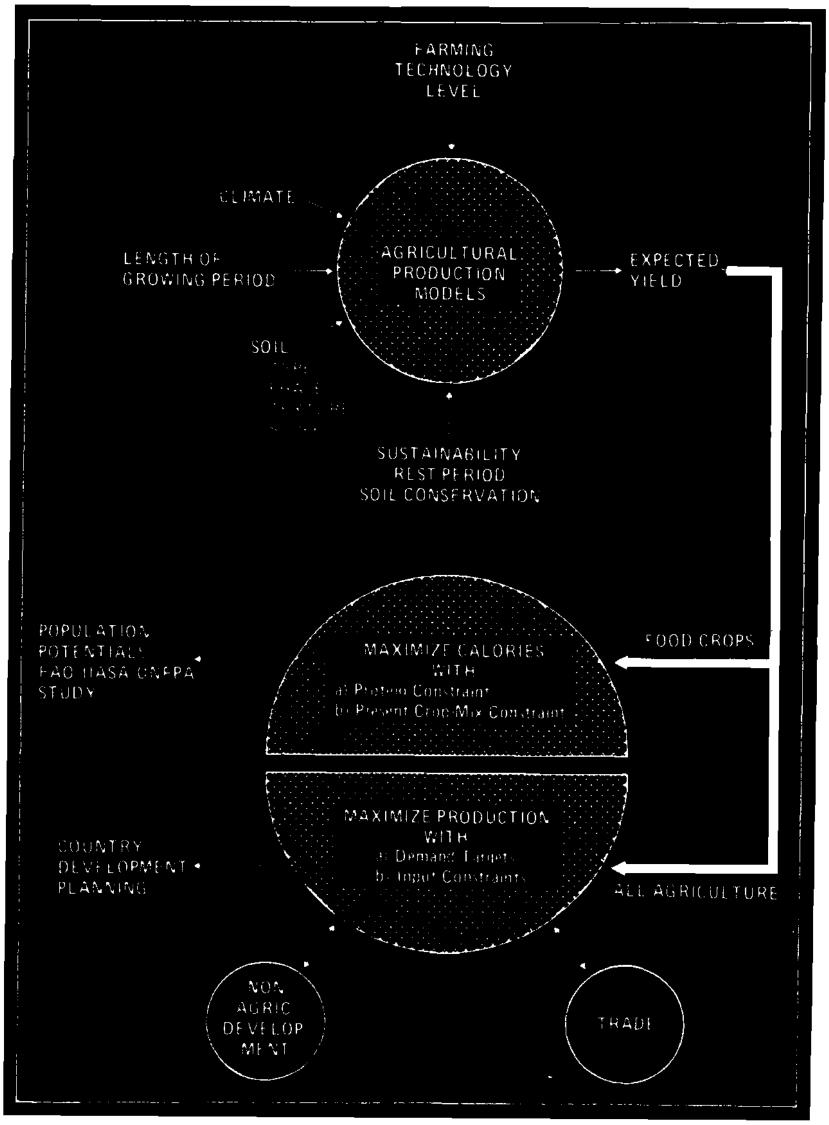

LAND RESOURCES AND PRODUCTIVITY POTENTIAL

AGRO–ECOLOGICAL METHODOLOGY FOR AGRICULTURAL DEVELOPMENT PLANNING

M.M. Shah, G.M. Higgins, A.H. Kassam and G. Fischer

FOREWORD

Understanding the nature and dimension of the land and water resources for food and agriculture development and the policies available to develop them have been the focal point of the work of the Land and Water Division of the Food and Agricultural Organization of the United Nations and 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 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) How does this production potential in specific areas (within countries as well as groups of countries) compare to the food requirements of the future populations of these areas? potential?

(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 resource 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, inter-generational equity as well as of political stability and peace.

We hold ecological considerations to be of critical importance in answering the questions posed above. Limits to food production are set by soil and climatic conditions and by the use, and management, of the land. In the long term, any "mining" of land beyond these limits will result in degradation and decreased productivity. Accordingly, there are critical levels of production obtainable, in perpetuity, from any given land area and hence critical levels of populations that can be supported from this area. It is crucial to take account of the physical resource base for potential production as well as the socio-economic aspects that will influence the actual production.

The population and land resources study, carried out by the Food and Agriculture Organization of the United Nations in collaboration with the International Institute for Applied Systems Analysis, with funding from the United Nations Fund for Population Activities, is concerned with the quantitative evaluation of the land resources' food productive capacity on the basis of soil, climate and crop data under specified technological conditions. The methodology and resource data base developed within this study provides a first approximation of the food production potentials and the population supporting potentials for 117 countries in five regions of the developing world.

The most fruitful and promising avenue for further work and application of the methodology is in relation to detailed country case studies. The aim of this report is to describe the agro-ecological methodology and specify the data needs, with special emphasis on methodological and data refinements for detailed country agricultural planning studies. The report should be of particular interest and use to institutions in countries considering an ecological-technological-economic approach to the planning of agricultural development.

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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.

The agro-ecological zone (AEZ) methodology is concerned with the quantitative evaluation of the land resources' food and agricultural productive capacity on the basis of land (soil and climate) resources and technological options.

This report describes the AEZ methodology and the resource data base in relation to:

- Assessment of food production and population supporting potential (Phase 1)

- Planning of agricultural development

  - Detailed country studies (Phase 2).

Phase 1 of the study was concerned with the development of the methodology and resource data base for 117 developing countries in Africa, Central America, South America, Southeast Asia and Southwest Asia. The computerized land resources data base for these countries was developed from an overlay of a climatic map -- providing spatial information on temperature and moisture conditions onto the FAO/UNESCO World Soil Map -- providing spatial data on soil type, phase, texture and slope. Each area of similar soil and climatic conditions was identified and termed an agro-ecological cell (10,000 hectares).

The Phase 1 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. These production potentials were estimated at three alternative levels of farming technology. A specific crop was chosen for each agro-ecological cell and the rainfed potential production together with irrigated production for the present (year 1975) and projected (year 2000) time periods was converted into food nutrients and, by reference to per caput human food requirements, to the physical potential of land resources to support present and projected populations. These results were used to identify and pinpoint localities where land resources are and/or will be insufficient to meet the food needs of present and future populations as well as areas with surplus potential. The methodology, results and policy implications of this "first" approximation of the food production and population supporting potential of the countries in the five regions of the developing world is presented elsewhere.*

Phase 2 of the study is concerned with the refinement of the AEZ methodology and the resource base to enable planning of agricultural development at a detailed country level. One detailed country study -- Kenya -- is presently being carried out by FAO and IIASA in collaboation with the Government of Kenya. Using this country study as an example, this report illustrates the type of methodological and resource data base refinements that are necessary to facilitate the integration of ecological, technological, social, demograhic and economic considerations for viable and sustainable agricultural development planning in a country.

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. This report, describing the agro-ecological zone methodology and the compilation of the resource data base, should be of particular interest to technicians and planners considering an ecological-technological-economic approach to planning of sustainable and viable agricultural development.

*Shah, M.M., Fischer, G., Higgins, G.M. and Kassam, A.H., People, Land and Food Production - Potentials in the Developing World, submitted for publication as a Research Report, IIASA, Laxenburg.

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1. INTRODUCTION

The future of mankind is closely linked with the world's capacity to meet the evergrowing demand for agricultural produce. It is therefore essential to know this productive capacity as well as the conditions under which it can be reached.

How can developing countries improve their food situation? The importance of this question is well reflected by the increasing number of studies and reports devoted to the subject. However, with exceptions, such reports tend to concentrate on the socio-economic aspects of the problem and largely ignore or at best gloss over the question of whether the land resources in the developing countries are adequate for food and agricultural self-sufficiency as well as exports or whether the productive land resources together with other available resources can generate sufficient export revenue to finance the necessary food and other imports.

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.

Limits to food production are set by soil and climatic conditions and by the use, and management, of the land. In the long term, any 'mining' of land beyond these limits will result in degradation and decreased productivity. Accordingly, there are finite levels of production obtainable, in perpetuity, from any given land area and hence certain levels of populations that can be supported from this area. It is crucial to take account of the physical resource base for potential production as well as the socio-economic aspects that will influence the actual production.

The agro-ecological zone (AEZ) methodology is concerned with the quantitative evaluation of the land resources' food and agricultural productive capacity on the basis of land (soil and climate) resources and technological options.

The aim of this report is to describe the AEZ methodology and the resource data base in relation to:

- Assessment of food production and population supporting potential (Phase 1)
- Planning of agricultural development
  - Detailed country studies (Phase 2)

Phase 1 was concerned with the development of the methodology and resource data base for 117 developing countries in Africa, Central America, South America, Southeast Asia and Southwest Asia. The computerized land resources data base for these countries was developed from an overlay of a climatic map -- providing spatial information on temperature and moisture conditions onto the FAO/UNESCO World Soil Map -- providing spatial data on soil type, phase, texture and slope. Each area of similar soil and climatic conditions was identified and termed an agro-ecological cell (10,000 hectares). The production potential of 17 most widely grown food crops and livestock (from grassland production) was estimated at three alternative levels of farming technology for each agro-ecological cell. A specific crop was chosen for each cell and the potential production under these different assumptions and for the present (year 1975) and projected (year 2000) time periods was converted into food nutrients and, by reference to per caput human food requirements, to the physical potential of land resources to support present and projected populations. These results were used to identify and pinpoint localities where land resources are insufficient to meet the food needs of present and future populations as well as areas with surplus potential. The methodology and the results of this "first" approximation of the population supporting potential of the countries in the five regions of the developing world has been published, FAO/IIASA/UNFPA (1983).

Phase 2 is concerned with the refinement of the AEZ methodology and the resource base to enable planning of agricultural development at a detailed country level. One detailed country study -- Kenya -- is presently being carried out by FAO and IIASA in collaboration with the Government of Kenya. Using this country study as an example, this report illustrates the type of methodological and resource data base refinements that are necessary to facilitate the integration of ecological, technological, demographic and economic considerations for agricultural development planning in a country.

1.1. Objectives

The overall objective of the Phase 1 AEZ study was to estimate the sustainable food and population supporting potentials of land resources under alternative farming technology levels and compare these estimates with data on present and projected populations to identify areas where land resources would be insufficient or surplus to meet the food needs of the populations.

The study 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.

The study has created a physical resource data base suitable for an assessment of the environmental and technological potential for food production of the land resources of developing countries. The generated information is particularly relevant for the formulation of policies for the development of land resources in relation to the future size and distribution of populations.

Altogether 117 developing countries/states (51 in Africa, 16 in Southeast Asia, 16 in Southwest Asia, 13 in South America, 21 in Central America) have been considered in this study.

1.2. Prerequisites

That the study was even considered feasible is due to no less than 20 years of prior work, undertaken mainly by the staff of the Soil Resources, Management and Conservation Service of FAO. This effort resulted, first, in the compilation and publication of the FAO/UNESCO Soil Map of the World (FAO, 1971-81). Concurrently with this work, the methodology and framework for land evaluation was developed (FAO, 1976a). The Soil Map and the methodology for land evaluation led to the agro-ecological zone project (FAO, 1978-81). This project was concerned with the assessment of land suitability for the production of specific crops in the developing world. The results of this project led UNFPA to commission the Land Resources for Populations of the Future Project, undertaken by FAO in collaboration with IIASA, to translate the food production potentials into assessment of potential population supporting capacities (FAO, 1978-80; FAO/IIASA/UNFPA, 1983).

1.3. Detailed Country Studies

The experience from this study in terms of the compilation of the physical potential resource base and the development of the methdology has illustrated the usefulness of this approach to the assessment of the environmental and technological limitations of cultivatable land resources. Refinements of the resource base and extension of the methodology suitable for detailed country agricltural planning studies is the most promising avenue for future work. One detailed country case study (Kenya) is already on-going; at this level of application a major effort is necessary, for example:

(a) To compile a resource inventory at a finer scale and on an administrative area basis. In the Kenya detailed case study, a 1:1 million soil and climate inventory by district has been developed.

(b) To take account of detailed country land use patterns, e.g. land resources for national game parks, land under forest areas, land under small and large scale irrigation schemes, etc.

(c) To assess all relevant crops, e.g. non-food crops such as coffee, tea, etc.; this entails development of physical crop production models for these crops.

(d) To formulate criterion of crop choice based on district as well as national considerations, e.g. self-sufficiency levels and export possibilities, inputs availability, soil conservation measures, etc.

The usefulness and relevance of detailed country studies may be illustrated by the following type of issues that can be analyzed:

Population

- Identification and assessment of critical and potential areas to estimate needs of human migration and/or food transfers within and across administrative areas with the aim of improving self-sufficiency and equities (income and land distribution).
- Chanelling of population planning programs to specific target areas.

Production

- What are the best crops to produce (ecological and economic comparative advantage) and what consumption and trade policies to be pursued (e.g. if wheat is ecologically unsuitable and sorghum is suitable then policies for sorghum consumption).
- What are the problems of and at what rate and how should the rainfed and irrigated land resources be developed in the future to reach higher potentials in specific locations within the country.
- What are the future farming technologies and soil conservation measures required and feasible for achieving alternative levels of self-sufficiency and export targets of various crops.

Land

- Information on potentially cultivatable land by extent, quality and location, and data on present land use provides a framework for the scope/timeframe for land-extensive agricultural development.

Inputs

- Seeds and crop varieties, fertilizers (organic and inorganic), pesticides and power (human, animal, tractor) and land conservation measures: present use and future requirements to design appropriate agricultural development policies to ensure the availability and use of improved farming technologies.

2. OVERVIEW: AEZ-METHODOLOGY

The population supporting capacity of land resources depends on the productivity of land. The potential productivity of land resources on a sustainable basis in turn depends on a large number of interacting factors, namely:

- climatic conditions such as temperature, sunshine, moisture, etc.
- characteristics of the land and soil
- kinds of crops grown
- farming practices (input levels and soil conservation measures)

The concepts and principles of the AEZ methodology for the assessment of food production and population supporting potentials are scale neutral; this study applied the methodology to countries in the five regions of the developing world on the basis of the 1.5 million scale land resources inventory. For detailed country planning studies more detailed and refined land resources inventories are necessary.

Figs. 1 and 2 show the methodological framework of the AEZ study and the detailed country study respectively. The numbers in Fig. 1 relate to the main steps in the application of the methodology and are described below. A numerical example of the application of the AEZ methodology for a particular agro-ecological cell is given in Annex 1. Various aspects of the methodology and data refinements for detailed country studies are dealt with in more detail later.

2.1. Main Steps in the AEZ-Methodology

The numbers in brackets relate to the numbers in Fig.1.

(a) Land resources: for each country

STEP 1: Computerize Soil Map. Using this as a base also computerize Climate and LGP Maps (1)

Fig.1 FAO/IIASA/UNFPA LAND RESOURCES FOR POPULATIONS OF THE FUTURE: METHODOLOGICAL FRAMEWORK

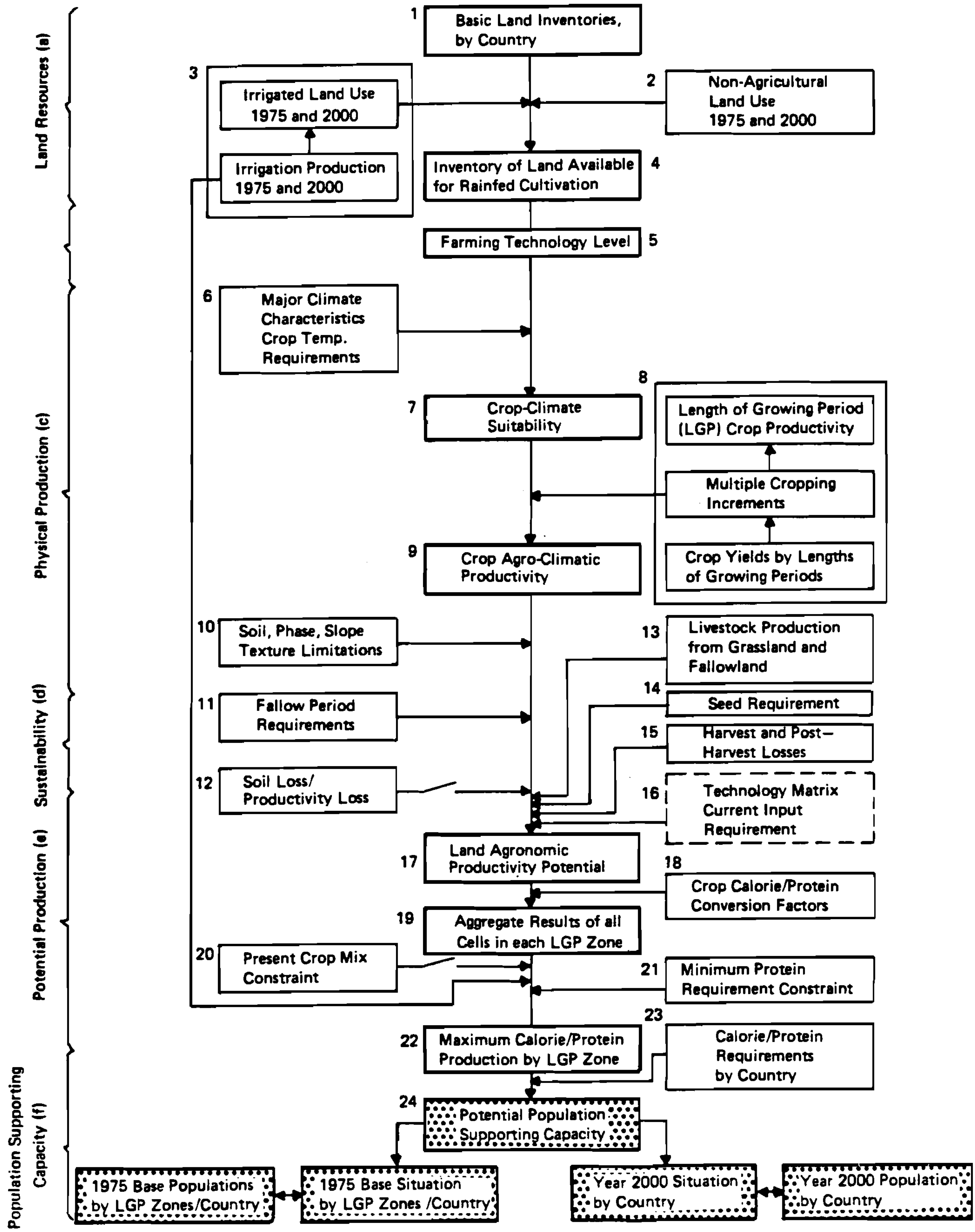
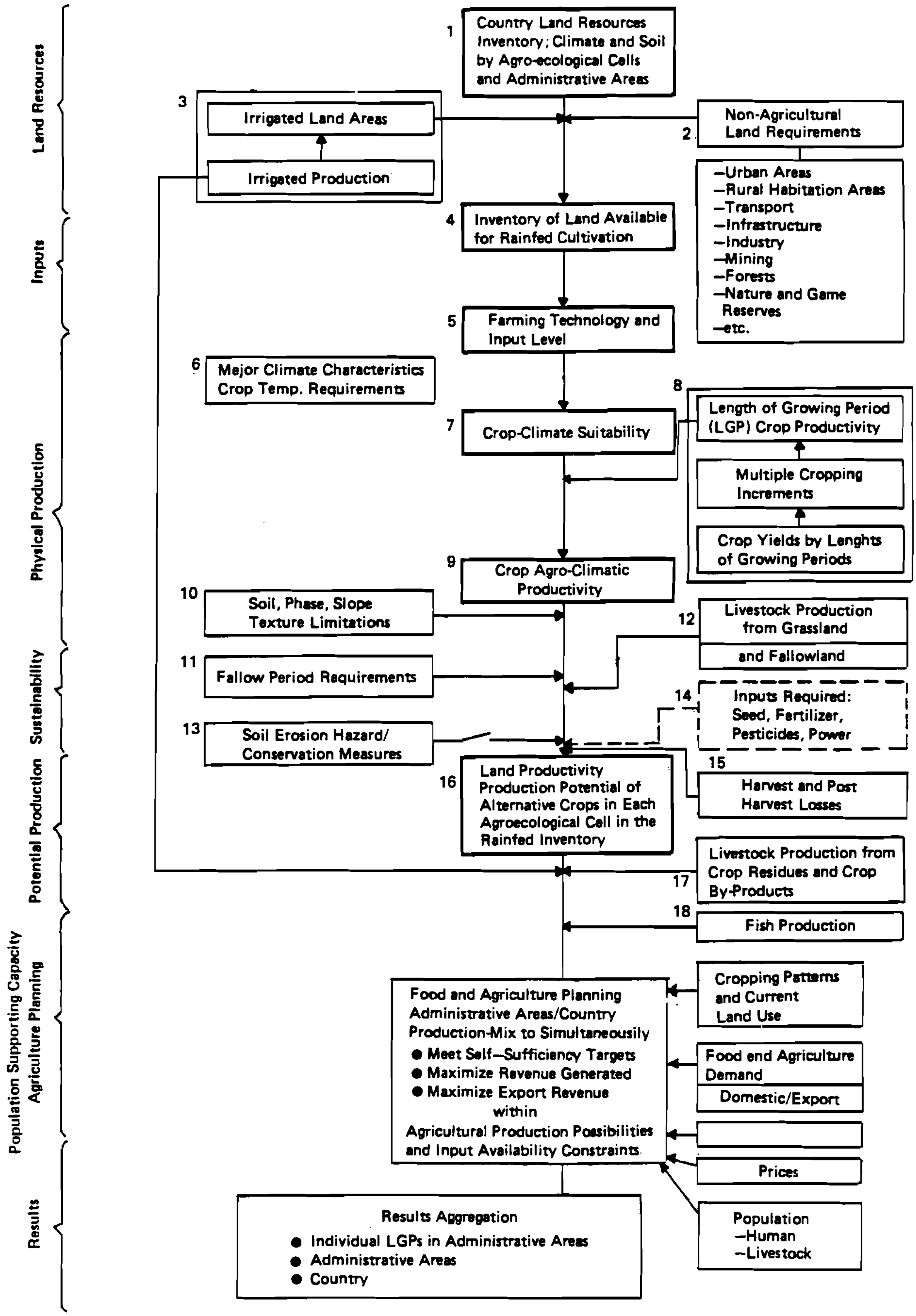


Fig. 2 AGRICULTURAL DEVELOPMENT PLANNING
— AGRO-ECOLOGICAL ZONE METHODOLOGICAL
FRAMEWORK FOR COUNTRY STUDIES



to obtain

BASIC LAND RESOURCES INVENTORY - BY COUNTRY

STEPS 2-4: Deduct non-agricultural and requirements (2) and irrigated land (3) areas by location

to obtain

INVENTORY (4) OF LAND AVAILABLE FOR RAINFED PRODUCTION (by agro-ecological cell)

(b) Farming Technology and Input Levels

STEP 5: Choose low, intermediate or high level (5)

(c) Physical crop production model: for each of the crops of the assessment

STEP 6-7: Apply crop-climate rules (6)

to obtain

CROP-CLIMATE SUITABILITY (7)

STEP 8-9: Apply crop yield - LGP rules (8)

to obtain

CROP AGRO-CLIMATIC PRODUCTIVITY (9)

STEP 10: Apply crop-soil rules (10)

to obtain

ANTICIPATED CROP YIELD

(d) Sustainability of production

STEP 11: Apply fallow period rules (11)

to obtain

(ANNUAL) ANTICIPATED CROP YIELD

STEP 12: Apply soil loss-productivity loss model (12)

to obtain

EXPECTED CROP YIELD

(e) *Potential production and input requirements*

STEP 13-15: Livestock (calorie and protein) production from grassland and fallow land (13)
Apply seed (14) and waste (15) coefficients
to obtain
CROP PRODUCTION: LAND AGRONOMIC PRODUCTIVITY POTENTIAL (17)

STEP 16: Use FAO global technology matrix (16) for each crop
to estimate
FERTILIZERS (N, P, and K), PESTICIDES, SEED (TRADITIONAL AND IMPROVED) AND POWER REQUIREMENTS

STEP 18-19: Apply crop calorie-protein conversion factors (18) and from the results of all crops in the assessment choose the crop giving maximum calories (19)
to obtain
CALORIE AND PROTEIN PRODUCTION IN EACH AGRO-ECOLOGICAL CELL

STEP 19: Aggregate these results for all cells in LGP zone and add livestock calories and protein and any irrigated production
to obtain
TOTAL CALORIE AND PROTEIN PRODUCTION, CROP-MIX AND INPUTS* REQUIRED IN EACH LGP ZONE

*Current production inputs (fertilizers by N, P, K type, power and seed).

STEP 20-21: Check calorie-protein ratio for each LGP ≤ country calorie-protein ratio, i.e. minimum protein availability constraint.

If not acceptable then repeat STEP 10 for some cells in the LGP zone until minimum protein requirement is met.

In the case of LOW and INTERMEDIATE inputs apply present crop-mix constraint (20)

to obtain

MAXIMUM CALORIE/PROTEIN PRODUCTION IN EACH LGP ZONE

(f) Population supporting capacity

STEP 22-24: Maximum calorie/protein production by LGP zone

Apply country calorie requirement (23) to estimate potential population in each LGP zone and compare with 1975 LGP zone population

to identify

CRITICAL AND SURPLUS LGP ZONES IN EACH COUNTRY

Aggregate LGP zone results for each country to estimate country potential population

to obtain

COUNTRY LEVEL RESULTS

For the year 2000 runs**, aggregate all LGP results in each country

to obtain

COUNTRY LEVEL RESULTS

**The difference in the year 1975 and year 2000 arises from irrigated area/production and non-agricultural land requirement; for the year 2000 only country level results are presented since the projected population by LGP zones are not available.

3. METHODOLOGY AND DATA REFINEMENTS FOR DETAILED COUNTRY STUDIES

In this section various components of the overall methodology as depicted in Fig.1 will be considered in detail. The description of the Phase 1 AEZ methodology and data will be followed by assessment of the refinements and extensions necessary for Phase 2 detailed country agricultural planning case studies (Fig.2).

3.1. Climate and Soil Resources for Agriculture Production

The primary aim of creating a climate and soil inventory is to predict crop productivity. Hence the basic inventory must be compiled in a form that will permit the interpretation of the climate and soil resources in terms of their suitability for production of crops under consideration. The appropriate climate adaptability and soil suitability attributes of the crops therefore will dictate what parameters are to be explicitly taken into account in the compilation of the inventory.

3.2. Soil and Climate Inventory

In the AEZ study, the FAO/UNESCO Soil Map of the world (FAO, 1971-81 and Dudal and Batisse, 1978) was used as the physical resource base map of the land inventory for each country. For each unit of land (a grid overlay of 2mm x 2mm on the Soil Map, i.e. 10,000 ha land units), the Soil Map provides data on soil type, phase, texture and slope (Table 1) by location in each country.

A climate inventory, in terms of prevailing temperature regimes and length of growing period zones, was overlaid on the soil map. This climatic inventory was developed on the basis of available meteorological data (rainfall, maximum and minimum temperatures, vapour pressure, wind speed and sunshine duration (FAO, 1976b)). For the temperature regimes, fourteen major climates were delineated, Table 2. The concept of length of growing period zones, characterizing

Table 1: SOIL CLASSIFICATION - AEZ STUDY

FAO UNESCO SOIL MAP: 106 DIFFERENT SOIL UNITS: 1 : 5 MILLION SCALE	
26 MAJOR SOIL UNITS	FLUVISOLS GLEYSOLS REGOSOLS LITHOSOLS CAMBISOLS LUVISOLS ARENOSOLS RENDZINAS RANKERS ANDOSOLS VERTISOLS PODZOLUVISOLS PODZOLS PLANOSOLS SOLONCHAKS SOLONETZ YERMOSOLS XEROSOLS ACRISOLS NITOSOLS FERRALSOLS KASTANOZEMS CHERNOZEMS PHAEZEMS GREYZEMS HISTOSOLS
3 TEXTURE CLASSES	COARSE, MEDIUM AND HEAVY TEXTURE
3 SLOPE CLASSES	0 – 8%, 8 – 30%, > 30%
12 PHASES	STONY, LITHIC, PETRIC, PETROCALCIC, PETROGYPSIC, PETROFERRIC, PHREATIC, FRAGIPAN, DURIPAN, SALINE, SODIC, CERRADO

EXAMPLE: KENYA COUNTRY STUDY: 380 SOIL MAPPING UNITS, CLASSIFICATION ACCORDING FAO/ UNESCO LEGEND, SCALE 1 : 1 MILLION 6 SLOPE CLASSES: < 2%, 2–5%, 5–8%, 8–16%, 16–30%, > 30%

the time (number of days) available when moisture conditions permit growth, was developed. A moisture supply from rainfall of half or more than half potential evapotranspiration (PET) was considered suitable to permit crop growth. A growing period with a humid period (i.e. a period with an excess of precipitation over potential evapotranspiration) is inventorized as a normal (N) growing period. A growing period with no humid period is inventorized as an intermediate (I) growing period. Altogether twenty-one growing period zones, Table 3, were delineated by isolines of growing period with values of 0, 75, 90, 120, 180, 210, 240, 270, 300, 330, 365- and 365+ days.*

*365^- year round growing period
365^+ year round humid growing period

Table 2: CHARACTERISTICS OF MAJOR CLIMATES: AEZ STUDY

MAJOR CLIMATE	Major Climates during Growing Period		24-hr. Mean (daily) Temperature (C) Regime during the Growing Period
	No	Descriptive Name	
TROPICS	1	Warm tropics	More than 20
All months with monthly mean temperatures, corrected to sea level, above 18°C	2	Moderately cool tropics	15–20
	3	Cool tropics	5–15
	4	Cold tropics	Less than 5
SUB-TROPICS	5	Warm/moderately cool sub-tropics (summer rainfall)	More than 20
One or more months with monthly mean temperatures, corrected to sea level, below 18°C but all months above 5°C	6	Warm moderately cool sub-tropics (summer rainfall)	15–20
	7	Warm sub-tropics (summer rainfall)	More than 20
	8	Moderately cool sub-tropics (summer rainfall)	15–20
	9	Cool sub-tropics (summer rainfall)	5–15
	10	Cold sub-tropics (summer rainfall)	Less than 5
	11	Cool sub-tropics (winter rainfall)	5–20
	12	Cold sub-tropics (winter rainfall)	Less than 5
TEMPERATE One or more months with monthly mean temperatures, corrected to sea level, below 5°C	13	Cool temperate	5–20
	14	Cold temperate	Less than 5

Example: Kenya Country Data: Nine Major Climates defined by the following temperture regimes

> 25.0, 22.5–25.0, 20.0–22.5, 17.5–20.0, 15.0–17.5, 12.5–15.0,.10.0–12.5, 5.0–10.0,< 5.0 (Daily Mean Temperature ^{0}C)

Table 3: LENGTH OF GROWING PERIOD ZONES IN NUMBER OF DAYS WHEN WATER IS AVAILABLE FOR PLANT GROWTH

AEZ STUDY LGP ZONES(DAYS)		EXAMPLE*: KENYA COUNTRY DATA LGP ZONES(DAYS)	PATTERN* MAPPING UNIT
365+	(N)	365+	1
365–	(N)	365–	H–1
330–364	(N)	300–364	1–H
300–329	(N)	300–329	1–H–2
270–299	(N)	270–299	1–2–H
240–269	(N)	240–269	1–2
210–239	(N)	210–239	1–2–3
180–209	(N)	180–209	1–3–2
150–179	(N)	150–179	1–2–D
120–149	(N)	120–149	1–D–2
90–119	(N)	90–119	1–D
75– 89	(N)	60– 89	2
1– 74	(N)	30– 59	2–1
0 DRY'		1– 29	2–1–H
1– 74	(I)	0 DRY	2–1–3
75– 89	(I)		2–3
90–119	(I)		2–3–1
120–149	(I)		2–3–4
150–179	(I)		2–1–D
180–209	(I)		3–2
0 COLD			3–2–1
			3–2–4
			D

(N) NORMAL LENGH LENGTH OF GROWING PERIOD
(I) INTERMEDIATE LENGTH OF GROWING PERIOD

365+ IS CONTINOUSLY HUMID
365– IS NOT CONTINOUSLY HUMID

1, 2, 3, 4 RESPECTIVLY REPRESENT NUMBER OF LENGTH OF GROWING PERIODS PER YEAR AS MAPPED IN KENYA CLIMATE INVENTORY

*In Kenya Country Study 15 LGPs Zones and 22 pattern mapping units are recognized. For example the pattern coded 2–1–3 represents the number of growing periods per year in order of frequency of occurance.

The above soil and climate inventory for each country was computerized in the form of agro-ecological cells; each cell was specified by major climate, length of growing period zone, soil type, soil phase, soil texture, soil slope and extent of land in the cell. This information forms the basis of the Basic Land Resources Inventory available for each country in the AEZ study.

3.2.1. Country Refinements and Extension

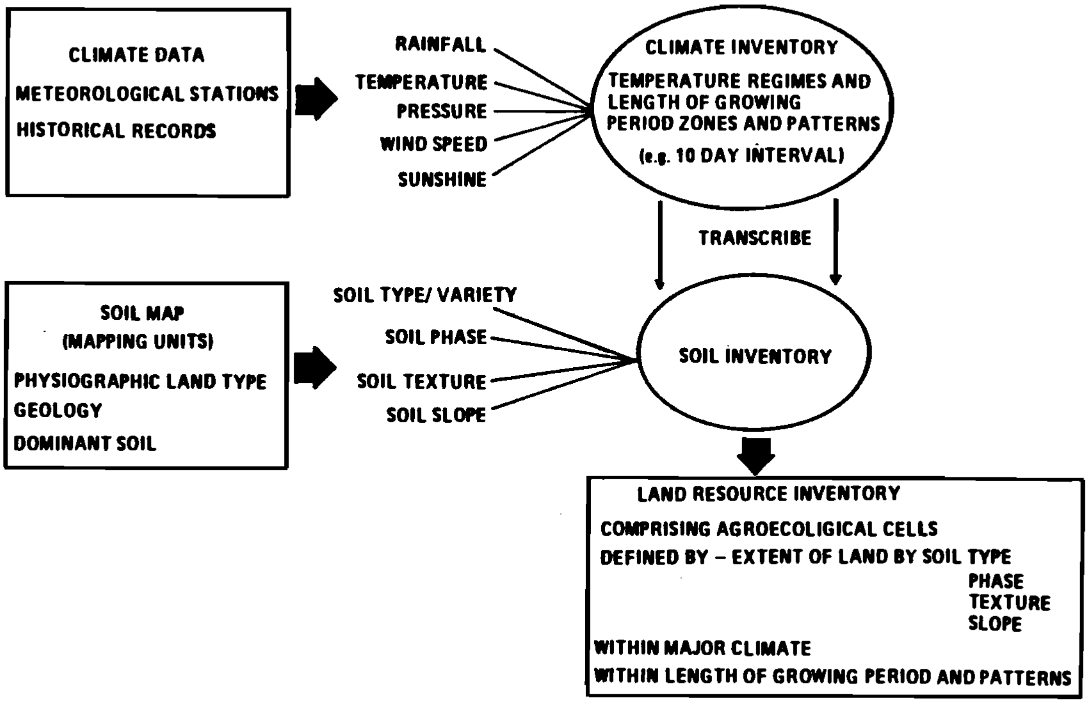
Depending on the country level soil and climate data available, the basic land inventory can be refined or replaced by a detailed inventory. Fig.3 shows the data relevant for compiling such an inventory. At the country level it is important to develop the basic land inventory by state, district and/or province, i.e. administrative areas; these localities are often relevant for planning. Examples of the type of country refinements are shown in Tables 1-3 for soils, climates and length of growing period zones respectively. The refinements of the soil and climate resources inventory for a particular country will depend on the information available. For countries with little or no information the FAO Phase 1 land resources inventory provides a starting point.

3.3. Land Use

Not all the inventorized land in the inventory is available for rainfed agricultural production. Land requirements for irrigated use and non-agricultural use need to be considered.

In the AEZ study land under irrigation (in year 1975 and projected to be in year 2000) was identified by extent and location on the soil map for each country (Wood, 1980). The basic country level information was obtained from FAO's AT2000 study and the irrigated areas were located on the map according to country information and/or expert knowledge. Once located, the irrigated acreages were deducted from the relevant agro-ecological cells. It should be

Fig. 3 COMPILATION OF CLIMATE AND SOIL INVENTORY-COUNTRY STUDY



noted that irrigated production is included in the assessment of population supporting potential (Fig.1, step 3).

For the non-agriculture land use (Hyde, 1980), lack of country level data resulted in the adoption of an assumption that non-agricultural land use is related to the population distribution within the country. Population census data for each country was used to locate the population by length of growing period zones in each country. Within each LGP zone it was assumed that the non-agricultural land use is equivalent to 0.05 ha per person. Accordingly, the extent of land in each agro-ecological cell within a zone was reduced according to the population density.

The above 'deductions' for irrigated and non-agricultural land use in the total land inventory for each country resulted in the quantification of the inventory of land available for rainfed cultivation.

3.3.1. Country Refinements and Extension

Country information, Fig. 4, by state, district and/or province should be used to quantify the extent and location of irrigated areas (present, planned and potential areas in the future), non-agriculural land use, 'other' agricultural land use and forest land use on the country soil/climate map.

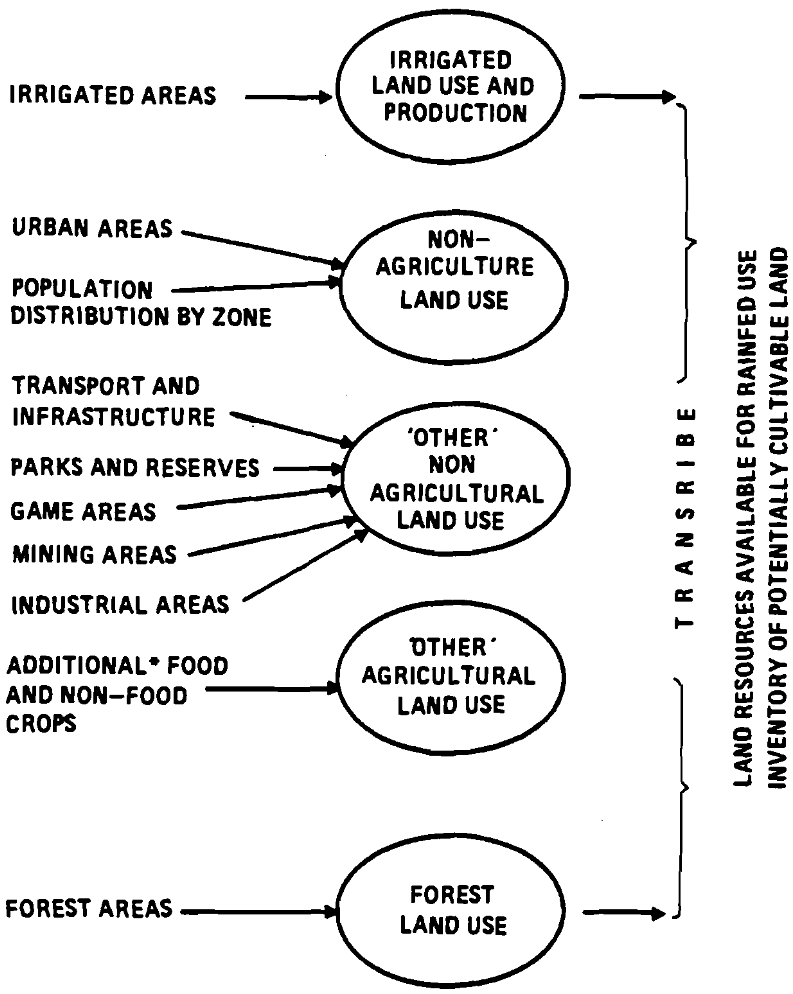
Non-agricultural land requirements will include areas required for habitation (e.g. boundaries of towns, cities, etc.), industry, mining, recreation (e.g. national parks and reserves), transport and infrainfrastructure, etc. Note that due to extensive distribution of the rural population, an approximate allowance for habitation in terms of hectares per person will still be necessary. For the 'other' agriculture use, areas under crops (which are not formally being considered in the detailed country study) should be identified on the country soil map and appropriate land use 'allowance' be made. Present and future forest-designated areas, especially productive forest reserves for fuel wood and timber will need to be located and explicitly considered.

At the detailed country level study, an effort should be made to formally include all important crops; for any additional crops an appropriate area 'allowance' will have to be made, e.g. vegetables grown throughout the country to some extent may be considered in this manner.

3.4. Land Resources Available for Rainfed Production

The land resources available for rainfed production are quantified from the basic land resources inventory after making appropriate deductions for the requirements of irrigated, non-agriculture, 'other' agriculture and forest land use, Fig.4. At this stage, for a particular country, the land resources inventory available for rainfed production comprises of the following hierarchy:

Fig. 4 ESTIMATION OF RAINFED LAND RESOURCES: COUNTRY STUDY



*Crops not formally considered in the study

- within each major climate there are a number of length of growing period zones
- within each LGP zone there are a number of agro-ecological cells

- each cell is a basic land unit specified by extent of land in the cell, soil type, soil phase, soil texture and soil slope.

The next step in the methodoloy is to choose a particular farming technology and input level and then to assess the production potential on a crop-by-crop basis in each agro-ecological cell.

3.5. Crops of the Study

Fifteen food crops, Table 4, were chosen on the basis of the most important crops (in terms of the acreage planted) in the world and in some cases in the developing world. The latter applied to banana/plantain and oil palm. Two of the crops, namely rice and wheat were considered according to type, namely upland rice, paddy rice, winter wheat and spring wheat. Note that grassland is considered as a crop for the rangeland production of livestock.

Table 4: CROPS CONSIDERED IN AEZ STUDY

CROPS OF THE AEZ STUDY	SPRINGWHEAT, WINTER WHEAT, PADDY RICE, UPLAND RICE, MAIZE, WINTER BARLEY, SORGHUM, PEARL MILLET, WHITE POTATO, SWEET POTATO, CASSAVA, PHASELOUS BEANS, SOYABEANS, GROUNDNUT, SUGAR CANE, BANANA/PLANTAIN, OIL PALM, GRASSLAND/ LIVESTOCK
EXAMPLE: KENYA COUNTRY STUDY ADDITIONAL CROPS CONSIDERED	COFFEE ARABICA, COFFEE ROBUSTA, SISAL, PINEAPPLE COTTON, TEA, PYRETHRUM, CASTOR BEAN, SESAME, SUNFLOWER, TOBACCO, FUEL WOOD AND TIMBER, CASHEW

3.5.1. Country Level Choice of Crops

For a detailed country study, the most important crops including food and non-food crops will have to be considered. Note that for all crops formally considered in the study, it will be necessary to develop appropriate crop production models as described in Section 3.7. If it is not feasible to do this for some of the crops and/or for other minor crops, data on present and future acreage and production by location within the country will be required to make an allowance for this land requirement. Such information may be generated from district surveys/plans, Landsat imagery etc. Examples of relevant additional crops for a country study are shown in Table 4.

Another important aspect to be considered is in relation to crop-mix and cropping patterns. Generally crops are grown in rotation and mixes rather than individual crops. In the application of the methodology especially at sub-national level such aspects will need to be incorporated through explicit consideration in the crop production models or as a constraint in crop choice.

3.6. Farming Technology and Input Levels

Three separate levels of input, namely Low, Intermediate and High are defined in the study to represent subsistence, subsistence/commercial and commercial farming systems respectively, Table 5. Corresponding to the three input levels and each crop of the study, yield tables according to LGP zones have been developed on the basis of physical crop production models.

The crop yield-input relationships from the Global Technology Matrix (GTM) of the AT2000 study (FAO, 1981), Table 6, is 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 gives the yield-input relation at four discrete yield levels; for yield in between these levels a

Table 5: 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 Conservation Measure.	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.
Power Resource	Manual Labour With Hand Tools	Manual Labour with Hand Tools and/ or Animal Traction with Improved Implements	Complete Mechanization Including Harvesting
Labour Intensity	High, Including Uncosted Family Labour	High, Including Part Costed family Labour	Low, Family Labour Costed if Used
Capital Intensity	Low	Intermediate with Credit on Accessible Terms	High
Market Orientation	Subsistence Production	Subsistence Production Plus Commercial Sale of Surplus	Commercial Production
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	Fragmented	Sometimes Consolidated	Consolidated
Current Inputs Required*	Seed Traditional Human Labour	Seed Traditional/ Improved Human Labour/ Animal Power Fertilizer N–P–K Pesticides	Improved Seed Mechanical Power Fertilizer N–P–K Pesticides

*For each crop of the assessment and the input level, the yield–input relationship from the FAO AT 2000 Study, Global Technology Matrix is used to quantity the current inputs requirements.

linear interpolation procedure is used to estimate the input requirements.

3.6.1. Country Level Refinement and Extension

For a country level study, relevant farming technologies and local crop yield-input response relationships have to be considered. For example, the high input yield level for a particular crop may entail a mixture of human, animal and mechanical power rather than only mechanical power as considered in the Phase 1 study. The issue of management (e.g. timeliness and efficiency of oprations such as planting, weeding, etc.) has a significant effect on the yield level

Table 6: 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	16.00	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	86.56	96.94	122.53	49.24	72.02	73.49	80.42	60.23	91.66	106.22	138.95
Fertilizer Nitrogenous	kg/ha	0.0	2.09	44.24	163.30	0.0	0.31	6.92	31.80	0.0	1.99	42.26	179.96
Fertilizer Phosphatic	kg/ha	0.0	1.36	28.89	119.71	0.0	0.21	4.61	21.20	0.0	1.30	27.76	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

and such considerations should be incorporated in defining farming technologies and input levels as well as quantifying yield-input responses for particular LGP zones. Information on crop yield-input response may come from existing fertilizer demonstration/trials and other experimental station data. The presently used farming technology needs to be evaluated and the time-path and feasibility of future technological development assessed in the context of desirable food and agricultural self-sufficiency and trade targets.

3.7. Crop Production 'Models'

Corresponding to the three input levels considered in the AEZ study and for each of the fifteen food crops (and grassland/livestock) of the study, a physical crop production 'model' has been developed for each of five regions: Africa, South America, Central America, Southwest Asia and Southeast Asia. These crop 'models', comprising a set of climate rules (crop-climatic suitability), LGP zone rules (agro-climatic yield levels), soil rules (soil suitability yield classes), rest period rules (crop-fallow period requirements), degradation rules (soil loss-productivity loss relationships) and wastage losses (harvest and post-harvest losses), provide a framework for the estimation of the expected yield and productivity for a particular crop in an agro-ecological cell characterized by its Climate, Length of Growing Period and soil attributes.

Fig. 5 shows the framework of a crop production model. The six main components of the model to estimate the annual rainfed yield and productivity at each of the three input levels are: agro-climatic suitability taking into account the length of growing period available, soil suitability, rest (fallow) period reqirements, degradation losses, wastage and seed requirements.

3.7.1. Agro-Climatic Suitability

For each crop that can be grown in an area, there is an optimum agro-climatic yield potential dictated by climatic conditions (Kassam 1977, 1979a). As an example, Table 7a shows the agro-climatic yield for maize in some of the warm tropics by length of growing period zones at the three input levels. Agro-climatic constraints of pests, diseases, weeds, workability and rainfall variability have been considered in arriving at these potential yields, as have increases in productivity from multiple cropping.

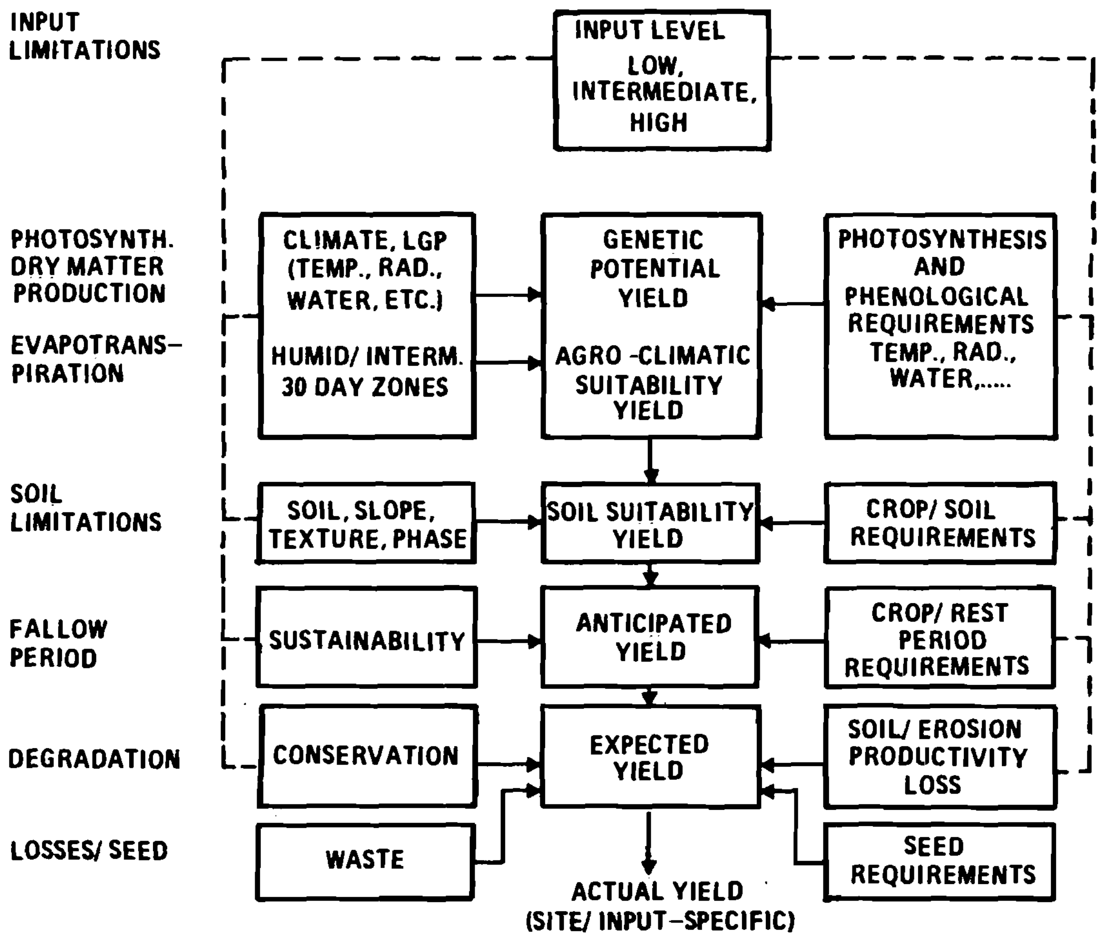
3.7.2. Soil Suitability

Soil conditions modify the agro-climatic potential yield and determine the attainable yield (Sys and Riquier, 1980). Table 7b shows the soil limitation ratings for maize for some main soils.

3.7.3. Rest Period

In their natural state, many soils cannot be continuously cultivated with annual food crops without undergoing some degradation in the form of

Fig. 5 CROP PRODUCTION 'MODEL'



deterioration in soil structure, nutrient status and other physical, chemical and biological attributes. Rest period, i.e. time over which land is not cultivated and allowed to revert to 'natural vegetation', is required to control and keep in check this degradation (Young and Wright, 1980). The extent of the necessary rest period is dependent on the level of input and soil and climatic conditions. Table 7c shows the rest period requirements of major soils under humid and semi-arid climates at the three input levels.

Table 7a: MAIZE YIELDS UNDER VARIOUS CLIMATIC CONDITIONS AND BY INPUT LEVEL (MT PER HA - DRY WEIGHT)

WARM TROPICS LGP (DAYS)	LOW INPUT	INTERMEDIATE INPUT	HIGH INPUT
75-89	0.2	0.5	0.9
120-149	1.2(1.4)	3.5(4.0)	5.4(6.3)
150-179	2.3(2.8)	5.1(6.5)	7.1(9.4)
180-209	2.5(3.7)	5.7(9.2)	7.9(13.3)
270-299	2.1	3.3	4.1

Country Refinement: Figures in brackets show the yield levels for Kenya country study: differences in yield due to the existence of a second growing period in the LGP zones in Kenya.

3.7.4. Land Degradation

Land degradation refers to the partial or total loss of productivity resulting from processes such as soil erosion by water or wind, salinization and alkalinization, water logging, depletion of plant nutrients, organic matter, deterioration of soil structure, and pollution (FAO, 1979).

In the study, the effects of water and wind erosion are assessed by estimating the soil erosion losses and linking these losses to productivity losses. Estimation of soil erosion are based on a parametric approach, Fig.6, using climatic (rainfall and wind erosivity indices), soil, topographic, texture and vegetation/land use factors. The levels of soil loss are related to productivity losses using relationships as shown in Table 8.

3.7.5. Wastage

Wastage due to harvest and post harvest losses have been assumed to be 10% of the anticipated yield for all three input levels.

Table 7b: LIMITATION SOIL RATINGS FOR MAIZE BY INPUT LEVEL

SOIL	LOW INPUT	INTERMEDIATE INPUT	HIGH INPUT
LITHOSOLS	N2	N2	N2
ACRIC FERRALOSOLS	N2	N1	S2/N1
ORTHIC ACRISOLS	S2	S2	S1/S2
CAMBIC ARENOSOLS	N2	S2/N2	S2
CALCIC 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

3.7.6. Seed Requirements

Estimates of seed requirements by crop as assumed in the study are shown in Table 9. Note that the same seeding rates are applied to all three levels of input; in reality the seeding rate would vary somewhat with the level of input.

The application of the above set of rules and relationships (Section 3.7.1 to 3.7.6) for a particulr input level, crop and agro-ecological cell in the inventory results in an estimate of crop yield (Fig.5) in each cell.

Table 7c: REST PERIOD REQUIREMENTS (CULTIVATION FACTORS)* FOR SOME MAJOR SOILS ACCORDING TO CLIMATIC AND LEVEL OF INPUT CONDITIONS

	Low Inputs		Intermediate Inputs		High Inputs	
Soil	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 which it is possible to cultivate the land, as a percentage of the total cultivation and non-cultivation cycle.

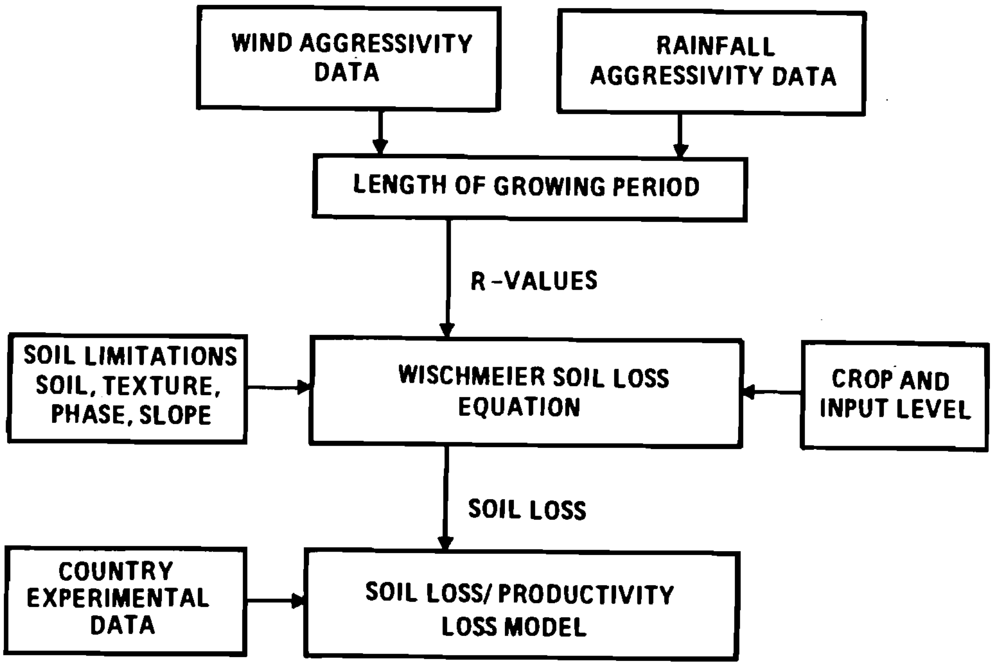
3.7.7. Country Refinements and Extensions

In the Phase 1 AEZ study, fifteen food crops and grassland were considered. For a country level study, additional food and non-food crops have to be incorporated and appropriate crop production models will need to be developed.

Also country specific data and information will be required to improve the 'regional' crop production models as used in the Phase 1 study. Examples of possible refinements and extension for such improvements are given below:

- Modifications of crop-climate (temperature regimes) suitability rules according to country information and experience with local crop varieties.
- Modification of crop yields by LGP zones according to country data and practice, e.g. intercropping and multiple cropping practices in different locations and existence of additional growing periods, etc.

Fig. 6 METHODOLOGY OF LAND DEGRADATION HAZARDS: SOIL EROSION AND PRODUCTIVITY LOSSES: COUNTRY STUDY



- Modification of crop soil suitability rules according to country detailed data.
- Modification of rest period requirements according to country data on recommendations and practice; Fig.7 shows the necessary information for this.
- Modification of estimates of soil and productivity losses. Country data should be used to estimate the parameters of the soil loss model. The 'link' between soil loss and productivity loss (in terms of broad classes, Table 8) as used in the study has been improved by theoretically/empirically estimating soil loss/productivity loss functions for particular soils and crops, Shah et al (1985). Information on crop productivity losses caused by unchecked soil erosion is essential to farmers and governments to justify

Table 8: ASSUMPTIONS FOR SOIL LOSS–PRODUCTIVITY LOSS RELATIONSHIP

Severity of Degradation. Rate of Soil Loss (metric tons per ha per annum)	Long Term Productivity Losses
< 12	No Change in Land Productivity Values
12 to 50	50 Percent of Very Productive Land Downgrades to Productive Land: Remainder Remains Unchanged
51 to 100	100 Percent of all Productive Land Downgrades by one Productivity Class
100 to 200	50 Percent of all Productive Land Downgrades to Not Suitable (Non-Productive Land): Remainder Downgrades by one Productivity Class
> 201	All Productive Land Downgrades to Not Suitable (Non-Productive Land)

Production Classes:

Very Productive Land (VH) = More than 80% of Ymax
Productive Land (H) = 40 to 60% of Ymax
Moderately Productive Land(M) = 20 to 40% of Ymax
Low Productive Land (L) = Less than 20% of Ymax
Not Suitable Land (NS) = Zero Yield
Ymax is Maximum Attainable Yield

Table 9: SEED REQUIREMENT – AEZ STUDY

SEED REQUIREMENT AEZ STUDY	KG/ HA DRY WEIGHT	SEED REQUIREMENT AEZ STUDY	KG/ HA DRY WEIGHT
WHEAT	85	SWEET POTATO	135
MAIZE	30	CASSAVA	0
MILLET	20	BEANS	40
SORGHUM	20	SOYABEAN	40
RICE -UPLAND	30	GRUNDNUT	75
RICE -PADDY	90	BANANA	0
BARLEY	75	SUGARCANE	350
WHITE POTATO	300	OIL PALM	0

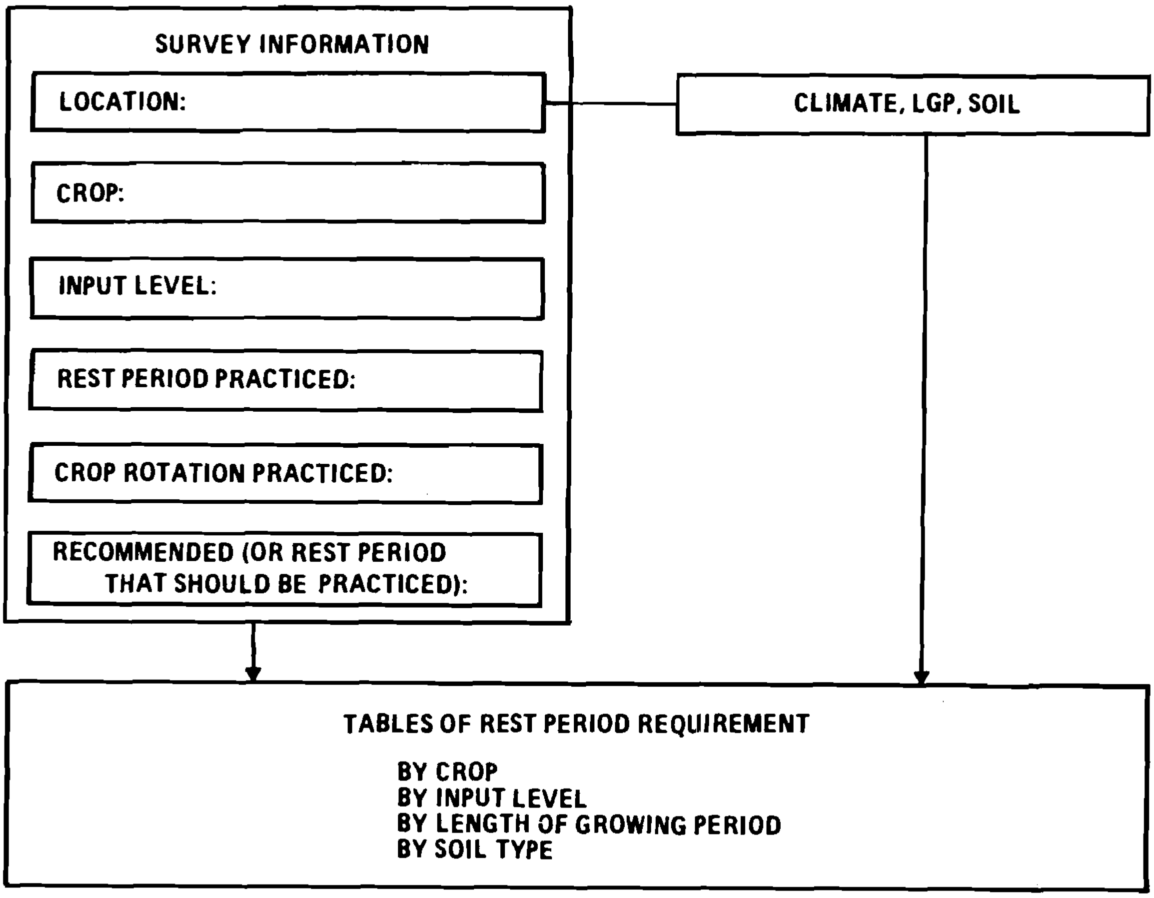
EXAMPLE: KENYA COUNTRY STUDY

MAIZE: SEED (TRADITIONAL/ IMPROVED) REQUIREMENT, LOW INPUT = 22/ 0 KG/HA

INTERMEDIATE INPUT = 12/12 KG/HA

HIGH INPUT = 0/ 30 KG/HA

Fig. 7 COMPILATION OF DATA ON REST PERIOD REQUIREMENTS FOR CROPS AND BY REGIONS WITHIN A COUNTRY



and apply soil conservation measures (Shah, 1982).

- The wastage loss assumed in the study is approximate and here country data by crop, location and input level should be used. The wastage losses should not only include losses in the production sector but also in the consumption sector. Estimates for the latter sector may be obtained, for example, from the consumption and nutrition surveys in the country.
- Country level data on recommended and practiced seeding rates at various input levels should be used to estimate seeding rates by input level (see

Table 9).

3.8. Livestock Production

In the study grassland is used to assess the production of calories and protein from livestock (Blair Rains and Kassam, 1980). According to climatic conditions, primary production of herbage, leaves and fruits of woody plants and crop residues were assessed and related to production of livestock products (meat, milk and blood) from cattle, sheep, goats and camels. Table 10 shows livestock yield (calories and protein) by major climate and length of growing period zones.

Table 10: CALORIE AND PROTEIN (KG) PRODUCTION PER HA IN IN SUMMER RAINFALL AREAS FROM GRASSLAND/ LIVESTOCK (i.e. MAJOR CLIMATE 1, 2, 3, 7, 8, 9)*

INPUTS	PRODUCT	LENGTH OF GROWING PERIOD (DAYS)			
		1–74	75–149	150–269	270–299
LOW	CALORIE	19941(M)	37528(H)	39709(H)	60825(VH)
	PROTEIN	0.99(M)	1.85(H)	1.97(H)	3.01(VH)
INTERMEDIATE	CALORIE	39882(M)	75056(H)	79418(H)	121650(VH)
	PROTEIN	1.98(M)	3.70(H)	3.94(H)	6.02(VH)
HOGH	CALORIE	79764(M)	150112(H)	158836(H)	243300(VH)
	PROTEIN	3.96(M)	7.40(H)	7.88(H)	12.04(VH)

VH = VERY HIGH PRODUCTION CLASS
H = HIGH M = MODERATE L = LOW

*As shown in Table 2

3.8.1. Country Refinements and Extension

Apart from the rangeland production of livestock, in many locations livestock and crop production activities co-exist. In such situations, especially in the developing countries, livestock feed often comprises of a mix of natural vegetation, weeds, crop residues, crop by-products and also crops. From the production potential of a particular crop, an estimate of crop residue and by-products possibly available as livestock feed can be made and linked to the production of livestock. The methodology of estimating livestock production via grassland as used in the study needs to be supplemented by country relevant integrated crop and livestock production systems. If livestock census data is available, then the feed requirements in each LGP zone can be assessed against feed (grassland, crop residues, crop by-products) availability and an assessment of livestock supporting potential can be carried out. This approach has recently been applied to all tsetse infested countries in Africa (Fischer, Shah and Rollinson, 1984).

3.8.2. Fish Production

In the Phase 1 study fish production and its contribution to population supporting potential was not considered. In some countries, the contribution of fish to human nutrition is important. For the detailed country studies, information on present and potential fish production and consumption by location will have to be considered and incorporated.

3.9. Land Productivity and Criterion of Crop Choice

For each of the agro-ecological cells in the land inventory, the application of the crop production models results in the assessment of land productivity, i.e. the expected yield of each feasible crop individually grown in the cell. The choice of the crop that should be grown in a particular cell depends on the criterion of choice. In the AEZ study the aim was to assess the population supporting potential and hence in this case the criterion of crop choice was related to maximizing calorie production - with a minimum protein availability constraint at the LGP zone level.

3.9.1. Potential Population Supporting Capacity Study

In the AEZ study the potential population supporting capacity for the year 1975 and for the year 2000 were assessed according to the following three alternative farming technology levels:

- Low Input level, continuation of present crop mix*, no soil conservation measures.
- Intermediate Input level, continuation of present crop mix on part of land and remainder under 'optimal' crops ('optimal' refers to crop producing maximum calories with a constraint of minimum protein availability at the LGP zone level), 50% soil conservation measures.
- High Input level, 'optimal' crops and full soil conservation measures.

For the above three alternatives the estimated rainfed production potentials, derived on the basis of appropriate linear programming models, Shah and Fischer (1980), were converted into total calorie and protein production in each length of growing period. This was combined with the production from the irrigated land. The total calorie production potential under each alternative was converted into population supporting potentials by dividing by per capita calorie and protein requirements from country tables prepared by FAO/WHO (1973).

For the year 1975, results comparing present and potential population for individual length of growing period zones and major climates within each country were analyzed. Note that for the year 1975, population distribution by LGP

*Data on present (1975) crop-mix, i.e. acreage under each crop, by individual country LGP zones was estimated from the sub-national (generally administrative areas) data reported by the country. An example of this data aggregated for the five regions of the study and for Kenya by LGP zones for the warm tropical climate are shown in Tables 11 and 12 respectively.

Table 11: CROP DISTRIBUTION* (RAINFED AND IRRIGATED) BY LENGTH OF GROWING PERIOD ZONES IN WARM TROPICS: BY REGION, 1975

Length of Growing Period (Days)	% Zone, Area Occupied	Climate I: Warm Tropics				
		Africa	S.W. Asia	South America	Central America	S.E. Asia
365+ (N) Humid	> 50					Rice
	25–50	Cassava		Maize		
	10–25	Maize/Banana Rice/Groundnut		Groundnut/ Banana		Oil Palm/ Maize
	5–10	Beans/ Oil Palm		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/ Oil Palm		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	Sorghum/Wheat		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) 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		

*Aggregated regional data compiled from individual—country LGP zone data for 1975. (Table 12)

Table 12: CROP DISTRIBUTION (RAINFED AND IRRIGATED) BY LENGTH OF GROWING PERIOD ZONES– KENYA, 1975

Length of Growing Period (Days)	% Zone Area Occupied	Major Climate		
		Warm Tropics	Moderately Cool Tropics	Cool Tropics
240–269(N) Subhumid	>50		Maize	Beans
	25–50	Maize/ Beans		Spring Wheat
	10–25		Beans	
	5–10	Millet/ Cassava		
210–239(N) Subhumid	>50		Maize	Beans
	25–50	Maize/	Beans	Spring Wheat
	10–25	Sorghum/ Beans		
	5–10	Millet/ Cassava/ Sugarcane		
180–209(N) Subhumid	>50		Maize	Beans
	25–50	Maize	Beans	White Potato
	10–25	Sorghum/ Beans	White Potato	Spring Wheat
	5–10	Sugarcane		
150–179(N) Subhumid	>50	Maize	Maize	Beans
	25–50		Beans	White Potato
	10–25	Sorghum/ Beans	White Potato	
	5–10	Banana/ Sugarcane		Spring Wheat
120–149(N) Semi Arid	>50	Maize	Maize	Beans
	25–50		Beans	White Potato
	10–25	Beans	White Potato	
	5–10	Sorghum	Spring Wheat	Spring Wheat
90–119(N) Semi Arid	>50	Maize	Maize	Beans
	25–50		Beans	White Potato
	10–25	Beans	White Potato/ Spring Wheat	Spring Wheat
	5–10	Sorghum/ Banana		
75–89(N) Arid	>50	Maize	Maize	Spring Wheat
	25–50	Beans		Beans
	10–25		Spring Wheat/ Beans	White Potato
	5–10	Sorghum/ Banana	White Potato	
1–74(N) Arid	>50	Maize	Maize	Spring Wheat
	25–50	Beans		Beans
	10–25		Spring Wheat/ Beans	White Potato
	5–10	Banana	White Potato	

zones was derived on the basis of population census data from the individual countries.

For the year 2000, the projected country population (UN, 1979) has been distributed by LGP zones and major climates on the assumption that this distribution is the same as the known distribution for 1975. The implication of this assumption is that population in individual-country LGP zones increases from 1975 to year 2000 with the same rate of increase as the overall country population, i.e. there is no migration between zones during the period 1975 to 2000. Identification of potential and critical LGP zones in the year 2000 in this manner provide the basis for the formulation of future (up to year 2000) migration policies to distribute population within the country according to food production potentials in various LGP zones -- and/or food distribution policies, i.e. food transfers from surplus to deficit areas.

At the detailed country level study the population supporting capacity assessments should be carried out by region (e.g. administrative area). Also the design of the scenarios should take account of country situations in relation to likely levels of inputs available (fertilizers, labour etc.), soil conservation measures, consumption-mix, etc. Typically, criteria of crop-choice will include self-sufficiency and export targets within the objective of maximizing income and employment opportunities.

3.9.2. Country Level Food and Agriculture Development Planning Study

The refined and extended physical resource data base as well as the AEZ methodology for a detailed country study provides the basis for an 'ecological-economic' approach to the planning of Food and Agriculture development by region within a country. An outline of some of the main issues to be considered is presented below:

Production and Demand

(a) Given the physical climate and soil resource base of the country, at a regional-administrative level, assess and quantify (at various alternative input levels) what food and non-food crops are best to produce in various areas of the country from the viewpoint of land productivity potential.

(b) Compare the production potentials of (a) together with any irrigated production with the regional/national domestic demand and national export targets for specific crops for the future. From this evaluation formulate regional production targets.

(c) Using the above production targets as constraints, quantify regional production possibilities. The regional constraints on input availability (e.g. fertilizer, labour, etc.) would also be introduced here. The results of this assessment will enable a quantification of feasible production levels for each crop and inputs required on a regional level. Any infeasibility in the preliminary production targets in a particular region have to be made up by transfer from other surplus regions, irrigated production and/or national imports. Future land requirements compared to present land use provide data to design appropriate investment and development strategies for land expansion.

(d) The crop residues and by-products of potential crop production together with grassland production is used to quantify the livestock production potential. A comparison of this potential with the present livestock population provides data for future development of the livestock sector.

(e) Present and potential fish (marine and inland) production by location need to be quantified and included in the assessment of food availability.

Issues of Equity and Distribution

Given the production levels and pattern on a regional basis within the country, quantify the value of production in each LGP zone in each region. With data on existing and/or projected population in each zone, estimate:

(i) per capita income generated from agricultural production in each zone

(ii) per hectare income generated in each zone.

Based on this data and equity considerations, policies on migration and population distribution, food distribution and marketing, land distribution and income distribution (including the need for alternative or additional sources of income, e.g. industrial development) may be formulated.

Technology

The assessment of the production possibilities as in (c) above will enable an identification of the inputs required by crop and region. This input utilization is a measure of the technology used and issues of what are feasible and likely technologies, infrastructures, research and extension efforts required, etc., can be considered on a regionl basis within the country.

Environmental Conservation

The assessment of production possibilities ((c) above) with various levels of assumed soil conservation measures can be used to generate information of necessary levels of soil conservation measures. The costs of the implementation of these measures together with the likely benefits (in terms of higher production) can be used to design subsidies/incentives for particular crops on a regional basis.

The scope of Food and Agriculture Development planning and the general assessment of the types of issues discussed above will very much depend on the level of detail used to quantify the physical resources base and all other associated information. Typically for a country level study, a base map of 1:1 million scale, if available, provides an appropriate level of detail. A summary of the type of data to be computerized in obtaining a physical land resource inventory for a detailed country-study is given in the next section.

4. CONCLUDING REMARKS

The methodology and resource data base developed within the agro-ecological zone study provides a first approximation of the food production potentials and the population supporting potentials for a large number of developing countries. The most fruitful avenue for further work and application of the methodology is in relation to detailed country case studies. Over the coming decades, a technological transformation of agriculture in the developing countries is anticipated. In some countries this transformation will be constrained by resource limitations and this could have serious environmental consequences. Typically, the relevant future issues of Agricultural and Resource development to be answered are:

- What is the stable, sustainable agricultural production potential of various regions within country? Of a country?
- Can the population in the regions within a country and of the nation as a whole be supported adequately by this stable, sustainable production potential?
- What alternative transition paths are available to reach desirable levels of this production potential?
- What are sustainable efficient combinations of techniques of agricultural production?
- What are agricultural and population policy implications at regionaland national level?

The application of the AEZ approach at a detailed country level would provide an analytical framework to integrate ecological and socio-economic considerations for development planning on a regional level within a country. Examples of the application of the AEZ methodology and national and international policies that can be formulated and evaluated are described in Shah and Fischer (1982a), Shah (1983), Fischer, Shah and Rollinson (1984), Shah et al (1984, 1985a-b).

4.1. Summary of Data Requirements for Country Studies

For all developing countries considered in the AEZ study a 1:5 million scale computerized land resources inventory is available. For a detailed country study a more refined data base is required. Technical requirements dictate at least one observation or a set of colleced data for each cm^2 of the resource inventory map being applied. A 1:1 million scale provides an appropriate level of analysis; increasing the scale to 1:100,000 would result in up to a hundred fold increase in required data inputs. The main components of the data (in map form to be digitized) required to compile and computerize a land resource inventory are:

- Soil Map (soil, texture, slope and phase)
- Administrative Area Map
- Climate (Temperature Regimes) Map
- Length of Growing Period (water availability) Map
- Rainfall Pattern Map (form and variability of LGP)
- Irrigated Areas and Production
- "Other" Food and Non-Food Crop Areas and Production
- Fish Production
- Forest Areas and Production (Fuelwood and Timber)
- National Reserves (Parks, Game Reserves, etc.)
- Urban Areas

- Industrial/Mining Areas
- Population Distribution
- Present Crop-Mix, Acreages and Inputs

All the above data may not be readily available in a compiled map or digitized form and the first task would be to assemble all the relevant information and build up the resource inventory stage by stage.

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APPENDIX 1

Numerical results of the application of the AEZ methodology to an agro-ecoloical cell are presented; the computer flow diagrams of the methodology are shown in Figs. A1-A2.

Cell of total extent 18000 Hectares. The cell is situated in warm tropical climate (01), length of growing period: 240-269 days (05) and tesoil (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 cm (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, are 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 (Fig.A1).

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 or 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 phaselous beans as a potential crop in cell (0105 Fx 20 B1): results from the application of land prductivity 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 technoloy levels. While the slope does not reduce productivity under low technology, 85% of the land has to be left uncultivated (fallow requirements). 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 asumption of low, intermediate and high technology for this cell are given in Tables 2a, 2b and 2c respectively.

Table 2(a-c): Evaluation of the potential for all food crops in cell (0105 Fx 20 B1): results of the land productivity program, (Fig.A1) and the optimum crop-mix progam (Fig.A2).

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, soyabean, 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), grassland 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 LGP). Nevertheless, oil palm is also chosen in MODE 2. When the present crop mix constraint is imposed upon the crop choice (MODE 3), 46.3% 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 soyabean, beans, sweet potato, cassava, upland rice and groundnut the production potentail 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 ad high technology are shown. Under both technology levels oilpalm 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 prodction. 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.

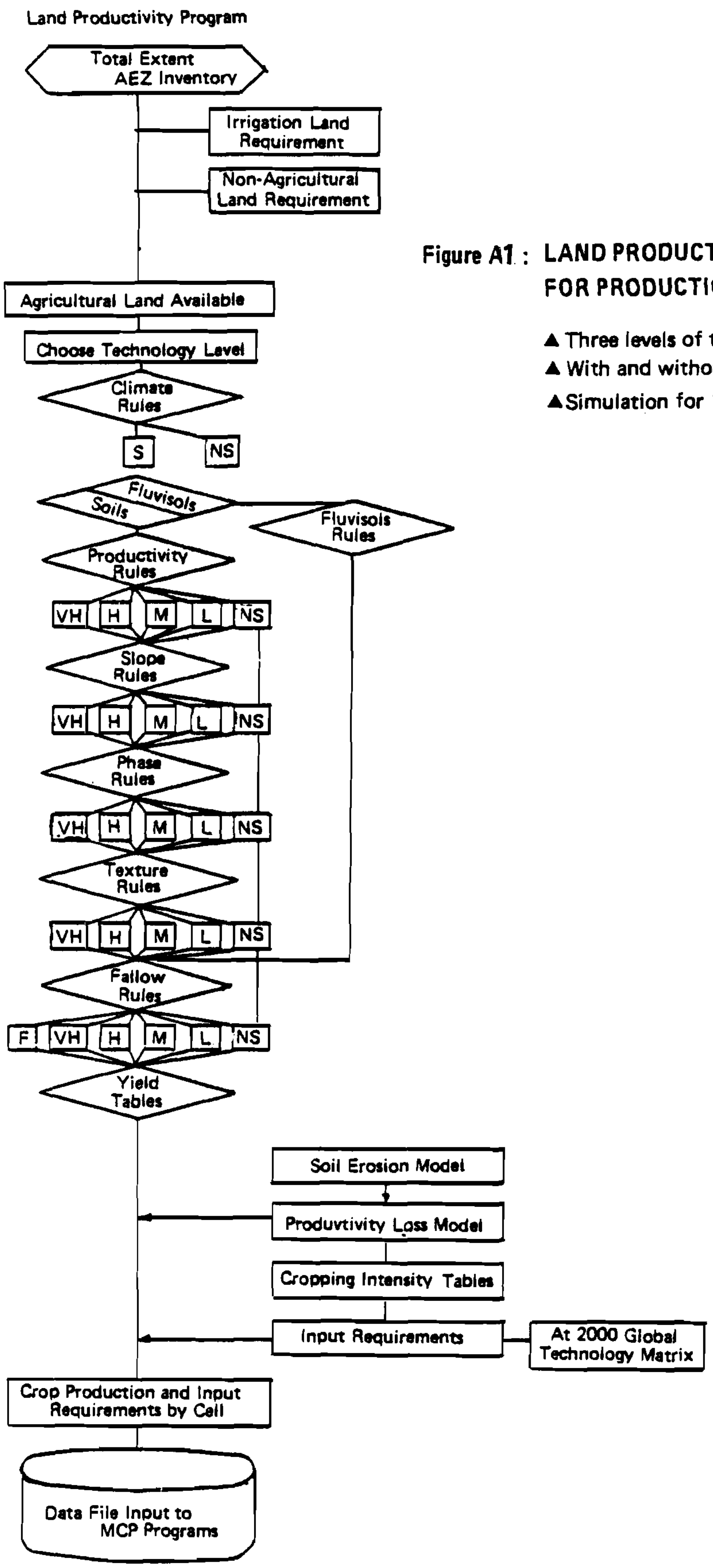
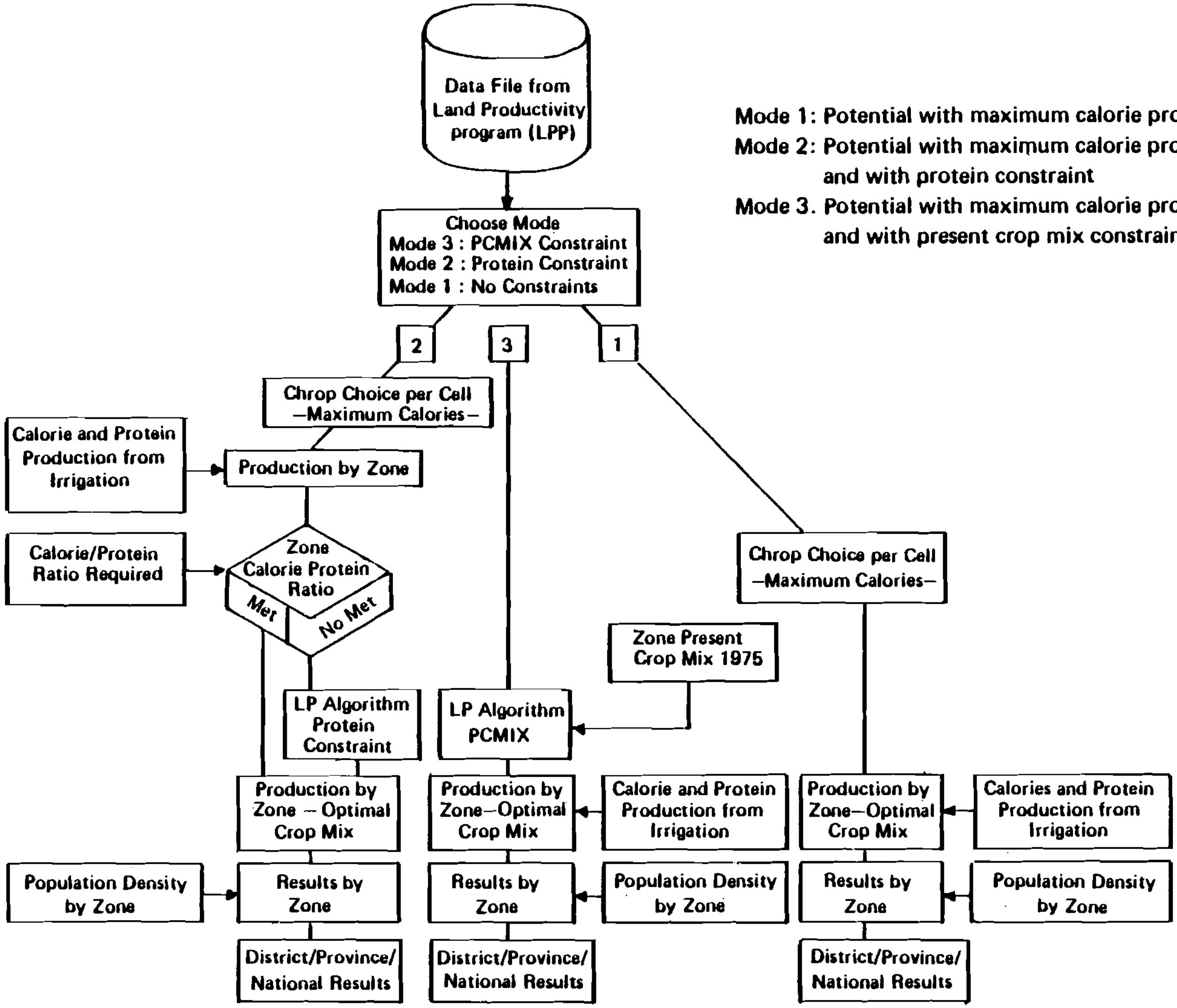


Figure A1 : LAND PRODUCTIVITY PROGRAM (LPP) FOR PRODUCTION ASSESSMENT

- ▲ Three levels of technology
- ▲ With and without degradation hazards
- ▲ Simulation for 1975 o r (2000)

Figure A2: OPTIMAL CROP MIX PROGRAM (MCP)



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

TABLE 1a: Cell Example

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 Mill 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

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	CALORIES Millions		PROTEIN Millions gms		CALORIES Millions		PROTEIN Millions gms		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 2a : Cell Example.

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*				2.45		13.75	1856.0	52.77			
MILLET					16.2		0	0			
SORGHUM				2.45		13.75	1536.9	45.26			0.466
					16.2		0	0			0
MAIZE			2.45			13.75	3510.6	81.58			
					16.2		0	0			
SOYBEAN			2.45			13.75	1686.5	191.21			
				1.2	8.1	6.9	340.4	38.89			
PHASEOLUS				2.45		13.75	785.9	50.93			0.534
BEAN				1.2	8.1	6.9	393.0	25.47			1.000
SWEET			2.45			13.75	4143.3	46.94			
POTATO				1.2	8.1	6.9	787.2	8.92			
CASSAVA			2.45			13.75	4424.0	36.48			
				1.2	8.1	6.9	1106.0	9.12			
BUNDED				5.4	10.8		2620.6	49.30			
RICE				5.4	10.8		2620.6	49.30			
SPRING					16.2		0	0			
WHEAT					16.2		0	0			
WHITE					16.2		0	0			
POTATO					16.2		0	0			
WINTER					16.2		0	0			
WHEAT					16.2		0	0			
WINTER					16.2		0	0			
BARLEY					16.2		0	0			
UPLAND			2.45			13.75	4262.7	80.19			
RICE				1.2	8.1	6.9	1000.1	18.31			
GROUNDNUT				2.45		13.75	2174.5	101.90			
				1.2	8.1	6.9	1087.2	50.95			
BANANA				16.2			9700.8	110.64		0	
PLANTAIN				16.2			9700.8	110.64		1.000	
SUGAR				2.45		13.75	72.8	0.49			
CANE				2.45		13.75	72.8	0.49			
OIL PALM				16.2			38605.	0	1.000	1.000	
				16.2			38605.	0	1.000	0	
GRASSLAND			16.2				323.5	15.96			
(LIVESTOCK)			8.1	8.1			242.6	11.97			

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

M1, M2, M3 represent Modes 1, 2, 3 respectively.

TABLE 2b : Cell Example

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
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.

M1, M2, M3 represent Modes 1, 2, 3 respectively.

TABLE 2c : Cell Example

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
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.

M1, M2, M3 represent Modes 1, 2, 3 respectively.