Determination of agro-ecological zones in Africa: ILCA activities and expectations

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Summary

EFFECTIVE LAND-USE *planning is necessary if optimal use is to be made of land for sustained and increased agricultural production. Agro-ecological zonation can help in the process of planning development strategies and research programmes by providing comprehensive information on land resources.*

This paper outlines some of the work being done by ILCA in the field of agroecological zonation and the use of models to predict the effect of environment on pastoral and agricultural systems. Plans for future developments and the potential benefits of the work are also given.

Research results from a particular site can be expected to be applicable to other areas with similar agro-ecological conditions, and knowledge of agro-ecological zonation will help to speed up the process of transfer of research results from the research station to the farmer. In addition, research can be more accurately targeted on the basis of agro-ecological zones rather than on the basis of broader agroclimatic zones as previously used.

Introduction

Optimal use of land for sustained and ultimately increased agricultural production requires effective land-use planning. This in turn requires comprehensive information on land resources so that development strategies and research programmes can be assessed in terms of geographical and climatic realities.

The land and climatic factors that influence agricultural potential can be quantified or estimated and used to cluster environments into classes or agro-ecological zones (AEZs). Research results from sites representative of a particular AEZ can be expected to be applicable to other areas with similar agro-ecological conditions. Thus knowledge of agricultural zonation will facilitate the transfer of new technologies from the research sites on which the research is done to other areas. ILCA is establishing a land resources data bank on Africa, which will be used to classify environments and determine AEZs.

Many of the components that are used to delineate AEZs are highly variable in time and space. Spatial variability when mapping soils, land form or vegetation is normally accommodated by appropriate sampling density and convergence of any additional evidence on trends between locations, and procedures for this are well established. Methods for overcoming the problem of location-specific sampling and approximation of discrete phenomena by continuous modelling of climatic variables are less well established.

Temporal variability in environmental factors that are used to delimit AEZs can be approached in two distinct ways. Firstly, probabilistic models of highly variable environmental factors, such as climatic variables, can be used to study the long-term effects of agricultural management strategies in relation to the known variation in these factors. ILCA is developing this type of agroclimatic model.

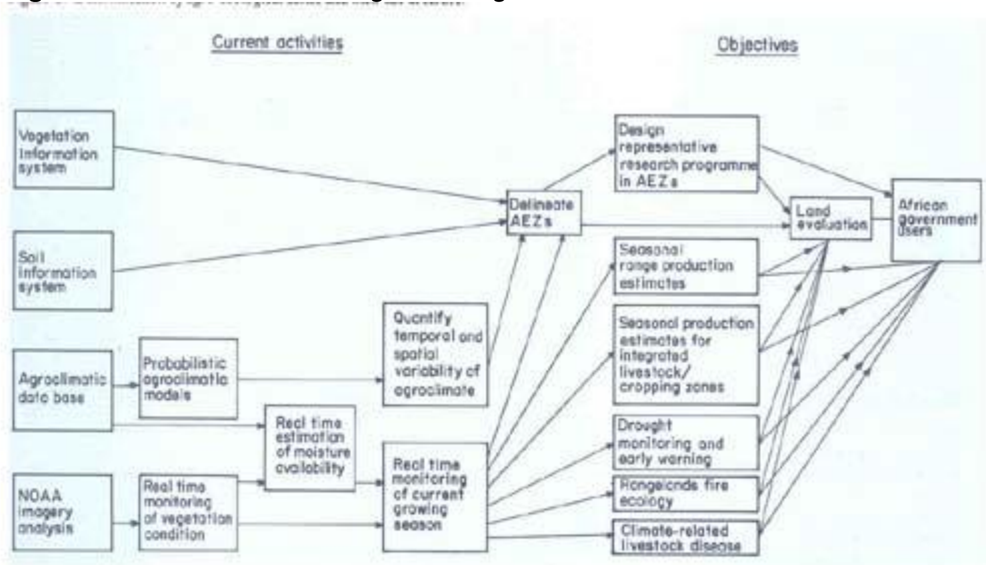
While probabilistic models give an indication of the likelihood of the success or failure of a particular agricultural strategy in a given environment, they do not provide information on the normality or otherwise of a particular production season. Thus there is a need for the second approach of monitoring agro-ecological conditions during the season to determine the progression of those events that influence agricultural production. This is particularly important in relation to factors that have a negative effect on production, such as drought or climatically induced livestock diseases.

ILCA's activities in agro-ecological zoning

In much of Africa there are no established, reliable data bases on which to develop effective regional planning of agriculture, and, without external assistance, assembling a resource inventory of the type needed is beyond the means of many African countries. ILCA is in a unique position to assist in this respect, as it is assembling a data base for Africa of meteorological, vegetation, soil, landform, production and socio-economic information. These data can be used to define AEZs. Representative research sites can then be identified, which will facilitate the extension of research results to other areas through land evaluation studies.

The relationships between the various components of ILCA's AEZ programme are represented schematically in Figure 1.

Figure 1. *Determination of agro-ecological zones and their use at ILCA.*



Agroclimatic data base

An extensive agroclimatic data base for sub-Saharan Africa is being assembled at ILCA with the help of African governments and international organisations such as the Food and Agriculture Organization of the United Nations (FAO). The data available are mostly for monthly periods, which limits their usefulness, but efforts are being made to collect all available data for daily and

10-day periods from synoptic stations in the region. These data are being stored on computer at ILCA's headquarters in Ethiopia.

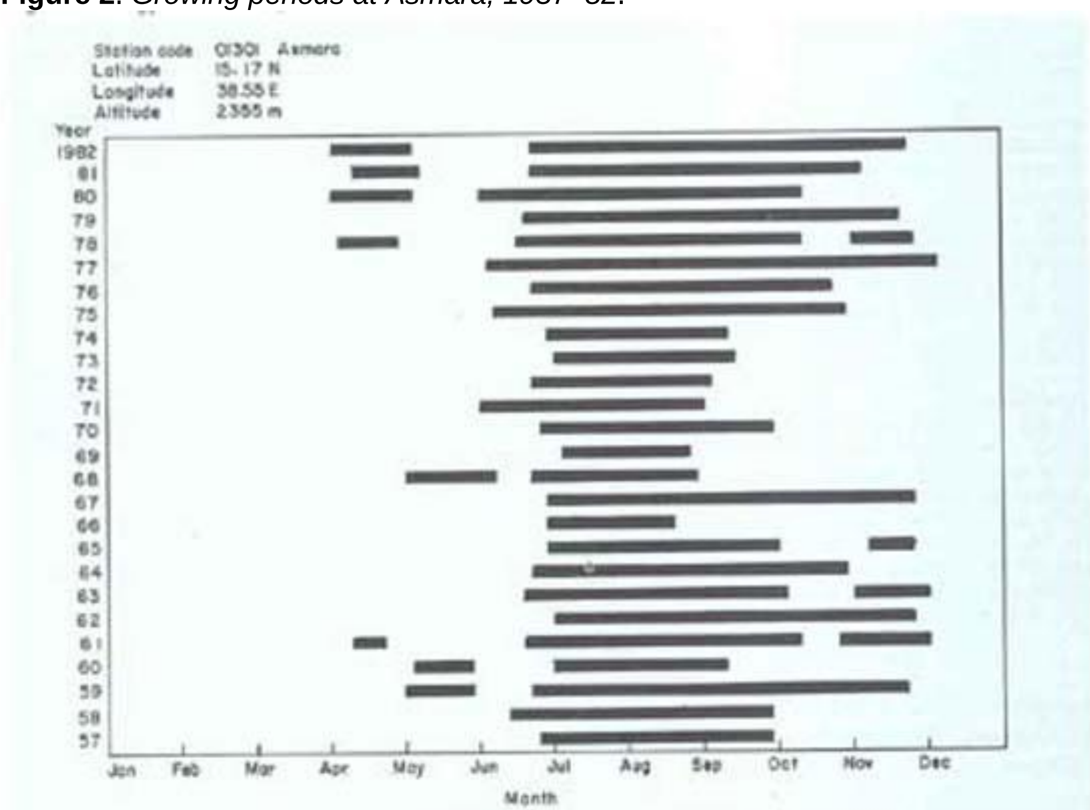
Agroclimatic models used

FAO length-of-growing-period model

A computer model originally developed by FAO for an agro-ecological study of Africa (FAO, 1978) has been installed on the computing system at ILCA headquarters in Addis Ababa. The program can be used to estimate the amount of moisture that is available for crop growth in individual months of the year from monthly precipitation (P), potential evapotranspiration (ETp) and estimated available water-holding capacity of the soils. Estimates of the amount of stored soil moisture (S) can be varied in the program from 0 to 200 mm in 50 mm steps.

Lengths of growing periods (LGPs) in individual years are calculated using linear interpolation for the period of time that P + S exceeds 0.5 ETp. The yields of many common crops decline markedly if the soil moisture falls below this level (Doorenbos and Kassam, 1979). The LGP excludes any period in which the temperature is unfavourable for crop growth. The program has been modified so that threshold values of ETp can be varied on a sliding scale, which may be important in assessing the length of the growing period for certain rangeland vegetation types. Statistical calculations related to the variability of LGPs over the years for which analysis is possible are included in the package. Bar graphs in Figure 2 illustrate the variability in LGP between years over a 26-year period at Asmara in northern Ethiopia.

Figure 2. *Growing periods at Asmara, 1957–82*.



The main limitations of the LGP-based model in its present form are its inability to analyse moisture availability precisely for periods of less than 1 month and the assumptions in the model concerning runoff and deep percolation.

Current applications of the LGP program in ILCA

Analysis of drought in Africa. The LGP program has been used mainly to study the nature and extent of drought in Africa. It has been used to analyse data for growing seasons both preceding and during severe droughts, and the results are revealing for countries that have been severely affected, such as Ethiopia. A drought early warning system has been devised based on the monthly moisture balance as determined by the LGP model. Additional work is continuing on calibrating the vegetation data derived from the NOAH meteorological satellite using the LGP concept.

LGP and biomass production. Yield data from ILCA research stations in the integrated livestock/cropping zone and dry-matter production data from West Africa are being compared in order to assess the influence of moisture availability on crop and rangeland production. LGPs form the basis of this research.

Productivity of forage legumes under different LGP regimes. ILCA is studying the adaptability of different forage legumes to various agro-ecological conditions. Agro-climatic zoning using the LGP program is an important building block in this research project.

Farming systems and increasing moisture availability. ILCA is studying ways of increasing the availability of moisture through changes in farming systems. LGPs give an indication of the potential increases in productivity of traditional farming systems that could be achieved through improved water management.

Attempts are now being made to use statistical parameters related to the variability of LGPs to determine the reliable onset and end of the main growing seasons in African countries that are affected by substantial rainfall variability. Changes in the timing of land preparation and seeding, and the use of early-maturing forage crops are being studied for their potential in increasing the use of available moisture in relation to estimates of the reliable onset of the growing periods.

Agroclimatic analysis is also being used to examine the potential of water harvesting in ponds to optimise and possibly extend the growing season artificially through small-scale supplementary irrigation. ILCA has developed a system of building surface ponds using animal traction.

CSIRO[1] WATBAL model

The WATBAL model is used to provide estimates of changes in soil-moisture status for use in pasture growth modelling. The program requires weekly or daily precipitation and evaporation data. Evaporation data can be either mean or actual values derived from measurements, estimates from any of the standard instruments, or empirical approximations.

1. Commonwealth Scientific and Industrial Research Organisation (Australia).

Two important assumptions are made in the model. Firstly, unless maximum soil moisture storage is known, a value has to be assumed. Secondly, it is assumed that no runoff or deep percolation occurs until this maximum storage capacity is reached. Rainfall data provide the positive inputs to soil moisture storage in the model, and an estimate of actual water demand is required to determine withdrawals of moisture from soil storage. To determine the actual water demand the relationship between maximum evapotranspiration for the vegetation type considered, given freely available water, and evaporation must be established for each week of the year. These values are expressed as coefficients and must be assumed if unknown (Keig and McAlpine, 1974).

Optional analyses of the various derived parameters are possible. For example, descriptive statistics such as means, medians and deciles can be plotted as well as frequency distributions of soil moisture based on either a long run of data or season-by-season data. In addition, periodicities and probabilities of defined events may be calculated along with the probabilities and standard errors of these events. Such events include estimation of the likelihood of drought or the length and reliability of growing seasons for locations with suitable meteorological data.

At present the main limitation to the use of this model in Africa is the lack of reliable daily or weekly precipitation and evaporation data. However, as the amount of agro-climatic data collected by ILCA grows, the WATBAL model will become more important in the efforts to develop an understanding of the effect of soil moisture availability on biomass production.

Rainfall classification and biomass estimation model for the Sahel

A model developed at ILCA (Hiernaux, 1984) for the Sahel relates daily rainfall data (amounts and duration) to biomass production. Rainfall patterns are classified in terms of amounts over time into six categories: strong or F (40 mm in 2 consecutive days, 60 mm in 5 days or 80 mm in 10 days), moderate or f (less than for strong, but other factors not limiting), interruptions or I (more than 15 days without rainfall), short interruptions or i (less than 15 days without rainfall), discontinuous or d (evapotranspiration falls to less than 3 mm/day) and continuous (evapotranspiration remains equal to or greater than 3 mm/day). Evapotranspiration of more than 5 mm/day indicates that there are no limitations related to moisture availability. Water storage in the soil is assumed to occur when rainfall exceeds evapotranspiration.

These symbols can be combined to describe seasonal patterns, e.g. FI (fd), which translates as strong rains followed by one long interruption, then moderate rains begin again with a discontinuous pattern.

Both runoff and infiltration are estimated to enable calculation of effective precipitation. Runoff is considered to be a function of precipitation, but is also influenced strongly by the topography, soils and geomorphology of the site.

Rains can be characterised quantitatively by two methods, one graphical, involving overlays of the different factors involved, and the other a computer program developed by ILCA specifically for this purpose.

The biomass prediction model was verified using data on biomass production from five sites in the Sahel, and a correlation was found between moisture availability and biomass production (r^2= 0.78).

The importance of vegetation type and complications induced because of the different photoperiodicity, growth cycles etc in, for example, annual and perennial vegetation types, is emphasised. For example, perennials generally have deeper rooting systems than annuals and thus may not respond in the same way as annuals to rainfall. Also, historical analysis of the sites is desirable because species composition in a given year was found to be influenced strongly by the establishment of a particular type in the previous year. In years of good rainfall, annual species tend to predominate; in dry years perennials predominate because of their deeper rooting systems. The predominant species types thus produce more seed, resulting in them being present in a relatively larger proportion in the following season, irrespective of the rainfall of that year.

Climatic surface models

A cooperative programme between ILCA and CSIRO has recently been started to construct 'climatic surfaces' using 3-dimensional plots to estimate the distribution of rainfall, temperature, evaporation, etc between sampling locations. This should help clarify the spatial distribution of climatic variables between discrete sampling points.

Other work is being done in connection with the generation of 'synthetic' rainfall data. Workers in the CSIRO Division of Water and Land Resources have developed a sophisticated suite of computer software that utilises time-series analysis for forecasting rainfall events. The time series are based on probability distributions of historical rainfall data.

Characterising agroclimatic zones on the basis of these activities should prove a valuable adjunct to the techniques that are already being used at ILCA.

Climate-related inputs to a future geographic information system

Climate-related resource data, such as temperature and LGP, will eventually be entered into a grid-cell-based geographic information system which is being developed at ILCA.

Soil information system

ILCA is using survey data to develop an information system on soils in sub-Saharan Africa. Country-wide studies have been made in a number of sub-Saharan countries, and efforts are being made to standardise the information from these, as the different studies use a wide range of map scales, classification systems and report details.

It is hoped that a common core of information can be entered on a grid-cell system for the continent to enable a geographic information system to be built up over time. A grid-cell of 25 km^2 is being used currently for data from Ethiopia.

A soil-related factor that is of considerable importance in defining AEZs is soil moisture storage, which is a critical factor in determining the length of the growing season. ILCA has recently installed soil moisture recording apparatus at its research sites, so that growing season estimates derived from agroclimatic models can now be compared directly with levels of soil moisture recorded under field conditions. This should enable more precise assumptions to be made concerning soil storage capacity in other locations and also in testing the overall validity of the agroclimatic models.

Vegetation information system

Research at ILCA has generated a wealth of information on the quality, quantity and types of vegetation in Africa. This information, and data from other sources, is being used to assess the adaptability and suitability of various forages to different climates and soils. Efforts are being made to provide vegetation-related data for sub-Saharan Africa to complement the geographic information system that ILCA is developing.

One area of research is to try to relate aspects of natural vegetation (e.g. the tolerance of different species to soil salinity, soil pH and drought) to the environmental adaptability of forage species. Preliminary quantitative analyses of native grass and legume floras suggest that the diversity of the spectra of many tribes in these families is related to climatic factors. An analysis of natural vegetation may, therefore, provide a useful tool for relating conventional, climatically defined AEZs to the range of environmental adaptation of both introduced and native forage species. It is hoped that multilocational trials at ILCA field sites and those of national programmes will be used to test the hypotheses about relationships between AEZs and the adaptability of forage species. This should provide ILCA with an objective basis on which to select forage screening sites for the different AEZs and, more importantly, for extrapolating site-specific adaptation data to larger areas of sub-Saharan Africa.

The use of NOAA satellite imagery in refining AEZs

Remote sensing can provide environmental data for large areas of the earth's surface, which can be used to help anticipate natural disasters and to increase food production in the developing world through a better understanding of the environment.

Satellites are a convenient platform for a number of sensors that record environmental data. Their main advantage is their rapid and relatively cheap coverage of large land areas. New technologies have been developed that can be used to monitor vegetation, and these show considerable promise for the development of early warning systems for such environmental changes as drought, and will provide increasingly important input for determining effective long-term land-use planning and agricultural management strategies.

Changes in vegetation cover reflect the individual or combined influence of such factors as seasonal precipitation, temperature, soil moisture conditions, occurrence of fire, floods or the influence of man. NOAA satellite imagery provides an opportunity to determine synoptically rates of change in biotic resources in response to these influences.

Healthy, synthetically active vegetation reflects near infrared light strongly, and it is mainly this characteristic that enables the AVHRR (an advanced very high resolution radiometer) of the NOAA satellite to monitor the dynamics of green vegetation from space. Reflectance measurements are transmitted to a ground receiving station where computers record the data on tape as an intensity array.

Potential benefits of NOAA imagery

Drought monitoring. A cooperative programme between ILCA and NASA/Goddard Flight Centre, USA, has demonstrated close relationships between spectral responses of vegetation (as measured by the normalised difference vegetation index, NDVI) and the occurrence of drought conditions in Africa in 1983 and 1984. This line of research is continuing at ILCA.

Direct measurement of plant biomass. ILCA, in conjunction with NASA, has carried out a considerable amount of research on using NOAA data to measure plant biomass in the rangelands of Mali, Niger, Ethiopia, Kenya and Nigeria. In much of Africa, measuring grassland production is complicated by the presence of perennial grasses and trees, the growth cycles of which are not necessarily geared to annual influences and whose deep-rooting habit allows them to use water that is not available to shallow-rooting annuals and thus to continue to grow during dry periods.

A number of studies have indicated that grazing pressure may reduce the sensitivity of the satellite data to changes in biomass production in areas that otherwise produce large amounts of biomass. Research is being conducted on the use of satellite imagery to follow grazing patterns and intensities over time in areas in which the bio-production is known, in order to overcome these problems.

Monitoring soil moisture conditions and growing season. NOAA satellite data give approximately 1 km x 1 km resolution, and once calibrated from limited ground and aerial survey data, they can be used to assess the total duration of the growing season and the extent of zones with similar lengths of growing season in a given year. This also offers the possibility of forecasting crop yields, since these are closely related to the length of the growing season.

Because the NOAA satellites make frequent observations (the NOAA-7 satellite makes measurements over Ethiopia for 3 consecutive days every 9 days), changes in the vegetation can be monitored during the growing season. While this can also be done using conventional meteorological data, there are drawbacks in that the quality and availability of these data are limited in Africa. The data are also location specific, and inferences have to be made about climatic gradients between collection points.

Meteorological conditions and livestock disease. A number of important diseases of livestock are affected by climatic conditions, prominent among which are trypanosomiasis and East Coast fever. Both of these diseases are transmitted by vectors that are influenced by seasonal changes in vegetation, which are climate dependent. ILCA plans to investigate the possibility of using vegetation and meteorological data from the NOAA satellites to determine bioclimatic and seasonal influences on the distribution and extent of livestock disease vectors such as the tsetse fly and ticks.

Burning and flooding. Pastoral lands in Africa are frequently burned, and NOAA imagery offers a convenient means for monitoring the effects that burning has on the ecology of the continent. Similarly, monitoring of the extent and duration of flooding is important in defining AEZs that are influenced by this phenomenon.

Desertification and deforestation. NOAA data provide a means for determining long-term trends in vegetation patterns in Africa, particularly in relation to such controversial subjects as desertification and deforestation. Until now there has been little verification of trends in desertification and deforestation by a scientifically reliable method and the NOAA data could fill this gap. However, data storage could prove to be a problem in the long term because of the large quantity of digital data recorded on each pass of the satellite.

Refinement of AEZ boundaries. AEZ boundaries derived from ground data may be modified in future as the amount of data on vegetation responses from the NOAA satellites increases. As yet, data from NOAA satellites do not span sufficient time for detailed statistical analysis of seasonal and annual variations in vegetation. However, the problems of data storage noted above will also be an important consideration in this case.

Expectations for the future refinement and use of AEZs by ILCA

Upgrading the climatic data base

The paucity of suitable short-term data on precipitation and related climatic variables is a major constraint on the further development of the agroclimatic models currently being used by ILCA. In an effort to overcome this constraint, ILCA is attempting to compile a comprehensive agroclimatic data base.

Agroclimatic modelling

The probabilistic agroclimatic models currently in use by ILCA will provide baseline data for much of the Centre's research into farming systems and the adaptability of forage species. The WATBAL program can be used on microcomputers, and the FAO/LGP program has recently been modified by ILCA to also run on microcomputers.

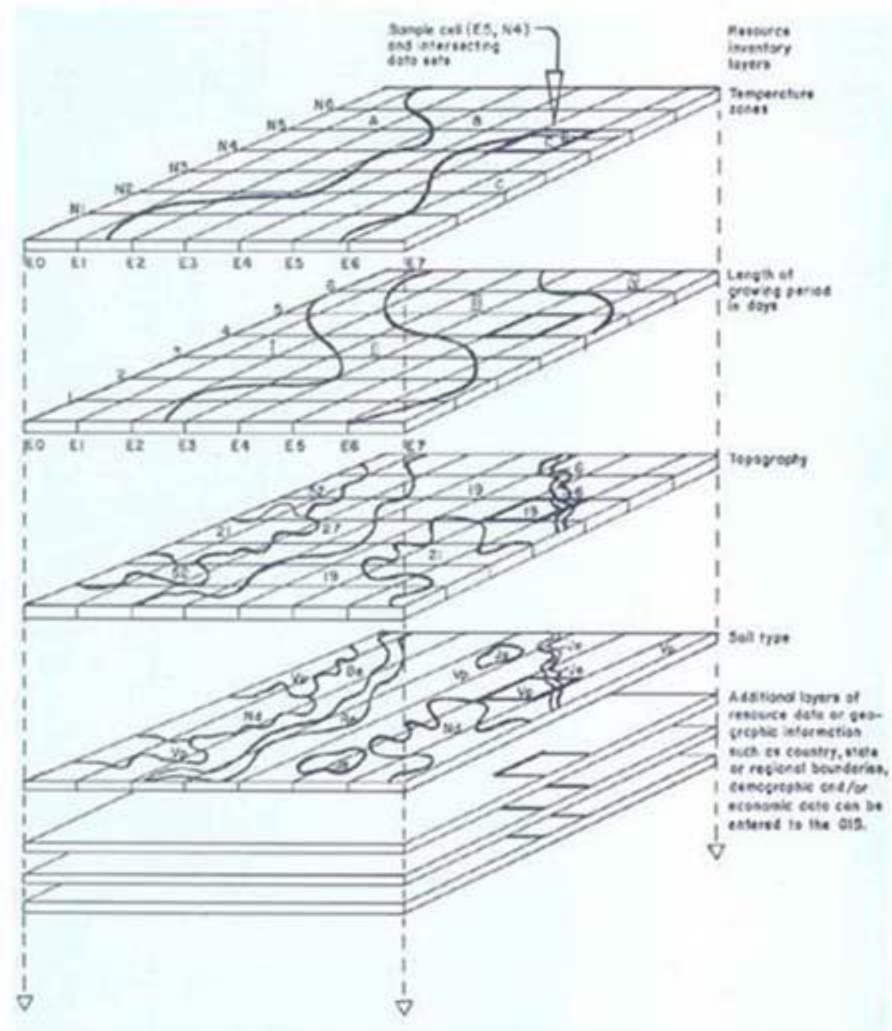
The expansion of climate surface modelling in the future will depend largely on the results obtained initially, but at present this form of modelling shows promise for being able to assess the likelihood of the success of introducing a forage species into a foreign but agroclimatically similar environment.

Geographic information system development

ILCA plans to continue development of the geographic information system (GIS). At present, the system is based on the HP 3000 computer system. The 25 km^2 grid-cell size for entry of soil, vegetation and agroclimatic data is being developed using the available processor capacity.

A schematic representation of the relationships between the various components of the GIS is shown in Figure 3. This represents the minimum expected development of the system. The GIS system should help to refine the definition of AEZs, by making new or more precise data more readily available.

Figure 3. *Schematic representation of the proposed Geographic Information System. The agroclimatic conditions in any grid-cell can be summarised by the computer, which 'looks down' through the different layers of the resource inventory and selects the information required.*



Summary of agroecological conditions in cell E5, N4: Temperature zone – B/C; Length of growing period – III; Topography – land unit 19/6; Soil type – Vp/Je, etc. (Divided grid cells can be described in terms of the relative proportions of each component if desired, eg. 60/40).

Future developments in computer hardware and software will open up the possibility of substantially more powerful GIS formats, operating on vector- or polygon-based software. Machine-based digitising of resource data using a system of this type should greatly increase the efficiency of building a suitably detailed GIS for sub-Saharan Africa. ILCA plans to move gradually across to such a system.

Land evaluation

ILCA has obtained computer software from FAO that was developed for land suitability assessment in the FAO/AEZ study of Africa (FAO, 1978). These programs have been installed on ILCA's computer system, and have been modified to enable crop and livestock farming system requirements to be matched to land inventory data in the GIS. Ultimately, the GIS will be linked with the land evaluation programs, which will permit production of computer-based land suitability maps by grid cell for prescribed land uses.

Establishment of a NOAA satellite-tracking and data-processing facility at ILCA

At present, use of data from the NOAH satellites depends on the cooperative programme between ILCA and NASA. There are a number of limitations to this system, including problems of timely transfer of the data between two continents and constraints imposed on manipulation of the data due to the format and resolution of the material readily available from NASA.

ILCA is hoping to establish its own ground receiving station, so data can be received directly from the satellites. Apart from servicing its own remote sensing research needs, ILCA will act as a distribution centre for raw or partly processed data from the NOAA satellites to interested international, bilateral and government agencies in Africa.

Conclusions

The expectations outlined offer exciting possibilities for agriculture in Africa through more precise definition of AEZs in the future. For example, extension of research results from research stations to farmers' fields will become more rapid. Confidence in the applicability of these results to locations with similar agro-ecological conditions will increase and research targets will be more clearly defined on the basis of AEZs rather than the broad agroclimatic zones previously used. More precisely defined environmental conditions will also enable increased use of modelling to predict pasture, forage and crop responses to the environment and so reduce the need for multilocation adaptation trials.

Establishing a computerised geographic information system will enable agroecological data for sub-Saharan Africa to be rapidly updated and a multitude of economic and demographic information to be interfaced with information on physical resources. This will assist scientists to develop a better understanding of African farmers' needs in relation to the agricultural resources available to them.

The variability of the climate from year to year will be monitored in the future using satellites to cover the vast extent of Africa, enabling more timely early warning of unfavourable conditions for agriculture on the continent. Satellite remote sensing of the environment in support of AEZ studies also offers the possibility of land management advice for farmers and pastoralists, both on a scale and with timeliness previously not possible.

Once defined, AEZs will also provide a clearer picture of land potential through matching of production system requirements with the land characteristics of AEZs stored on computer. Thus it will be possible to estimate the long-term benefits to be gained by introducing new or innovative farming systems using computer modelling techniques, based on AEZ data. Ultimately, the capacity of land to support the human and livestock population in Africa can be assessed.

At present the detail and quality of AEZ data is a constraint to providing reliable assessments of optimal land use. ILCA is therefore committed to improving the AEZ data base of Africa as quickly as possible to ensure that the advantages outlined in this article reach the population as soon as possible.

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