A Spatially Distributed. Soil, Soil Hydrological and Agroclimatic Model for the Prediction of Climate Change in the European Community

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Summary

Most attempts to predict the effects of potential climate change on the agricultural productivity of soils have been made either for small, intensively-managed experimental sites, or at scales and resolutions of several tens or hundreds of km. There are few predictive tools useful to the land use planner, or the policy maker, at the local or regional level, with the implications this has for spatial resolution on the ground. Within the European Community there is a large amount of detailed soil, land use and climatic data, much of it at very high resolution (tens or hundreds of metres). A very large part of these data is in digital form, and can be manipulated readily by computers, often within geographic information systems. The current project has produced a model which uses such detailed information to predict the effects of climate change on land use within the European Community. The model has been designed deliberately to make use of simple (but reliable) soil data from soil surveys, in relation to crop suitability, as well as data from experimental sites. The new model (**ACCESS** - **A**groclimatic **C**hange and **E**uropean **S**oil **S**uitability) thus runs at two levels, which complement each other. The essential difference is one of data availablility, because this affects profoundly the time steps at which the model can operate, and the level of detail with which processes can be simulated. **ACCESS-I** is a general approach to allow extrapolation to large areas of land, and has less intensive data requirements. It uses the results of the site specific, detailed data and modelling within the second part of the model - known as **ACCESS-II** - for validation and calibration. If sufficient data are available, ACCESS-II can be run for large areas, but this situation is likely to be unusual, and would be more demanding in computing time.

1.1 Introduction

The agricultural area of the European Community is about 1.3 million km^2, most of which lies between the latitudes 37°N and 58°N, and longitudes 10°W and 27°E. The Community is one of the largest agricultural producers in the world, and its Common Agricultural Policy is an important part of its budget. Thus, any change in food productive capacity, or in the boundaries of the regions in which major crops can be grown, is of considerable significance, as is the potential for the introduction of new crops. Further, a major practical aspect of research into the possible effects of potential climate change on soils is to define the potential effects on food supply. There is also a secondary interaction in that land use commonly has a profound effect on water supply, water quality, regional infrastructure and the planning process.

Global warming is predicted to give, for Europe as a whole, a mean rise in temperature of about 3^{0}C over the next 50 to 100 years (Viner and Hulme, 1993), whilst precipitation is expected to increase by about 10 per cent. Expected changes in the seasonal and spatial distribution of the latter are currently little known, and difficult to predict (IGCC, 1992). However, winters will probably become wetter, and summers drier, although the frequency and severity of so-called 'extreme events' e.g. severe storms, flooding etc. might increase (IPCC, 1990). The most important result of this overall change will, for land use considerations, be an increase in summer soil moisture deficits, which could be large in some regions. Some basic climate change scenarios are presented in section 2.7.

Recent attempts to predict the effects of climate change on land use within the European Community have important limitations e.g.:

i) they regard the soil as essentially uniform, and are driven almost entirely by climate;
ii) they operate at very coarse scales (Parry, 1990; DoE, 1991);
iii) they are essentially statistical in their approach and do not give enough attention to processes and mechanisms, particularly with respect to soil/climate interactions.

Such approaches can be useful in giving a very broad picture, but do not provide tools which give enough detail for realistic land use planning at the local or regional scale, nor consider the water resource implications of the potential changes in soil-climate-agriculture systems, nor allow accurate predictions in changes of harvests and matters related to the agricultural economic sector. Because of the very coarse scales, little use can be made of the very large amounts of high resolution soil, land use and climate information available within the Community (Hough, 1990; Commission of the European Communities, 1991; Narcisco et al., 1992).

The project described in this paper is concerned with modelling the potential impacts of predicted climate change; not with predicting climate change itself. The basic strategy was to build a model that uses climatic variables as part of the evaluation of land for crop suitability. Because the climate variables are not fixed, the approach can deal with any proposed climate change scenario. Validation of the model is, however, carried out against current climatic situations.

The main objective was to have the ability to predict the effects of any climate change scenario on the cropping potential of an area of land. The knowledge base is the known soil pattern, the properties of the soils, and the growth requirements of the intended crop(s). Historical meteorological data can be used to test the functioning of the model. Direct temperature effects on crop performance can be predicted from existing physiological models. However, the possible combinations of crop-soil-climate interactions are large and complex. Therefore, we chose to use data from national experimental soil-crop programmes as the basis for modelling and simulation. A novel aspect of the project is to support regional modelling. which we call Level I modelling (ACCESS-I, above), through detailed site modelling (Level II modelling - ACCESS-II). Thus, the more empirical-statistical, spatial approach of ACCESS-I is validated by the more process-based, but site-specific, approach of ACCESS-II.

We have taken the framework of an existing crop-agroclimate model, which relates crop requirements to soil-climate factors, and developed this into a tool usable over a wider spectrum. Initial development concentrated on improvements to the water balance-crop growth module, the erosion module, the land use/sustainability module and the fertility module. The second stage concentrated on extension of site-specific modelling to larger areas (a process called by us 'spatialisation'). Throughout the development of the model, considerable attention was given to assembly of databases with common data input formats, and standardisation of output formats compatible with common GIS formats.

The project began in late-1992 within England, France and Spain, and the initial development work was carried out between those countries, represented by the authors of this paper. Mid-way through the project, the work was extended to Hungary (Research Institute for Soil Science and Agrochemistry, Budapest) and Poland (Institute of Agrophysics, Lublin), increasing the potential area of application to agricultural land by about 250 000 km^2, and introducing a wider range of climate types and soil problems. The project is scheduled for completion in late-1994, so this paper describes the project at approximately the half-way stage. Thus, there are some questions to which the final answers are not yet certain. One of these is the methodology for calculating potential evapotranspiration, and it is clear from this text that more than one approach is under investigation at this stage. Likewise, the model has not, at the time of writing (November 1993), been subject to sensitivity analysis.

1.2 The Basic Model

The overall structure of the original land-evaluation model is derived from earlier work by Thomasson and Jones (1989). The compartments of this framework are sub-models; some complex, others very simple. These sub-models form a logical sequence, which lead to a suitability rating for a chosen crop-soil combination, run against given climate data. The model takes into account the limitations imposed by:

a) site factors: slope, aspect;
b) soil factors: depth, stoniness;
c) tillage properties: machinery work days, compaction risk;
d) agro-climatic factors: altitude, accumulated temperature;
e) crop available water: precipitation minus evapotranspiration.

The original model uses climate patterns derived from long-term meteorological datasets to give an average response of the soil i.e. to predict soil status and crop suitability in 6 years out of 10. However, it is possible to simulate a single growing season at a very simple level, using data for that year. The output of the model is the classification of a soil in relation to a particular crop, so that a soil map can then be classified in terms of crop suitability. The model can be run at a range of scales depending on the detail of the input data. Such suitability maps can be drawn automatically from a digitised soil map (see, for example, Rounsevell and Jones, 1993).

1.3 Data sources

The European Community is large and diverse so it was clear that the model had to be tested under a range of conditions. For this reason we selected three regions as test areas, each having good soil, crop and climate data, much of it in digital form, and a network of experimental sites/farms where extensive site-specific data are available:

a) central England: cool, humid climate;
b) Languedoc-Rousillon, France: Mediterranean climate;
c) Andalucia, Spain: very hot, dry summers, limited winter rainfall.

In Eastern and Central Europe the test areas are:

i) Lublin Upland, eastern Poland: warm continental, with snow cover in winter;
ii) Middle Tisza Region (Nagykunság), eastern Hungary: dry continental, cold winters, little snow.

The compilation of the databases concentrated on:

a) site factors - topographic maps and/or landform analysis;
b) soil factors - soil mapping (survey) and associated databases;
c) tillage properties - calculated from the number of days at which the soil is likely to be too wet for mechanical cultivation;
d) agroclimatic factors - from meteorological data;
e) crop-available water - calculated from precipitation data (long-term or short-term) and a simple model of soil hydrological properties.

The database for soils in central England was constructed in relation to the digital National Soil Map (Mackney et al., 1983), and its associated database (LandIS - see Ragg et al., 1988). Daily rainfall and temperature data for the test area were obtained for 30 years for 130 stations. In France (Languedoc-Rousillon) the climate data comprise daily values of rainfall and temperature over 20 years for 75 locations spread across Languedoc. Because soil data collected during soil surveys do not include the soil hydraulic properties, we carried out an extensive sampling program to determine these soil properties for the main soil units. The other soil data come form the soil databank for the region (Bornand et al., 1993). For Spain, soil and crop data were obtained from the Catalogo de Suelos de Andalucia (de la Rosa, 1984). Climate data were collected specifically for this project from 62 climate stations within Andalucia, and entered into a database. The Polish data come from the Institute of Agrophysics (Lublin) and the Institute for Soil Science and Plant Protection (Pulawy). In Hungary, the soil database is a compilation from the Hungarian Soil Information System (TIR) (Csillag, 1988) by the Research Institute for Soil Science and Agrochemistry (Budapest), whilst a database of climate data is being assembled by the Hungarian Meteorological Office. In addition, a comprehensive database of crop growth requirements, crop phenology, and crop yield was established for major crops for all the test regions by all the partners in the project.

2.1 Revision of the Basic Model Structure

This basic framework was developed for use in England, and assumes:

a) winter rainfall exceeds transpiration, and *vice versa* in summer; in relation to crop growth modelling;
b) an average level of management, and mechanised farming is usual;
c) there are no nutritional limitations (major or minor elements), and that soil pH is adequate;
d) no erosion risk;
e) crops are restricted to grass, winter cereals, potatoes and sugar beet;
f) no irrigation requirement.

Most soil-crop models are developed and validated from experiments made at specific sites. Large datasets with many variables can be obtained, and temporal and spatial distribution established with precision. Such models commonly require very large numbers of input variables, which cannot be obtained for several crop types on large areas of land, where soil and climatic variation can be considerable. This gives very real problems in applying crop/land use modelling to such areas, where this kind of modelling has an important role to play in supporting planning and policy decisions. The restriction of models solely to experimental sites, which will always be a small part of any environment, is to question the ultimate purpose of their development. Spatialisation of data is dealt with below. We developed the revised model (ACCESS) to work at two scales:

a) regional (Level I): large areas form several hundred to several thousand hectares in extent; this part of the model is known as ACCESS-I.
b) test sites (Level II): experimental sites, usually at the farm or field scale, where intensive collection of data has occurred, often over many years. Such sites provide the rigorous framework within which the model can be validated. This is ACCESS-II.

Although the two parts of the model are different in the amount of input data required, the scale at which they are intended to operate, and their targets, they are intended to work as one package. The user chooses the scale at which it is desired to work, and. the software within the model then selects the appropriate route through the sub-models. The most important difference between the two parts of ACCESS is the approach to the soil water-balance modelling. This is discussed below. Further, there is no reason why the model (at both levels) cannot deal with a wider range of crops than the original Thomasson and Jones model (loc. cit.), provided that the necessary parameters for modelling the crop are known e.g. phenology, water requirements etc. However, for the purposes of this project and the development of a working model, we concentrated on the following strategic crops:

ACCESS-I: maize, winter wheat, sunflower, potatoes, grass;

ACCESS-II: winter wheat, maize, sunflower.

It is important to realise, however, that the present form of the model makes no attempt to model crop quality except through yield, and this affects the choice of crop(s) to be modelled e.g. vines are not included because the judgement of the product is largely on the basis of what is in a bottle, and not what is on the plant. Nor, at the moment, does the model include routines to consider the socio-economic aspects of crop suitability e.g. through cost-benefit analysis, although such research is in progress.

It was clear from the beginning, that the basic model was inadequate in some respects, either because no routines existed for certain aspects e.g. soil fertility, salinization risk, or that the existing routines could not deal sufficiently well with a known problem throughout the Community e.g. erosion risk. The most important change, however, was to improve the soil water-balance model, so as to deal with different rainfall distribution patterns in relation to cropping seasons, more intense rainfall events, soils with well-developed vertic characteristics and so on. Changes in these components, and the ways in which they could interact, also required revision of the system of land-evaluation. The revised model is shown in Figure 1. In order to make the improved model widely available, it has been developed so that it will:

a) run on an IBM-compatible PC platform;
b) use standard data input formats;
c) provide output as standard file formats acceptable to a range of geographic information systems. All programming is compatible with Microsoft™ FORTRAN 5.1.

2.2 The Improved Water-balance and Crop-growth Model

Because ACCESS-I is the simpler component and is intended to be applied spatially over large geographical areas, a reduction in the number of input parameters was necessary. Simple soil survey information and a monthly meteorological time-step data are used, rather than the very detailed information, e.g. hourly or daily weather data, from experimental sites, which are not available for large geographic areas. The simplified inputs can cause certain difficulties in the development of such a model especially if a process-based approach is to be maintained. In particular, problems are encountered with the distribution of rainfall over the month where daily properties must be considered *e.g.* surface runoff and workability.

The central component of ACCESS-I is the soil water balance. This is a simple capacity model which considers transpiration, evaporation, root-front development and density, and the phenological development of the crop (from accumulated temperature). Water-limited crop yields are estimated from biomass accumulation using the principle of water-use efficiency (Feddes et al., 1978). Algorithms for the calculation of pedotransfer functions have been developed to enable prediction of soil physical properties from simple soil survey data. Potential evapotranspiration is calculated according to Thornthwaite's formula, with adjustment for latitude based on day-length. The potential evapotranspiration (PET) is separated into potential evaporation and potential transpiration following the Beer-Lambert law, and is based on leaf-area index (LAI). Root development is calculated from soil water pressure and soil resistance to penetration using the theory of root growth mechanics (Dexter, 1987). Actual transpiration is related to soil water pressure and a root sink term. The calculated monthly soil water balance is used to calculate the field capacity period by an interpolation technique. Likewise, the start and end of the growing season is calculated following the FAO approach, by which the growing period is defined as the time in the year during which rainfall exceeds 0.5PET, extended by the time that a maximum available water content of 100 mm in the soil has been depleted. In addition, the growing period is considered to be interrupted during the time that the mean air temperature is below 6.5^0C. Accumulated temperature sums are estimated using TRIM (Temperature Remainder Index Model (Robertson, 1983)), whereas day-length and effective photoperiod are derived from Julian day number and latitude. Biomass accumulation is based on water use efficiency and accumulated transpiration deficit (van Keulen, 1982). The partitioning of the newly synthesised biomass of plant roots is based on phenologically dependent co-efficients. Final crop yield is obtained from final total biomass using a crop dependent harvesting index. ACCESS-I is validated by ACCESS-II i.e. the output from the site specific model is used to assess the validity of the output from the simple model.

The soil water-balance model within ACCESS-II is derived from the French model MOBIDIC (Leenhardt, 1991), which is summarised in Figure 2 (our development stems from route 3), and the overall structure of the model is shown in Figure 3. The main simulation features of ACCESS-II are: i) simulation of evapotranspiration processes by separate simulations of soil evaporation and plant transpiration, ii) transpiration simulation based on an electrical analogy, iii) soil profile discretization into five centimetre layers (although the upper 5cm of the soil is treated as two 2.5cm layers so as to improve the simulation of evaporation), iv) simulation periods that extend over years so as to represent different climate change scenarios. Calibration of the model parameters was performed for different experimental data sets for soya, wheat and maize crops, provided by two agricultural experimental stations within Languedoc-Rousillon. Although calibration was satisfactory in most cases, further improvement of the model is necessary for the specific situation where moving water tables exist.

The main objectives of the crop growth part of ACCESS-II are simulation of leaf area growth, root growth, and yield, in relation to the availability of soil water during the growing season (Rambal and Cornet, 1982). The crop growth model used for calculating potential yields is derived from the EPIC model (Williams et al. 1983), but is revised for use in European conditions, using the same experimental data used in the validation of the soil-water balance approach (Figure 4) (Quinones and Cabelguenne, 1990). The root development model assumes a curvilinear development of roots against maximum depth attained in relation to the number of days between emergence and maturity (Borg and Grimes, 1986). The root density function is similar to that in the CORNGRO model (Childs et al., 1977). The model runs on daily meteorological data. For model run periods of 15 days or more, the differences between the evapotranspiration components of ACCESS-II tend to become small, seemingly due to mutual error cancelling.

The partitioning of daily rainfall into flow classes (macropore or 'by-pass' flow), run-off and infiltration) is made by a simple **S**oil **W**ater **P**artitioning model (**SWAP**), which requires hourly rainfall intensity data. Because such data tend to be available only at a few stations, the latter are used to derive regression equations between hourly totals, hourly intensities and daily totals. These regression equations are then used to derive the required hourly data from the daily data from other meteorological stations in the test area. In SWAP, the soil moisture balance is calculated without attempting to identify the redistribution of water within the profile, this being estimated by a separate sub-model derived from an h-based scheme of the Richards' equation.

The hourly hyetograph can be compared with matrix infiltration and macropore infiltration capacity to partition rainfall into: recharge to the soil moisture store, macropore flow, and surface runoff. Rainfall up to and including maximum infiltration capacity is matrix infiltration, any excess up to maximum macropore infiltration rate is macropore flow, and any excess above that is surface runoff. The thresholds - maximum matrix infiltration rate and maximum macropore acceptance rate - are functions of the soil state; in particular, the degree of soil structural development and moisture content. The model calculates a soil water balance for a single soil store, with matrix infiltration and evapotranspiration being added to and removed from the store as required. Macropore flow, however, is assumed to move directly to the drainage system, and is therefore unavailable to the soil storage.

The model has been used with both current climate data and data perturbed to represent a climate change scenario, the latter assuming a temperature increase of 3 ^{o}C, a 10 % increase in winter rainfall and a similar decrease in summer. Evapotranspiration was recalculated for each day from a series of monthly coefficients derived from climatic data, to give a relationship between temperature and evapotranspiration.

Initial work has run the model against 11 years of data for a site within central England. The mean contributions to each of the flow components were calculated for both current and changed climates. The results show that the amount of actual evapotranspiration will increase with change in climate, but there is no major increase in the macropore or surface flow.

2.3 The Land use-Sustainability Model

The central purpose of ACCESS is the estimation of water-limited crop yields, because we see water-stress as the major limitation to agricultural production. This has very practical consequences in the assessment land use potential for farmers, planners etc., and ACCESS is meant to be a practical tool. The basic concept is that of 'attainable productivity' for selected strategic crops, expressed as a yield value or yield class. This is the maximum possible productivity of a land unit within the constraints of the land unit e.g. drought stress, workability, length of growing season. These factors are clearly linked to the parameters considered by the crop-growth/water-balance model, and the latter can be used to guide the estimation of this parameter. However, in reality, the 'attainable productivity' is an ideal, and 'actual productivity' is the norm. The latter depends on management, which often affects the constraints imposed through the properties of the land unit. For example, irrigation could be seen as a management input, although a crop might not succeed without it. However, the economic return on the crop would still be too poor to pay for the irrigation infrastructure and the water.. Thus, the actual productivity can be regarded as an 'efficiency indicator' of the potential of a land unit. In order to put these predictions of productivity into context, the modelled yields are categorised into one of four yield classes; high, medium, low and unproductive, which are derived from thresholds of attainable yield (Figure 5). The boundaries between each yield class are different for individual regions of the Community because they refer to the current state of agricultural output in each region. This means that, for example, winter wheat productivity of 6 t ha^{-1} in England and 4 t ha^{-1} in Spain can both be classified as medium yields because of the difference in the socio-economics of the two farming systems. These regional differences are defined by the Regional Economic Minimum Productivity (REMP) which represents the minimum yield that can sustain economic crop production.

If the actual productivity is less than the attainable productivity estimated by ACCESS, then clearly the farming system has reserves of productivity, which could compensate for climate change. A novel development is to extend the productivity concept to the definition of Land Use Types (LUT). Traditionally (e.g. FAO, 1976) the assessment of land use types i.e. agricultural systems that have developed in response to local circumstances, is made in subjective terms before a suitability assessment is made. We are using 'allowable' productivity i.e. the acceptable quantity of crop produced which allows a farmer to cultivate a particular land unit in a specified region, to define the LUT. Thus, there can be several LUTs for the same crop distributed through the European Community in terms of allowable yield. Figure 6 gives an example of the data input for a Land Use Type.

2.4 The Soil Erosion Risk Module

Predicted climate change, in southern Europe, will reduce vegetation cover. Under certain conditions, rainfall intensity could also increase. Thus , climate change should not be studied only from the standpoint of agricultural production. It is also necessary to examine the increase in the possibility of erosion i.e. the risk of damage to the soil. This refers back to the revision of the basic model (section 2.1.d). In the context of this project, erosion is the risk of water erosion on agricultural land, and uses the concept of an 'attainable erosion risk' class. This is the maximum possible erosion risk based on relief, soil erodibility and rainfall erosivity; these factors are known as 'land qualities' - LQ. Relief is self-explanatory, erodibility is a measure of the detachibility of soil particles without regard to the influence of topography, and rainfall erosivity is a measure of the power of raindrop impact. Much of the initial approach is given in CORINE (1989). Relief is one of four slope classes which reflect low, moderate, strong and very strong risk of severity of erosion. Erodibility is a complex concept in that there is interaction between effective rooting depth, particle size distribution class, surface stoniness, surface horizon bulk density, and surface horizon permeability, giving four classes of severity (very low, low, moderate and severe). Erosivity is defined in terms of the 'derived Fournier/aridity index' (Morgan, 1979), and again gives four classes:

low, moderate, high, very high. The application of this system, via a matrix, to give the 'attainable erosion risk class', can be seen in Table 1.

2.5 The Natural Fertility Module

This project has assumed (2.1.c) that fertility is not normally a land use limitation in Europe, as it is a management option, but this is not necessarily always true. Further, climate change could delineate areas of land which are suitable for agriculture apart from a lack of natural fertility, which is defined chemically for the upper 20cm of the soil (topsoil) and the layer between 20cm and 50cm. Our system uses ten criteria, of which up to three can be identified as limiting. The criteria are: pH, weatherable minerals, CEC, base saturation, exchangeable sodium percentage, electrical conductivity/salinization, C/N ratio, gley properties, K-supplying power, P-fixation power. Each category has two classes (high and low), the 'low' categorisation being non-limiting. The system does not give a quantitative measure of the degree of remediation required. It indicates where there are problems. These will require further investigation to give a reliable estimate of the degree of infertility and the practicability of remedial action. The combination of categories gives 18 fertility classes.

2.6 Spatialisation

The extension of site-supported modelling (ACCESS-II) to larger areas, requires spatial extension of soil properties measured previously at single points. In all the test areas, use is made of pedotransfer functions *i.e.* equations relating soil hydraulic properties to basic pedological variables available in soil databases. The pedotransfer functions were developed from the set of samples where both the pedological variables and the hydraulic properties were measured. They take the form of sets of algorithms or regression equations valid for the range of soils occurring in each region. Routines have been developed to estimate the soil water-release curve from particle size distribution, bulk density and organic carbon, over the range 0.05 to 15 bar suctions, unsaturated hydraulic conductivity, and soil resistance to root penetration (Simota and Loveland, In preparation). Methods have also been developed to estimate crop yield from similar data in conjunction with monthly weather data.

A more difficult problem was the interpolation of site-specific weather data to soil polygons. These polygons are 'better defined' spaces than climate zones, so the boundaries were kept, except where clear climate boundaries could be identified crossing the polygons. For practical purposes we worked with a lower polygon size of about 100 ha., although smaller areas could be modelled. In temporal terms, it was difficult to extend daily meteorological data to large numbers of polygons, because of the demands on computing time. Most of the development has thus run at decadal time-steps. The problems arising from the spatially irregular distribution of meteorological stations in relation to the distribution of soil polygons is dealt with by a technique involving 'spatial deformation' (Monastiez et al., In press).

Finally, the problem of irregular runs of climate data. or runs of data of various lengths for different sites, was approached through the use of a stochastic weather generator.

2.7 Climate Change Scenarios

The predictions of potential climate change are uncertain. General Circulation Models used for such prediction operate at very coarse scales e.g. predictions are often given on the basis of cells approximately 250km by 250km. Consequently, only regional approximations of climate change can be made at present, and Table 2 summarises the scenarios from which a choice will be made to test the model described in this paper (Kenny et al., 1993).

3.1 Conclusions

We have developed a model to estimate the suitability of soils within the European Community for a range of strategic crops under different climate change predictions. The model uses site-specific data to validate a simpler, regional model. The project has been developed within test regions from central England, southern France and southern Spain, and is being applied in Central and Eastern Europe. The model contains a robust crop-growth/soil water-balance component, and routines have been developed to assess soil erosion, soil fertility and new approaches to land use. The model accepts standard data entry and output in formats compatible with a range of geographic information systems. Equations have been developed to calculate pedo-transfer functions from simple soil data, and new methods of spatialisation of data have been developed. This model is a powerful tool to evaluate crop suitability and land use within the European Community and related areas in relation to changes in climate.

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Table 1. Part of the decision-tree approach to assessing the 'attainable erosion risk' class.

Evaluation		Severity Level			
Step	Variable	1	2	3	4
A	Relief	>B	>C	>D	>E
B	Erodibility	>F	>G	>G	>H
C	Erodibility	Small	>I	>J	>K
D	Erodibility	>L	Moderate	>K	High
E	Erodibility	>K	High	High	High
F	Erosivity	Very small	Very small	Very small	Small
G	Erosivity	Very small	Very small	Small	Small
H	Erosivity	Small	Small	Moderate	Moderate
I	Erosivity	Small	Small	Small	Moderate
J	Erosivity	Moderate	Moderate	Moderate	High
K	Erosivity	Moderate	Moderate	High	High
L	Erosivity	Small	Moderate	Moderate	Moderate

Note: Under each severity level, the symbol > followed by a letter (B to L) is used to direct the user to the next step in the decision tree.

Table 2. Current predictions for climate change scenarios (after Kenny et al., 1993).

Region	Year	ΔT (^{0}C)		ΔP (%)	
		Winter	Summer	Winter	Summer
Britain	2010	0.5 - 1.0	0.0 - 0.5	2 - 4	0 - 2
	2030	1.0 - 1.5	1.0 - 1.5	4 - 8	0 - 4
	2050	2.0 - 3.0	1.0 - 2.0	6 - 12	0 - 6
Scandinavia	2010	0.5 - 1.0	0.0 - 1.0	2 - >4	0 - 2
	2030	1.5 - 2.5	1.0 - 1.5	4 - >8	4 - >8
	2050	2.0 - 4.0	1.0 - 2.0	6 - >12	6 - >12
Mediterranean -					
south	2010	0.0 - 1.0	0.0 - 0.5	-2 - 0	-4 - -12
	2030	1.0 - 1.5	1.0 - 1.5	-4 - 0	-4 - -12
	2050	1.0 - 2.0	1.0 - 3.0	-6 - 0	-6 - -18
north	2010			0 - 2	-4 - 0
	2030			0 - 4	-8 - 0
	2050			0 - 6	-12 - 0
Europe -					
continental	2010	0.5 - 1.0	0.5 - 1.0	2 - 4	0 - 2
	2030	1.5 - 2.0	1.0 - 1.5	4 - >8	0 - 4
	2050	2.0 - 3.0	1.0 - 2.0	6 - >12	0 - 12
west (marine)	2010	0.5 - 1.0	0.5 - 1.0	2 - 4	-8 - 2
	2030	1.0 - 2.0	1.0 - 1.5	4 - 8	-4 - 4
	2050	1.0 - 3.0	1.0 - 2.0	6 - 12	-6 - 6
russian	2010			2 - >4	0 - 4
	2030			4 - >8	0 - >8
	2050			6 - >12	0 - >12

ΔT and ΔP are the changes in temperature and precipitation, respectively.

Figure 1. Information flows within the ACCESS model

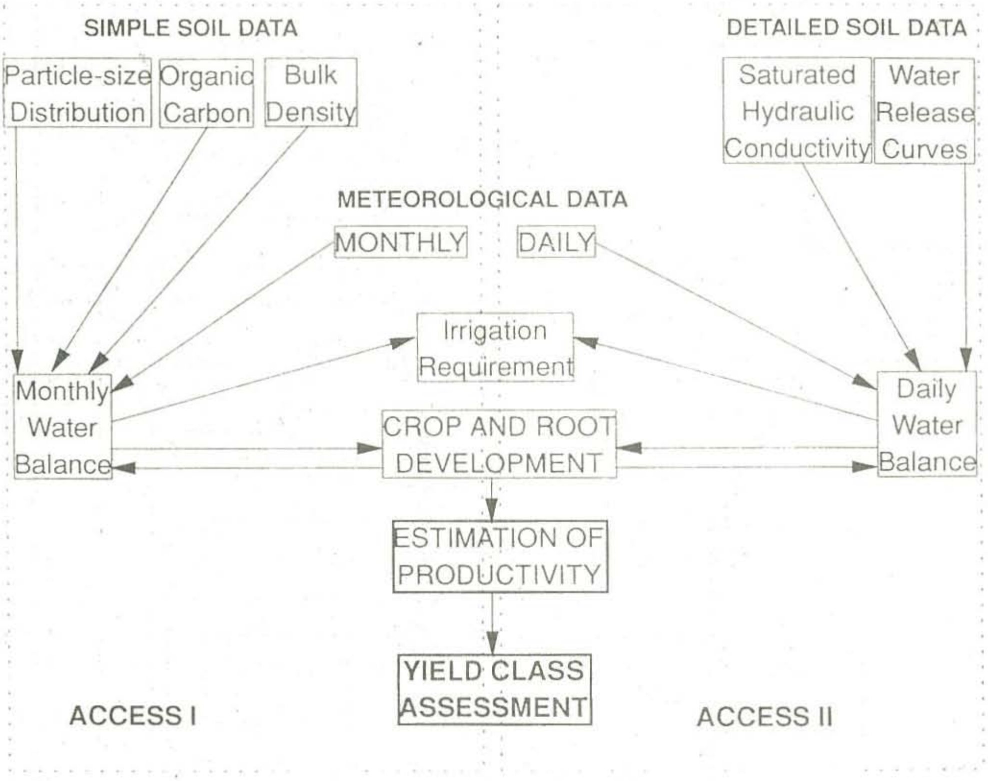

Figure 2. The structure of MOBIDIC (after Leenhardt, 1991). The development of ACCESS-II follows route 3.

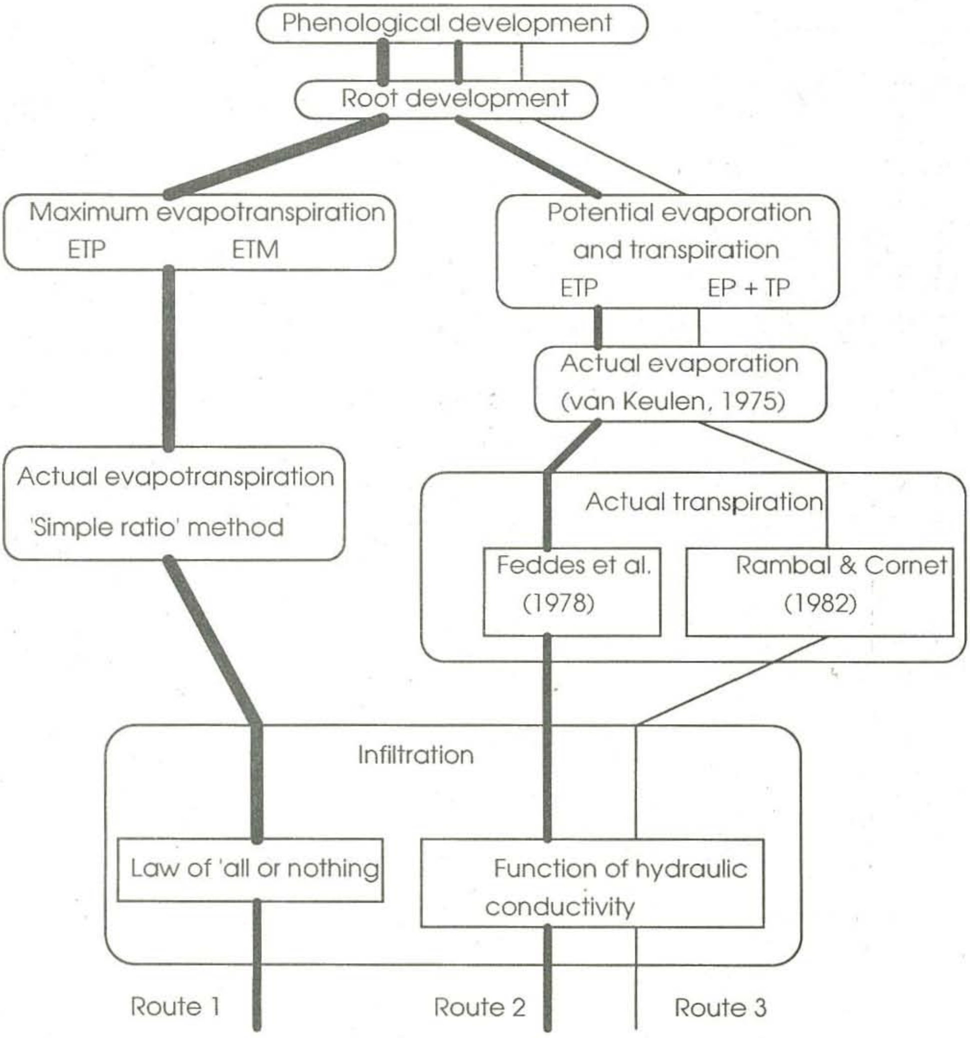

Figure 3. Basic structure of ACCESS-II

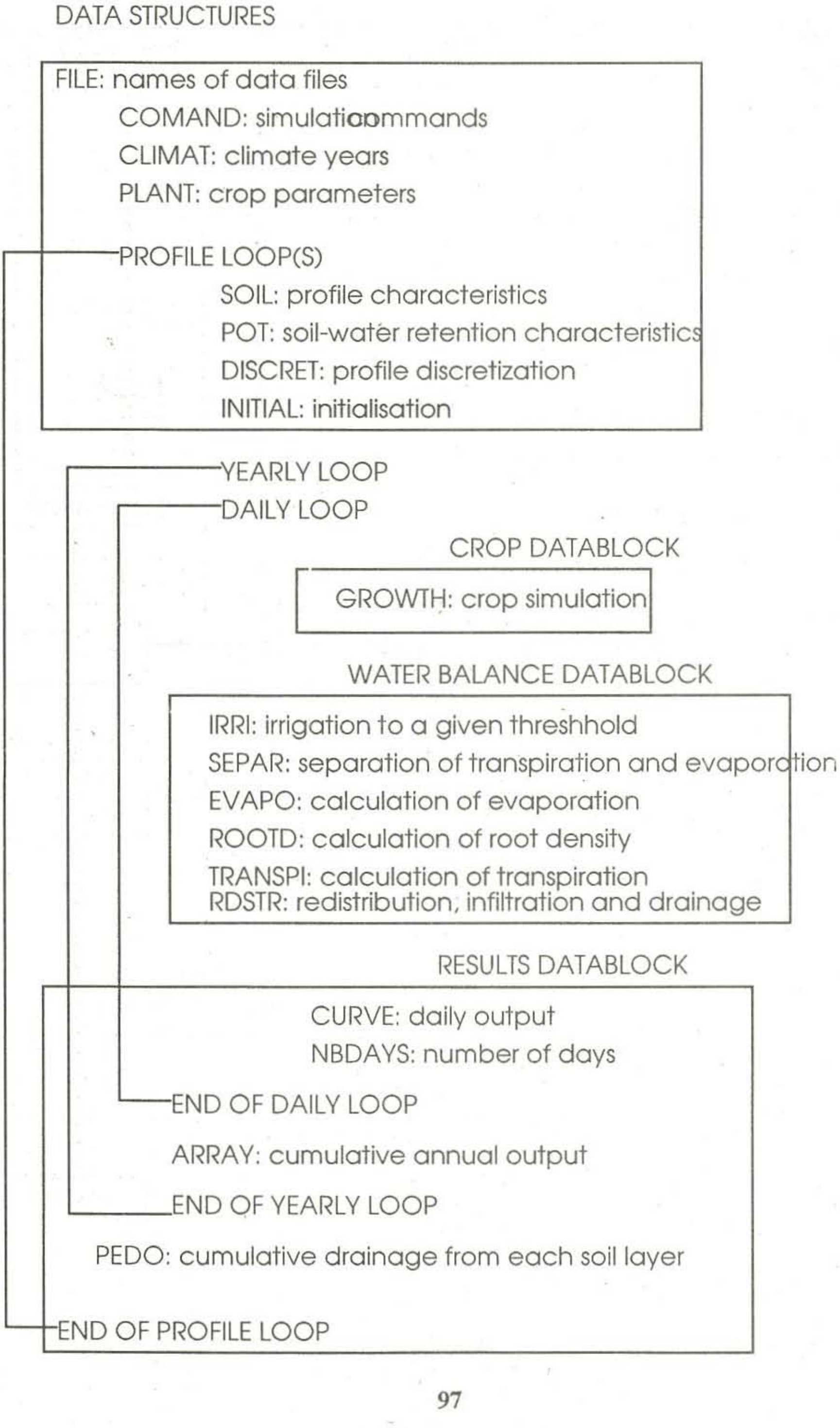

Figure 4. Information flows within the modified EPIC model.

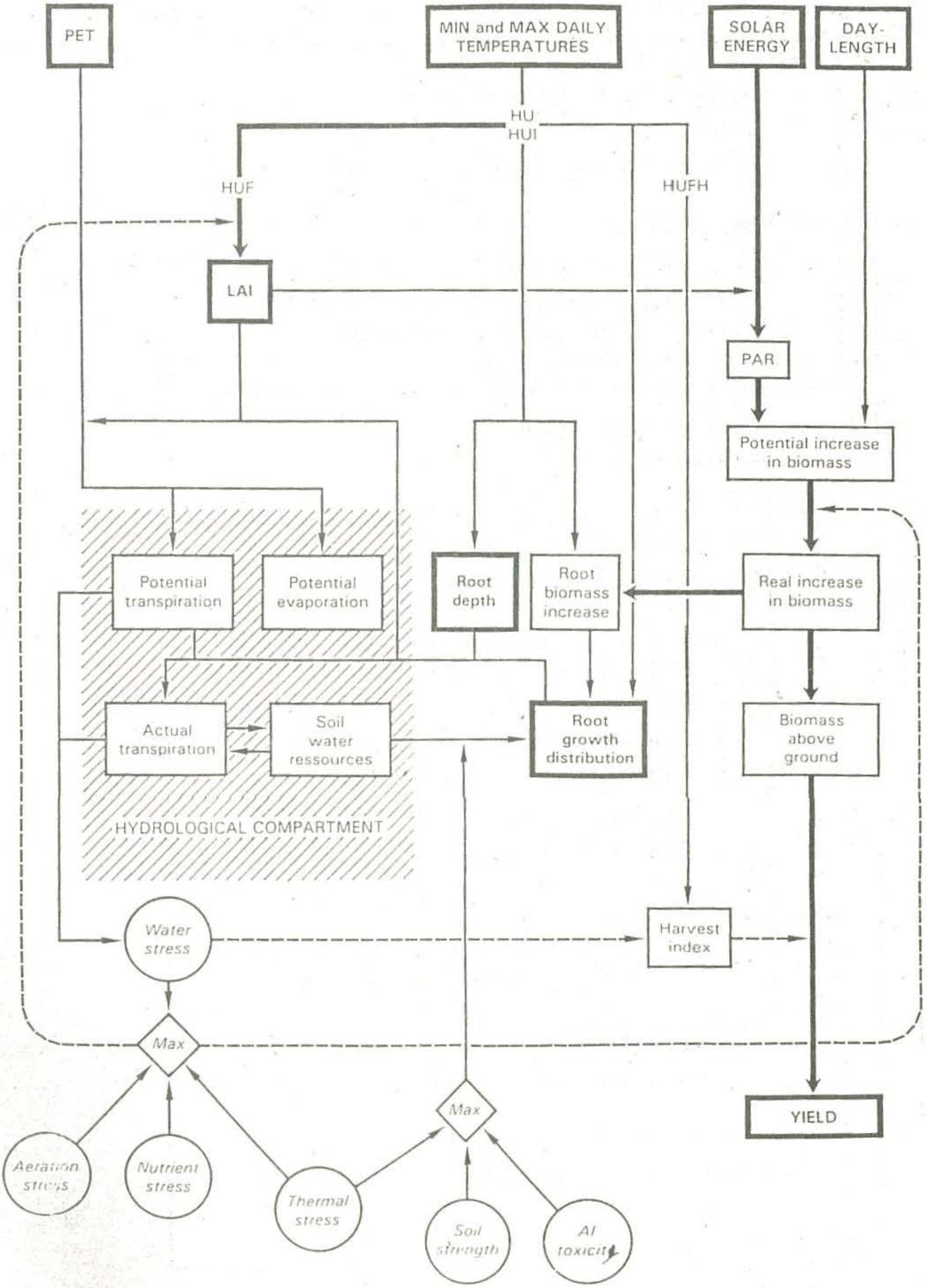

Figure 5. A hypothetical example of a regional analysis of crop yields used to define boundaries between yield classes.

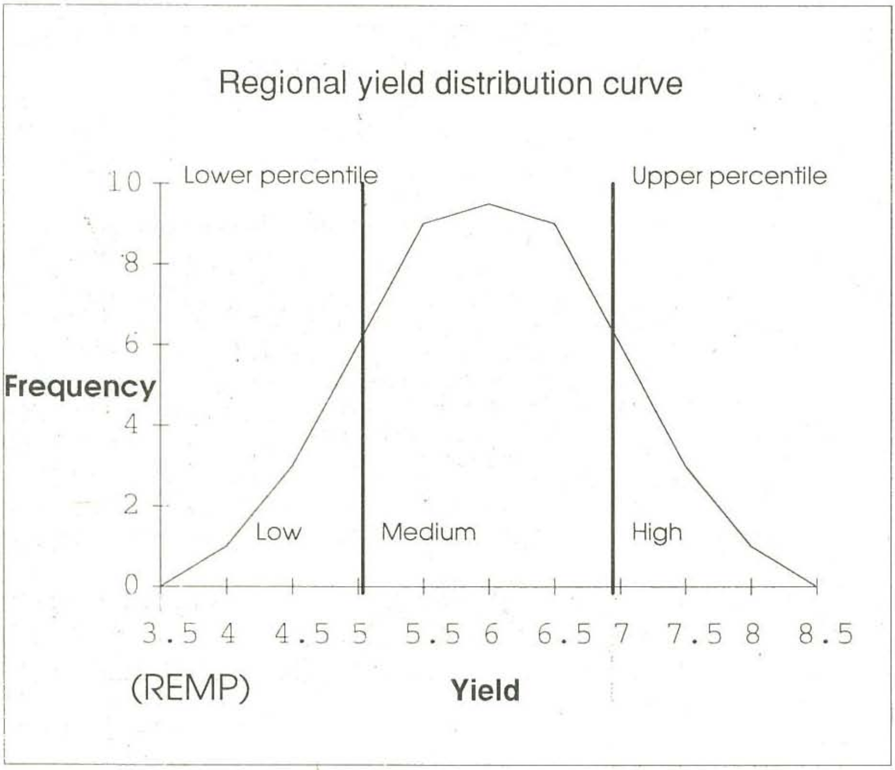

Figure 6. An example of a land utilisation type (LUT) from southern Spain.

Current Conditions for the LUT: Sunflower/Rainfed
*BENCHMARK AREA: CAMPINA (SE-03), ANDALUCIA, SPAIN

*CROP (Helianthus annuus)
Main varieties: Florasol; Ariflor; Hysum-33
Growing season length: 159 days (mean); range 126-184
Maximum rooting depth (cm): 80-100
Phenological calendar: Emergence: end Feb/mid Apr; Ripening: mid July-end Aug

*MANAGEMENT PRACTICES
Primary tillage: 1 - mouldboard plough, September; 3 - disking, December-January
Secondary tillage: 1, interrow rotavator - end March - early May
Sowing: 4-8 kg seed/ha, 70cm row spacing, mid February - end March
Fertiliser: Urea 46% N, 100-150 kg/ha; December-January
Herbicides: 1.5 L/ha, trifluralin, mid February - end March
Pesticides: 50 kg/ha, Lindane 2%, mid February - end March
Harvesting: combined, end July - early September
Residues: straw ploughed in, October
Irrigation: nil
Artificial drainage: nil

*PERFORMANCE IN THE BENCHMARK AREA
Indicative yield/quality: 1.9 - 2.2 t/ha seed; 46 - 50% oil
Environmental impact: high erosion risk; low pollution potential