PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

# Land Resources Inventory and Productivity Evaluation for National Development Planning [and Discussion]

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*Phil. Trans. R. Soc. Lond. B* 1990 **329**, 391-401
doi: 10.1098/rstb.1990.0181

# Land resources inventory and productivity evaluation for national development planning

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**SUMMARY**

The developing countries would need to achieve an increase in their agricultural output by more than threefold during the next century to keep up with increasing demand, stemming from growth in population, incomes and urbanization. There is an urgent need for each country to quantify its long-term food and agricultural requirements and assess them against the possibilities of sustainable production from its own land resources. The extent to which physical resources of soil, climate, terrain and water can be utilized to produce food and agricultural products is limited. The ecological limits to production are set by soil and climatic conditions as well as by specific production 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 outputs, unless attention is paid to the management, conservation and enhancement of the natural resource base. The United Nations Food and Agricultural Organization agro-ecological zone (AEZ) methodology is concerned with the quantification of land resources and their potential agricultural productivity and population supporting capacity for development planning. The AEZ Kenya country methodology is described.

## 1. INTRODUCTION

According to the United Nations (UN) medium projections, world population could reach a stationary level of some 10.5 billion by the year 2110, compared with 5 billion at present, 6.1 billion projected for the years 2000, 7.8 billion for the year 2020 and 9.3 billion for the year 2055. Almost all the population increase (95%) will occur in the developing countries which, on average have low per caput consumption levels. The simplest lesson of the projection is that by the time the world is reaching close to population stability, demand for food and agricultural products could be more than three times its present level (FAO 1981).

One of the features of this growth pattern is that it will be fastest precisely in those countries where land resources are least adequate to meet the needs of their populations. Projections show that over the next 40–50 years, the developing countries will see the largest additions to their populations in all history. Consequently, the most critical phase of the world increase of population and the associated desirable socio-economic growth, and its most serious potential confrontations with soil, water, nutrients, flora, fauna, energy resources, and the living environment in many areas of the world, both north and south, are still to come.

Though the major obstacles to increasing agricultural production in many developing countries is shortage of capital investment, modern inputs, management and technical skills and research capability, the ecological limitations of the natural resource base in relation to demand and infrastructure is equally important. This is because the ability of land to produce is limited and the limits to production are set by soil, climate and landform conditions, and land use and management. Accordingly, knowledge on land resource endowment and its potential is an essential prerequisite to planning of optimum land use and subsequent sound 'long-term' agricultural and national development.

In particular, for planning optimum land use and formulating national agricultural development policies, answers are need to the following types of questions: (i) is there sufficient land to meet future food and agricultural needs? where are the potentially utilizable areas and what are their extents? for which land uses are they suitable and what is the range of their potential? (ii) which level of technology is required under these various circumstances? what is the risk of land degradation and environmental pollution, and what measures are required to minimize the risk? (iii) where can maximum returns from increased inputs be obtained and on what land uses? (iv) what levels of investment are needed to obtain these returns? (v) what are the limitations to production increases? (vi) where should research, extension and education efforts be concentrated?

Equally important is the need for developing countries to formulate an international policy frame based on national level assessments of land resource potentials to address questions of trans-national concern such as:

(i) which set of neighbouring countries may constitute a natural cooperative unit for trade, food and economic security and development of natural renewable resources?

(ii) what levels of international assistance and cooperation will be needed to promote a certain level of regional and global agricultural development?

Aware of these issues, the Food and Agricultural Organization (FAO) began in 1976 the Agro-ecological Zones Project (AEZ) (FAO 1978–81) to assess production potential of land resources in the developing world, and to provide the physical data base necessary for planning future agricultural development. Soil, landform and climate data were combined into a 1:5 million scale computerized land resources inventory of nearly 45000 unique agro-ecological cells. For each of these, crop ecological and agronomic requirements and crop growth models were applied to estimate rainfed yields and outputs at low (subsistence farming), high (commercial, modern farming) and intermediate (mixture of subsistence and commercial farming) levels of agricultural inputs.

This subsequently made it possible for FAO to undertake with support from United Nations Fund for Population Activities (UNFPA), and in collaboration with the International Institute for Applied Systems Analysis (IIASA), assessments of the potential population supporting capacities of 117 developing nations, grouped into five regions: Africa, Southwest Asia, Southeast Asia, Central and South America (FAO 1982). The study showed that 64 nations, out of the 117 studied, would be unable to, by the year 2000, to feed their populations from their own land resources, using low inputs. There would be an excess of population over the supporting capacity of 0.5 billion, no less than 48% of the population of the 64 critical countries. Twenty eight of these nations would cease to be critical if they were to reach the intermediate-input level of agricultural technology, but the excess of population over the supporting capacity by that time would be 140 million (29% of total population of the critical nations). Another 17 nations would no longer be critical if they applied high level of inputs; but 19 nations would remain critical even with high inputs, with an excess population of 48 million (46% of total population of the critical nations).

When allowance was made for non-food needs and food consumption factors, the number of critical nations with low inputs in the year 2000, for example, increased from 64 to 75. The number of critical nations with intermediate inputs rose from 36 to 43 and with high inputs, from 19 to 29 (FAO 1984). However, in many cases, potentially critical countries are adjacent to countries that could produce considerable surpluses. Utilizing this potential would stimulate intra-regional trade, and increase in regional food security by reducing dependence on food production and stocks from distant countries.

The FAO-AEZ methodology and the findings were deliberated over a full-day session by the 1983 FAO Conference which, recognizing the importance of such work for development, recommended that future activities be concentrated at the country level (FAO 1984). The AEZ regional assessments, in effect, ascertained country situations within a regional context; the AEZ country assessments of land productivity and population supporting capacity are intended to quantify sub-national situations within national contexts. For example, in the Mozambique (Kassam *et al.* 1982) and Bangladesh (Brammer *et al.* 1988) AEZ studies, the main objective was to provide national inventories of land resources and land suitability assessments to serve the needs of agricultural research, extension and development planners at national, regional and local levels. These national AEZ systems are capable of being continuously updated and extended as new information is provided by future soil and land use surveys, agricultural and forestry research, and field experience with individual crops and management practices.

This paper presents an overview of the recent work (Kassam *et al.* 1989) concerned with the development and implementation of a national level methodology for the determination of land use potentials of land resources of individual districts in Kenya, as a tool in policy formulation and national development planning. The work has been carried out by FAO and IIASA in collaboration with the Government of Kenya, and is part of the follow-up programme thrust to implement the 1983 FAO Conference recommendations.

The main objectives of the Kenya national assessment are to develop a national planning tool that can quantify:

(i) how much land of different quality is contained by each district;

(ii) what alternative kinds of land uses can be considered on land of different qualities in different districts, and what are their productivity potentials at different levels of production inputs;

(iii) how many people can be supported at those different levels of production inputs, and at what costs;

(iv) what are the policy implications of these land and population potentials for food and economic self-sufficiency, when examined against the background of present and future population needs.

## 2. METHODOLOGY

The overall methodology is schematically presented in figure 1, and comprises of the following fifteen activities:

1. formulation and selection of alternative crop, livestock and fuelwood land utilization types (e.g. species, input level, markets);
2. determination of ecological (soil and climate) requirements of crops, livestock and fuelwood land utilization types;
3. compilation of climatic resources inventory;
4. compilation of soil and landform resources inventory;
5. compilation of land use (including socio-economic aspects) inventory;
6. compilation of 1:1 million scale computerized land resources inventory (agro-ecological cells) of each district;
7. determination of land under other uses including areas under irrigation schemes, 'cash' crops and non-agricultural use;
8. determination of land available for crop, livestock and fuelwood productivity assessments;

9. formulation of crop productivity model, and assessments of land productivity potentials for crop production;

10. formulation of livestock productivity model, and assessments of land productivity potentials for pasture and livestock production;

11. formulation of fuelwood productivity model, and assessments of land productivity potentials for fuelwood production;

12. assessments of land productivity potentials from crop, livestock and fuelwood;

13. assessments of potential population supporting capacities, taking into account human nutritional requirements;

14. estimation of production inputs and soil conservation requirements;

15. addressing a range of policy issues for development planning, based on a set of scenarios embodying present and future populations, food and agricultural demands, and socio-economic development needs, opportunities and constraints.

The above 15 activities can be grouped into four sets, namely:

(i) definition of land utilization types and their ecological requirements (activities 1 and 3);

(ii) compilation of national land resources and land use inventory (3, 4, 5, 6, 7, 8);

(iii) formulation of crop, livestock and fuelwood

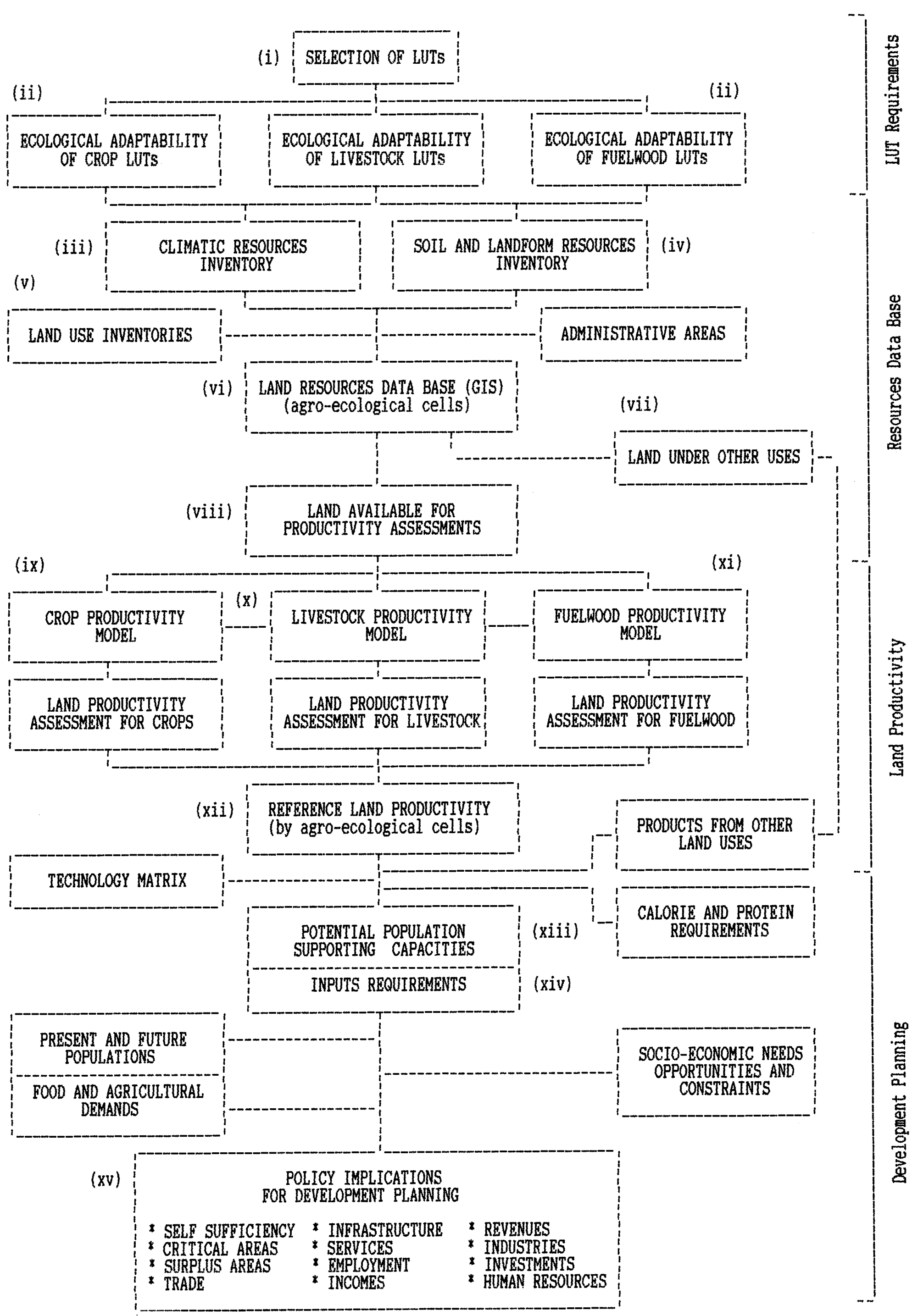


Figure 1. Schematic presentation of methodology.

productivity models, and assessments of land productivity potentials (9, 10, 11, 12);

(iv) development planning involving assessments of potential population supporting capacities and input requirements to address policy issues (13, 14, 15).

Activities related to the formulation and selection of land utilization types and their ecological requirements overlap with those activities concerned with the compilation of land resources inventory. This overlap is necessary to ensure that the land qualities which determine productivity are, as far as possible, explicitly characterized in the land resources inventory, and that land use requirements are formulated in terms of such land qualities.

Subsequently, the productivity models of crops, livestock and fuelwood are applied on the land resources inventory to estimate land productivity potentials of alternative kinds of land uses (land utilization types). These land productivity potentials in turn form a basis for quantifying potential population supporting capacities and input requirements at several levels of geographical and administrative aggregation (e.g. sub-district, district, province, nation). When set against present and projected future population distribution, food and agricultural demands, socio-economic development needs, opportunities and constraints, such assessments of land and population potentials provide an ecologically sound and coherent basis for national development planning.

## 3. LAND UTILIZATION TYPES AND ECOLOGICAL REQUIREMENTS

### (*a*) *Land utilization type*

The term 'land utilization type or LUT' has a specific meaning in land evaluation activities (FAO 1976). It represents a defined set of attributes (e.g. species, inputs, infrastructure, services) for each production system being assessed or evaluated.

In the crop productivity model, a total of 25 crop species are considered. They are differentiated into 64 crop types to account for differences in ecotype adaptation, crop phenology and growth cycles within each species. The crops comprise: 7 cereal food grain crops (wheat, barley, oat, rice, maize, pearl millet and sorghum); 6 leguminous food crops (cowpea, green gram, groundnut, phaseolus beans, pigeonpea and soybean); 3 root and tuber crops (potato, sweet potato and cassava); 9 'cash' crops (banana, oil palm, sugarcane, coffee, cotton, pineapple, pyrethrum, sisal and tea).

In the livestock productivity model, a total of 32 pasture and fodder species of grasses and legumes, and 6 livestock types are considered. The grass and fodder species comprise: 20 pasture grasses, 4 fodder grasses and 8 pasture and fodder legumes, and are considered at three levels of inputs. The 6 livestock types considered in the livestock productivity model are: cattle, goat, sheep, camel, poultry and pig, of which the first four are considered under 9 non-pastoral systems and 8 pastoral systems. The livestock model makes a provision for 19 livestock LUTs at three levels of inputs.

In the fuelwood productivity model, 31 species of fuelwood are considered at three levels of inputs (96 LUTs), of which 13 species have nitrogen fixing ability and 18 do not.

The three levels of inputs used in the models are: low inputs, intermediate inputs and high inputs. The low level circumstances assumes low capital input and subsistence management practices, the use of 'indigenous' cultivars of crops and breeds of animals, hand labour only, no use of fertilizers or biocides, no conservation measures, and cultivation in rotation with bush fallow to maintain soil fertility. It can be compared to traditional systems of bush fallow rotations. The intermediate level circumstance assumes medium capital input, partly subsistence and partly commercial management practices, the use of improved cultivars of crops and breeds of animals (including crossbred animals), use of improved hand tools and draught implements, some mechanization, some use of fertilizer and biocides, some soil conservation measures, and cultivation in rotation with grass fallow. The high level circumstance assumes capital intensive management practices, full use of most productive adapted cultivars of crops and breeds of animals (including exotic breeds), complete mechanization, optimum use of farm chemicals, and full soil conservation measures.

### (*b*) *Climatic and edaphic requirements*

Determination of the climatic and edaphic (soil) requirements of crops, livestock and fuelwood LUTs used in the Kenya national assessment has been a major activity. Previous attempts to quantify climatic requirements of crops (including pasture and fuelwood) have not adequately recognized the importance of the time course of temperature and soil moisture balance (including seasonal and between-year variations) in relation to crop growth (photosynthesis), development (phenology) and production (yield). Adequate emphasis has been placed on these two sets of environmental parameters (temperature and soil moisture regimes) in this national assessment.

Of similar significance is the nature of the photosynthetic response to temperature and radiation, which determines crop yield and land productivity when crop phenological requirements are met during the period when soil moisture is available for crop growth, accordingly, an inventory of crop, pasture and fuelwood species was prepared, based on their climatic requirements for both photosynthesis and phenology. Four main climatic adaptability groups of crops, pasture grasses and legumes, and fuelwood species are recognized in the assessment. This inventory gives, among other information, ranges of temperature requirements for different aspects of growth and development. These requirements are subsequently matched to the prevailing thermal climatic conditions.

Once the photosynthetic and phenological thermal requirements are met, the agronomic (and silvicultural) yield potential of a crop, under constraint-free conditions, is governed by the number of days (or years) to maturity. This, in turn, is determined by the





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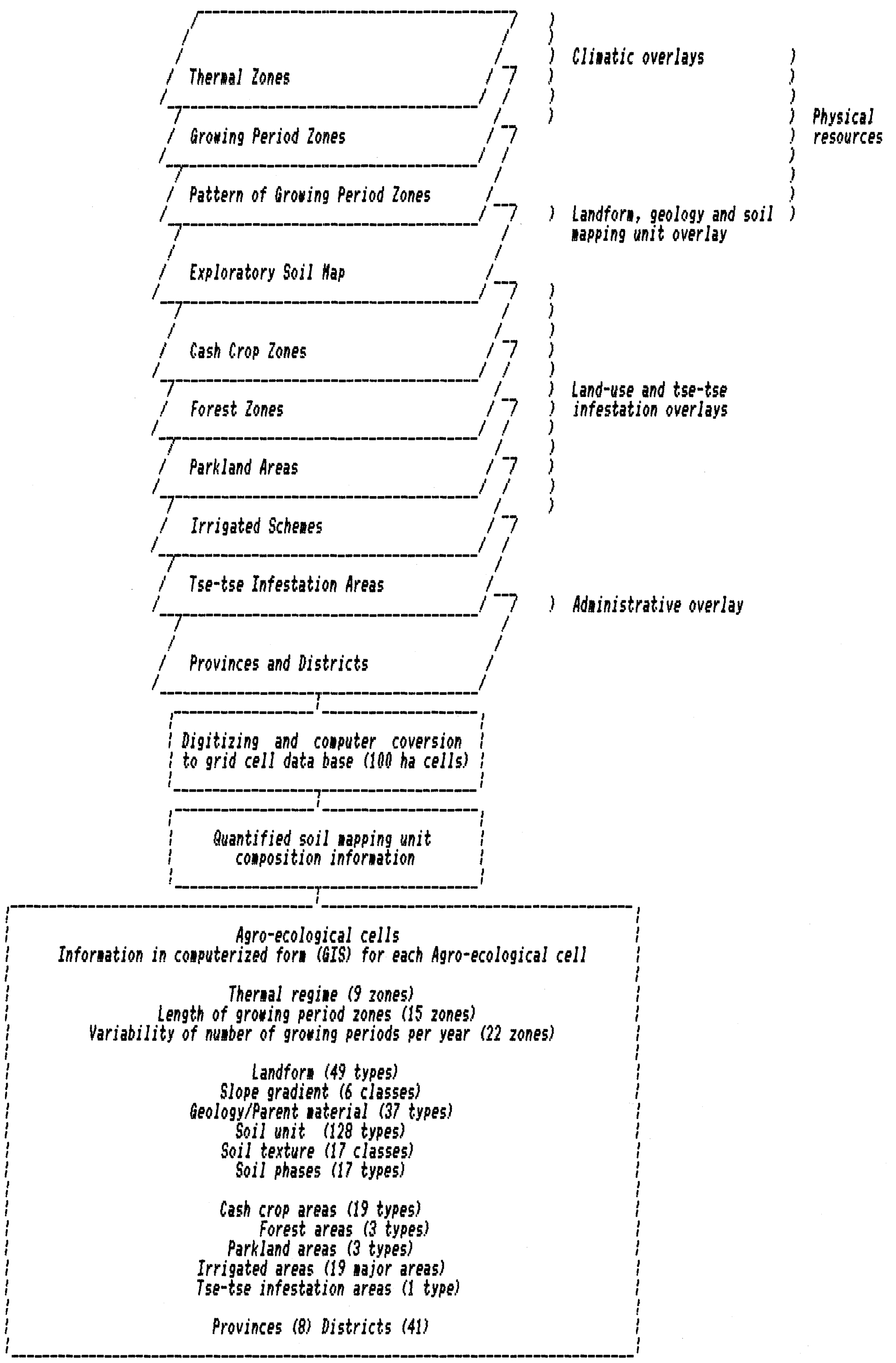


Figure 2. Make-up of land resources inventory.

length and quality of growing period (including its year-to-year variation). Constant-free yields are computed for all crop, livestock and fuelwood LUTS participating in the national assessment for all lengths of growing period. Such data are used as the basis of the climatic suitability assessments.

Soil requirements of LUTS are assessed as follows: for each crop, pasture and fuelwood species, available data on soil characteristics considered meaningful for production are listed, e.g. soil depth, texture, salinity, stoniness, flooding, etc. For each LUT, each property was then quantitatively subdivided into those for optimum conditions and for a range of conditions. When a property fell outside the defined range, the soil is considered as currently not suitable. The information on optimal and minimal values of soil properties for each LUT formed the basis for subsequent suitability ratings of soil units for production of crops, pasture and fuelwood.

## 4. COMPILATION OF NATIONAL LAND RESOURCES AND LAND USE INVENTORY

The land resources inventory brings together two layers of information on physical environmental resources (climate and soil), and allows the creation of unique agro-ecological land units (agro-ecological cells) within which soil, landform and climate conditions are known and quantified. This information, compiled at 1:1 million scale at the national level, by province and district, constitutes the inventory of the physical resource base (figure 2).

In the case of climate, temperature and soil moisture availability are key factors in determining the spatial and temporal distribution of rainfed crops. In combination with solar radiation, these climatic factors condition photosynthesis and allow plants to accumulate biomass (and accomplish successive development stages) according to their physiological rates and patterns.

Temperature (heat) attributes were quantified by defining thermal zones, and defining the various thermal characteristics. To cater for the differences in temperature requirements of crops, pasture and fuelwood species, nine reference thermal zones were inventories based on 2.5 °C interval in daily mean temperature.

Moisture attributes were quantified through the concept of the reference length of growing period, defined as the duration (in days) of the period during which actual evapotranspiration, of soil moisture from precipitation and from storage in the soil profile, is greater than half the potential evapotranspiration.

Length of growing periods were computed from historical data sets of some 435 locations, and average data sets of some 1500 locations for moisture supply from soil storage of up to 250 mm. With the historical data set, length of growing periods were computed for individual years, and frequency distribution for each mean length were computed for the historical series. Where there were more than one length of growing period per year, the total mean length as well as the individual mean lengths (e.g. two, three) and their frequency distribution were calculated. These computations represented the information on the length of growing period (LGP). Fifteen mean reference length of growing period zones (with 100 mm soil moisture supply from storage after the end of rains), at 30 days intervals, have been delineated in the climatic inventory of Kenya.

To inventory the year-to-year variation in the number of lengths of growing period, a historical profile was compiled showing groups of years each with a different number of growing periods per year. The proportional representation of each group in the total historical series was computed. This information represents the pattern of length of growing period (LGP-pattern). Twenty-two LGP-pattern zones have been recognized in the climatic inventory of Kenya.

For each LGP zone delineated, average values of major climatic elements (radiation, day and night temperature, humidity, etc.) were inventoried to characterize the climate during the growing period. These together with the information on the year-to-year variation in the number of length of growing periods per year and in each component length of growing period, formed the basis for subsequent matching and productivity estimation.

The soil inventory was compiled essentially from the 1:1 million scale Exploratory Soil Map of Kenya (KSS 1982), which is composed of 390 different soil map units. For each map unit, information on landform, geology/parent material, soil unit (with implied characteristics), slope-gradient, soil texture and soil phases, in terms of description, classes and extents was transferred to form the soil resources inventory of this assessment.

On completion of the climatic inventory, the three layers (thermal zone, LGP zone and LGP-pattern zone) were superimposed on the Exploratory Soil Map of Kenya. The resultant map output created the 35475 unique agro-ecological cells of the inventory, whose land attributes, defined by climate, soil and landform, are known and quantified. The different layers of climate and soil information were digitized and the information was converted to a land resources inventory of 576072 one millimetre square grid cells, each corresponding to 100 ha. This information, compiled at the national level by province and district, constitutes the physical land resources inventory of Kenya.

Additional seven layers of information were also digitized and overlaid on the land resources inventory. These layers contain information on cash crop zones, forest zones, parkland areas, irrigated schemes, tse-tse fly infestation areas, districts and provinces areas.

The climate, soil-landform and land use inventories make up the computerized land resources data based for the Kenya assessment (figure 2), and allow any desired geographical and administrative aggregation to be made of the inventoried parameters and results.

## 5. PRODUCTIVITY MODELS AND ASSESSMENTS OF LAND PRODUCTIVITY

### (*a*) *Productivity models*

The crop, livestock and fuelwood models are all specially designed to operate on the computerized land resources inventory. They permit quantitative land suitability assessments to be made based on growth and yield predictions of each LUT and combinations of LUTs in each agro-ecological cell. All the three productivity models include a provision for quantifying soil erosion hazard of each LUT in terms of productivity loss. This is achieved through the soil erosion and productivity loss model which also estimates 'tolerable' soil loss, and costs of alternative conservation measures.

The crop productivity model has five parts, and for each crop-LUT in each agro-ecological cell of the land resources inventory it: (i) undertakes land suitability assessment and selection of suitable crop options; (ii) formulates cropping pattern options, including multiple cropping; (iii) formulates crop rotation options, including fallow requirements; (iv) quantifies productivity potentials of crop rotation options to meet a given food demand, taking into account desired levels of production 'stability' at the micro (farm) level, and (v) interphases with livestock and fuelwood productivity models.

The livestock productivity model has five parts. For each livestock-LUT and agro-ecological cell, it: (i) estimates feed supply potential (primary productivity); (ii) characterizes livestock systems; (iii) determines herd performance; (iv) estimates feed requirements, and (v) quantifies livestock productivity potential (secondary production: milk, meat, wool, draught power) from the estimated primary productivity potential.

The fuel wood productivity model quantifies wood biomass productivity potential in terms of mean annual increments over the rotation age of each fuelwood-LUT.

The land suitability assessment of individual crop-LUT, pasture-LUT and fuelwood-LUT in the crop, livestock and fuelwood productivity models are made according to the FAO-AEZ method, and involves: (i) matching climatic requirements of LUTs with the characteristics of the inventoried climatic zones (thermal zones and growing period zones), and quantifying the climatically attainable yield potential; (ii) matching edaphic (soil) requirements of LUTs with the characteristics of the inventoried soil units, textures, phases and stoniness to rate edaphic limitations; (iii) quantifying soil erosion hazard (topsoil loss) in each climate-soil unit and the associated productivity loss, and (iv) modifying the climatic yield potential (in i) according to soil limitations (in ii) and erosion hazard (in iii) to quantify attainable yield potential (in tonnes per hectare) and corresponding ecological land suitability of each inventoried climate-soil unit for each LUT.

### (*b*) *Land productivity potentials*

The assessment of land productivity starts by formulating and selecting crop, livestock and fuelwood LUTs (shown at the head of the flow chart in figure 1), and their ecological (climate, soil, landform) requirements (ii).

Then, from the agro-ecological cells in the land resources inventory (iii, iv, v, vi), district by district, land-used or required for irrigation, cash crops and for non-agricultural purposes (vii) is deducted. The remainder is an inventory of land potentially available for rainfed crop, livestock and fuelwood productivity assessments (viii).

For each of the agro-ecological cells in this inventory, the next stage is to determine the potential rainfed yield or output of crops, livestock and fuelwood at one or more levels of inputs (ix, x, xi) to find out which LUTs (cropping patterns and rotations, livestock systems, and fuelwood land uses) are most productive, stable and sustainable in the unique conditions of the cell. The land productivity potentials can then be calculated (xii) by using multiple-goal linear programmes, either in a reference manner or within the context of specific (demand-driven) planning scenarios.

## 6. NATIONAL DEVELOPMENT PLANNING

### (*a*) *Potential population supporting capacity*

Beyond the computation of reference land productivity potential, the assessment continues into development planning. It involves the calculation of the quantities of edible calories and protein that would be produced by the different crops and livestock (and products from other land uses) from information on the nutritional composition of the products. The crops or crop mixes (including grassland) that can produce the largest or desired quantity and quality of calories and protein in each agro-ecological cell are then selected, and the results from each cell in each climatic zone in each district are added to determine optimal maximum potential production of calories and protein from each climatic zone in each district, from whole district and groups of districts, and from whole provinces and country.

Dietary and other constraints such as minimum protein requirements are applied to estimate potential population supporting capacity (xiii) at various desired levels of geographical and administrative aggregation. Similarly, by applying the FAO Technology Matrix for Kenya (including conservation inputs), the association inputs requirements (15) are quantified (Bruinsma *et al.* 1983). The Technology Matrix refers to the methodology developed in FAO's study 'Agriculture: toward 2000' (FAO 1981) to estimate input requirements associated with possible increases in production.

The potential population supporting capacity in (xiii) is computed as potential population density (persons per ha) which is compared with the present and future anticipated population densities, and examined against food and agriculture demands, and socio-economic needs, opportunities and constraints, to address a range of policy issues for development planning. These relate, for example, to: food and economic self-sufficiency, areas with surplus potential and areas that are critical, domestic and export trade, infrastructure, services, employment, incomes, revenues, industries, investments and human resources development (xv).

### (*b*) *Example results*

Summary of district results for Meru district in Eastern province for an intermediate inputs scenario is presented in table 1. The results show that Meru district with intermediate inputs has a population supporting capacity of 1.9 persons per hectare but this capacity would be exceeded by its year 2000 population density of 2.02 persons per hectare. The total rainfed land area in the district is made up of some 22% arable land, 22% range lands, 25% forest and park lands, and 20% non-suitable land. Such kinds of results can be produced for every district from the information generated at the agro-ecological cell level.

Example results at the province level (aggregated from the sub-district level) for intermediate inputs scenario (table 2) shows that six of the seven provinces were capable of supporting their 1986 populations with

Table 1. *District summary of results for intermediate inputs scenario—Meru district*

| district summary: Meru district – Eastern province | | |
|---|---|---|
| district population (present) | 889000 | |
| district population (projected) | 1974000 | |
| calories from rainfed production | 1569247 | |
| calories from irrigated production | 0 | |
| protein from rainfed production | 25152 | |
| protein from irrigated production | 0 | |
| calories/cap/day (avg.) | 2178 | |
| protein/cap/day (avg.) | 34.9 | |
| calorie:protein ratio (avg.) | 62.4 | |
| present population density (cap. $ha^{-1}$) | 0.910 | |
| projected population density (cap. $ha^{-1}$) | 2.021 | |
| supported population density (cap. $ha^{-1}$) | 1.897 | |
| present/supported density | 0.480 | |
| projected/supported density | 1.065 | |
| land use statistics: | | |
| | hectares | percentage |
| district area | 976700 | 100.0 |
| Urban Area | 98525 | 10.1 |
| agricultural land | 878175 | 89.9 |
| irrigated land | 0 | 0.0 |
| rainfed land | 878175 | 89.9 |
| forest/park land | 246739 | 25.3 |
| non-suitable land | 195093 | 20.0 |
| idle land | 0 | 0.0 |
| range land | 218869 | 22.4 |
| NS-range land | 298 | 0.0 |
| arable land | 217176 | 22.2 |
| fallow land | 48607 | 5.0 |
| area harvested, primary | 168569 | 17.3 |
| area harvested, secondary | 1587 | — |
| area harvested, total | 170156 | — |
| cropping intensity | 1.009 | — |

Table 2. *Province level results for intermediate inputs scenario*

| province | area/($10^3 \times$ ha†) | population in 1986/($\times 10^3$) | future population[a] ($\times 10^3$) | population supporting capacity/($\times 10^3$) |
|---|---|---|---|---|
| Central | 1322 | 2511 | 5525 | 2665 |
| Coast | 8429 | 1440 | 3245 | 4012 |
| Eastern | 15351 | 2917 | 6599 | 4380 |
| North-Eastern | 12749 | 404 | 995 | 356 |
| Nyanza | 1235 | 3058 | 6333 | 3530 |
| Rift Valley | 17454 | 3482 | 8199 | 11940 |
| Western | 869 | 1960 | 4209 | 3066 |
| Nairobi | 66 | 897 | 2396 | 1 |
| Kenya total | 57458 | 16669 | 37505 | 29950 |

[a] Future population predicted for the year 2000.
† 1 hectare = $10^4$ $m^2$.

intermediate inputs. However, by year 2000 only the Coast and Rift Valley provinces would be capable of supporting their respective populations with intermediate inputs. If Kenya, by year 2000, were to advance its agriculture to intermediate level throughout the country, it could meet from its own land resources the food needs of only 29.9 million people out of the projected 37.5 million. The shortfall would have to be made up through imports unless production inputs were increased further. (Under a high inputs scenario, Kenya could support more than 1.5 times its population.)

Arable land ranges from 0.8% in North-Eastern province to 42.5% in Western province, whereas rangeland ranges from 95.8% in North-Eastern province to 12% in Western province. At the national level, only 8.7% of Kenya's lands are suitable for arable agriculture, and 69.6% can be regarded as range lands. Also, 9% of the total land area is given over to forest and park lands, some of which is potentially suitable agricultural land.

### (*c*) *Food and agriculture development planning*

The physical resource and land use inventory as well as the AEZ methodology together provide the basis for an 'ecological-economic' approach to planning of food and agricultural development by region within a country. For the Kenya assessment, an outline of some of the main issues presently being considered is shown below.

(i) *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 or national domestic demand and national export targets for specific crops for the future. From this evaluation formulate regional production priorities and 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 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 and fodder crop production potential is used to quantify livestock production potential. A comparison of this potential with the present livestock population provides data for future development of the livestock sector. Similarly, information on fuelwood productivity potential provides data for future development of the fuelwood sector.

(ii) *Issues of equity and distribution*

Given the production levels and patterns on a regional basis within the country, quantify the value of production in each LGP zone in each region. With data on existing and projected population in each zone, estimate: (i) per capita income generated from agricultural production in each zone, and (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.

(iii) *Technology*

The assessment of the production possibilities as in (i*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, infrastructure, research and extension efforts required, etc., can be considered on a regional basis within the country.

(iv) *Environmental conservation*

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

## 7. FUTURE PROSPECTS AND CONCLUSIONS

The FAO-AEZ approach developed in the Kenya study consists of a set of procedures to organize, combine and analyse data drawn from many disciplines, and to generate from them quantitative information for planning, policy formulation and programming for development in agriculture and in the rural sector. Their underlying concepts are neutral as to scale and location. The basic concept of the approach is that of the agro-ecological cell, an area whose unique land attributes, defined by soil and climate, can be quantified sufficiently to assess potential land use performance.

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: (i) what is the stable, sustainable agricultural production potential of various regions within a country? and of the nation as a whole? (ii) 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? (iii) what alternative transition paths are available to reach desired levels of this production potential? (iv) what are sustainable efficient combinations of techniques of agricultural production? (v) what are agricultural and population policy implications at the regional and the national level?

The national AEZ methodology can evidently help governments and their institutions, and bilateral and multilateral development organizations, to understand and manage the potentials of the land resource base for sustained and increasing output as human needs require more output (per unit area of land, labour and inputs) up to levels that are at present uncommon in most farming communities in the developing world.

For this each developing nation will need to be able to assess, quantitatively the attainable potentials of the land within its borders, and, through cooperation with neighbouring countries and within regions, the most appropriate ways of meeting the needs of individual nations by the sensible use of comparative advantages and complementarities.

It seems clear that scientifically sound and practical methods, that can assess potential productivity of land quantitatively, and link it with population supporting capacity, are needed in setting development goals and elaborating programmes to attain them. These needs arise internationally as well as nationally. The application of the AEZ approach at a detailed country level would provide an analytical framework to integrate environmental and socio-economic and human 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 are described in FAO (1982, 1984); Shah & Fischer (1982); Shah *et al.* (1985).

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***Discussion***

D. DENT (*Environmental Sciences*, *UEA*, *Norwich*, *U.K.*). Who are the decision-makers that Dr Shah seek to influence or support and what use do they expect them to make of the information?

Bearing in mind the constraints under which the government of Kenya, for example, operates, how does Dr Shah suppose that information about land suitability will be translated to the smallholders who make the day-to-day decisions about land use? I am very conscious that their needs and viewpoint are not the same as that of the government.

M. M. SHAH. At the FAO Conference in 1983, the delegates from a number of developing and developed countries formally requested that the next phase of the FAO agro-ecological Study should focus on detailed country case studies, with the aim of providing agricultural land resource assessment information for planning and policy formulation.

With regard to the first case-study Kenya, the first collaborative task was

(i) to identify the relevant Government Departments in Kenya who could provide essential data and information for the study

(ii) to identify all Government Departments that could possibly use the results of the study

(iii) to identify particular planning and policy issues in formal Government Documents National Development Plan (1989–1993), Sessional Paper 1 of 1986: economic management for renewed growth, district development plans, national food strategy, etc.) where the study results would be a relevant and useful input.

The success of any work of relevance to real planning and policy critically depends on the ability of providing timely and credible information, particularly where new insights and hitherto unavailable analysis can be presented. For example, the National Development Plan presents a set of targets for food production, agricultural exports, employment and incomes, etc. The study results map out the interactions between these aspects and quantifies the feasibility of achieving these target multi-objectives at the district level. The latter is the central focus of Kenya's developmental strategy.

We fully recognize the difficulties and problems of linking the farming population's (especially small farmers) needs and concerns with the Government policies. The spatial aspect of the AEZ approach is particularly relevant in investigating regional level issues, e.g. crops with a comparative advantage in certain districts, population pressures, level of farming technology, land degradation etc. The important feature is to show how a national policy target e.g. export crops, etc. translates into district level implications and in turn quantify it's effect on the resident small farmers. We are perhaps fortunate in that the Kenya AEZ study is in the completion stage just at the time when district level regionalization of Kenya's agricultural development strategy in the medium term is of most concern.





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I. J. Graham-Bryce (*Shell, The Netherlands*). The table Dr Shah presented appeared to show that soil conservation measures resulted in a substantial yield penalty. On the other hand, presumably neglect of soil conservation would lead to progressive and possibly catastrophic yield loss through processes such as erosion.

Could Dr Shah expand on how sustainability is handled in the modelling process and indicate whether sustainability is a condition of the land use conclusions?

M. M. Shah. The table I presented showed a comparison of scenario results assuming: with adoption of full conservation measures; with adoption of 50% conservation measures; no conservation measures. In fact, these results showed that a considerable loss in land productivity would result unless soil conservation measures were adopted. For example, productivity loss was in excess of 50% over a 20-year period in many of the susceptible climatic and soil areas.

The issue of sustainability is fundamental to the assessment of agro-ecological potential of land resources. In our methodology, this is explicitly introduced through: rest period requirements; soil erosion, productivity and conservation practices in Kenya; crop mix and crop rotation. Full details of these are given in FAO Kenya AEZ Technical Papers No. 1, 4 and 6, respectively.

Yes, sustainability is an explicit condition of land use conclusions in our approach.



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