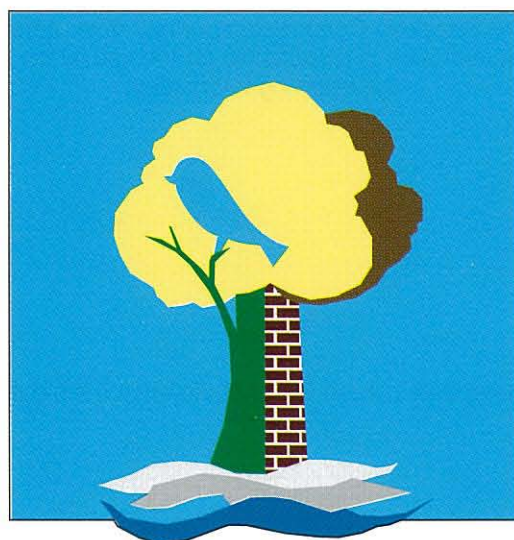

AgroClimatic Change and European Soil Suitability



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Research results

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AgroClimatic Change and European Soil Suitability

THE ACCESS TEAM

The construction of the ACCESS model represents the efforts of many people over a period of two and a half years.

Great Britain

P.J. Loveland (Co-ordinator), M.D.A. Rounsevell, T.R. Mayr, E. Peccol

Soil Survey & Land Research Centre (SSLRC), Cranfield University, Silsoe Campus, Silsoe, Bedford MK45 4DT.

FAX.: +44.(0).1525.863253

A.C. Armstrong

ADAS Land Research Centre, Gleadthorpe Research Centre, Meden Vale, Mansfield, Notts. NG20 9PF.

FAX.: +44.(0).1623.844472

A.M. Matthews and A.M. Portwood
ADAS Land Research Centre, Anstey Hall, Maris Lane, Trumpington, Cambridge CB2 2LF.

FAX.: +44.(0). 1223.841618

France

J-P. Legros (Leader - French Group), M. Voltz, D. Leenhardt
Science du Sol, Institut Nationale de la Recherche Agronomique (INRA), 2 Place Viala, 34060 Montpellier Cedex 01.

FAX.: +33.67.63.26.14

Hungary

K. Rajkai (Leader - Hungarian Group) and C. Farkas

Research Institute for Soil Science and Agrochemistry (RISSAC), Herman Ottó út. 15, 1022 Budapest II.

FAX.: +36.(1).155.8839

J. Fehér

Water Resources Research Centre plc (VITUKI plc), Kvassay Jenő út. 1, H-1095 Budapest.

FAX: +36.(1).216.1514

Poland

J. Glinski (Leader - Polish Group), C. Slawinski, H. Sobczuk, R. Walczak
Institute of Agrophysics-Polish Academy of Sciences (IA-PAN), ul. Doswiadczalna Nr 4, 20-236 Lublin.
FAX.: +48.(0)81.45067

Romania

C. Simota (Leader - Romanian Group) and G. Cojocaru
Research Institute for Soil Science and Agrochemistry (RISSA), Blvd. Marasti 61, 71331 Bucharest.

FAX.: +40.(1).222.5979

C. Ionescu

National Institute for Meteorology and Hydrology (NIMHB), Sos. Bucuresti-Ploiesti 97, sect. cod 1, 71552, Bucharest.

FAX.: +40.(1).312.9843

Spain

D. de la Rosa (Leader - Spanish Group), J.W.H.C. Crompvoets, F. Mayol, H.J. Hendricks-Franssen, G. Aguirre

Consejo Superior de Investigaciones Científicas - Instituto de Recursos Naturales y Agrobiología, (CSIC/IRNAS), Apdo. 1052, E-41080 Sevilla.

FAX.: +34.(5).462.4002

The European Commission

R. Fantechi (Head: Climatology and Natural Hazards) and D. Peter (Project Officer)

DGXII, Commission of the European Communities, rue de la Loi 200, B-1049 Brussels, Belgium.

FAX.: +32.2.296.3024

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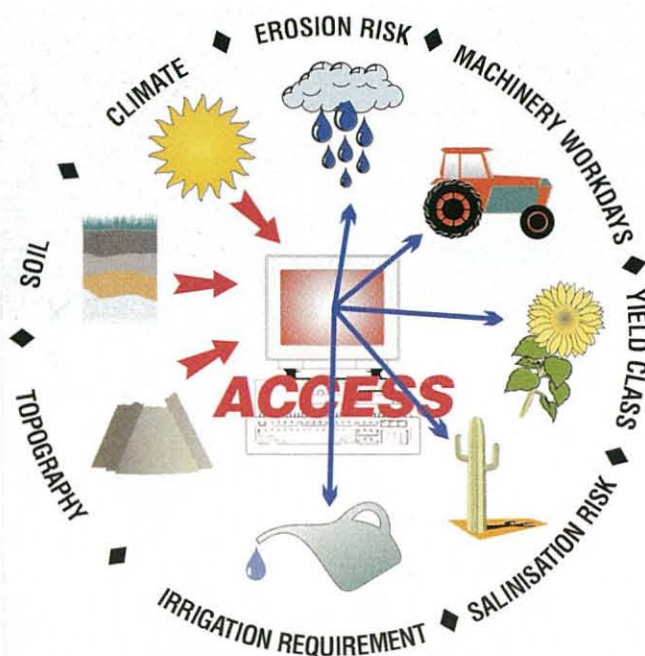
OVERVIEW

This report provides a summary of the ACCESS project (AgroClimatic Change and European Soil Suitability) sponsored by the Commission of the European Communities (EV5CT920129) under the Third Framework Programme.

The ACCESS project arose from the belief that land-use modelling is an essential tool for the proper implementation of policy choices concerning the utilisation of resources. Such choices can be local or national, but should be supported by the best information, or estimates, that modern science inter alia can provide. Policy has to deal with options at different spatial and temporal scales, and we have made this a central part of the design of the ACCESS model. The scientific core of ACCESS is a robust method for the calculation of the soil-crop-water relationship, which is central to any attempt to assess the suitability of land for agricultural uses. Additional features are the ability to:

- calculate soil hydraulic properties by means of widely-tested, robust pedo-transfer functions;
- model soil-water movement in cracking soils;
- assess the problem of soil salinity, using an expert system;
- estimate soil erosion risk, and vulnerability to agro-chemicals.

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 both the local and regional level, with the implications this has for spatial resolution on the ground.



Within the European Union 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). Large amounts of these data are in digital form, and can be manipulated readily by computers, often within geographic information systems.

The ACCESS project has produced a model which uses such detailed information to predict the effects of climate change on land-use potential within Europe. 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 ACCESS model thus runs at two levels: ACCESS-I and ACCESS-II, which complement one another. The essential difference is one of data availability, because this affects profoundly the time steps at which the model can operate, and the level of detail with which processes can be simulated. The model assesses land-use suitability in terms of the predicted yield of strategic crops (winter wheat, maize, soybean, potatoes, sunflower). A novel development of this approach is the introduction of Regional Yield Classes, which interpret the data in relation to local farming practice i.e. the local social and economic environment.

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 suffi-

cient 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. The model has a user-friendly, menu-driven front end, with clearly defined input and output data structures. Many of the latter are deliberately compatible with a wide range of geographic information systems, so that output can be obtained as maps. The model will run under Microsoft WINDOWS™ on an IBM™-compatible PC-platform, is written in Microsoft™ FORTRAN™ (version 5.1) and Microsoft VISUAL BASIC™, for ease of implementation, and is fully documented.

This report also includes demonstrations of the use of ACCESS in the countries represented by the consortium. Future developments of land-use modelling are also discussed.



NOAA-AVHRR mosaic of Europe (Copyright NRSC 1990)

BACKGROUND

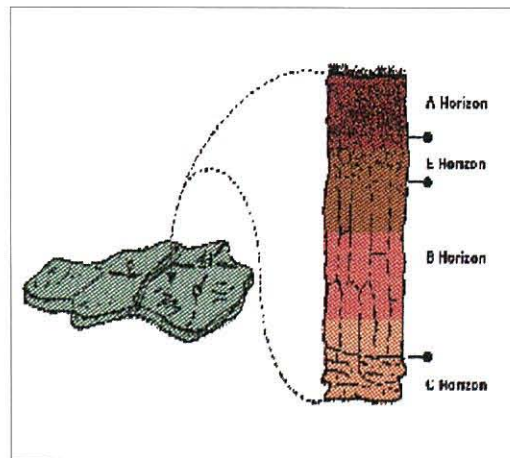
The agricultural area (excluding forestry) of the European Union is about 1.6 million km², most of which lies between the latitudes 37°N and 64°N, and longitudes 10°W and 23°E. If Hungary, Poland and Romania are included, *i.e.* the non-EU partners in this project, then the area of agricultural land increases to about 2.1 million km², and the geographic range extends to almost 30°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. In addition, the agricultural potential of the associated countries is considerable, and has important implications for future land-use policy within the EU, or an enlarged version of it. Moreover, 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°C over the next 50 to 100 years (Viner and Hulme, 1993), whilst precipitation is expected to increase by about 10 per cent. Likely changes in the seasonal and spatial distribution of the latter are currently little known, and difficult to predict (Carter *et al.*, 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). For land-use considerations the most important result of this overall

change will be an increase in summer soil moisture deficits, which could be large in some regions.

Many attempts to predict the effects of climate change on land-use within the European Community have suffered from important limitations, *e.g.*:

- they regard the soil as essentially uniform, and are driven almost entirely by climate;
- they operate at very coarse scales (Parry, 1990; DoE, 1991);
- 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. However, they do not provide tools which:

- give enough detail for realistic land-use planning at the local or regional scale;
- consider the water resource implications of the potential changes in soil-climate-agriculture systems;
- allow accurate predictions in changes of harvests, and thus factors related to the agricultural economic sector.



Because of the very coarse scales generally used, little attempt has been made to link with 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 ACCESS project 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 perturbation. Validation of the model is, however, carried out against current climatic situations.



AIMS, OBJECTIVES AND PURPOSE

The **aim** of the ACCESS project was to develop a model which could predict the effects of any climate perturbation on the cropping potential of any area of land within the European Union.

The **objective** of the ACCESS model is to assist scientifically the decision making process in relation to land-use. Within this framework, the project addressed the following criteria:

- the ability to predict land-use potential should be independent of scale, within the limitations of available data *i.e.* the model should be able to make a prediction for a single field or for a large region, without making impossible demands of the computing environment;
- the knowledge-base would be the known soil pattern, the properties of the soils and the growth requirements of the intended crop(s);
- the project would make use of current, well-researched and documented models of soil, crop and climate processes, as appropriate;
- direct temperature effects on crop performance would be predicted from existing physiological models, using data from national experimental soil-crop programmes as the basis for modelling and simulation;
- the user of ACCESS could use historical meteorological data to test the functioning of the model;
- regional modelling, which we call Level I modelling (ACCESS-I, above), would be supported 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.
- provision for the user of robust pedo-transfer functions to allow estimation of soil hydrological properties from simple soil survey data;
- the need for clearly-defined data input and output structures, the latter to be compatible with widely-available geographic information systems;
- that the ACCESS model would run on an IBM™-compatible PC-platform, through a user-friendly interface;
- that ACCESS would give the user tools to assess risks from erosion, agro-chemicals and salinisation, all of which were thought, by the team, to be factors which could assume much greater significance for land-use under a changed climate.

Thus, the user of ACCESS has a powerful, fully-documented model, based on sound scientific principles, and running on widely available hardware. The model **purposefully** sets out a method of estimating yields of strategic crops for a soil (or soils) of given properties, with any stated climate inputs, and at a range of geographic scales. The inputs can be judged against locally-derived yield classes.

THE PRODUCT

Both ACCESS-I and ACCESS-II share a common format for data input. The choice of route through the model depends largely on the time-step of the climate data. Both ACCESS-I and ACCESS-II will carry out the risk assessment and yield prediction, many of the routines being shared. The greatest difference lies in the mechanism for calculating the soil-water balance. This is much more detailed in ACCESS-II, reflecting the greater resolution of the climate data, than in ACCESS-I. The format for data output from both routes through the model is similar, and both are compatible with the input formats of many, widely-available GIS packages.

In order to make the improved model widely available, it has been developed so that it will:

- run on an IBM™-compatible PC platform;
- use standard data input formats;
- provide output as standard file formats acceptable to a range of geographic information systems. All programming is compatible with Microsoft™ FORTRAN v5.1.
- run under WINDOWS™ through a user-friendly 'front-end', itself written in Microsoft VISUAL BASIC™.

Availability

A copy of the ACCESS software and user documentation can be obtained from:

The Publications Officer
Soil Survey and Land Research Centre,
School of Agriculture, Fisheries and Food,
Cranfield University,
Silsoe,
Bedford MK45 4DT, UK.

GENERAL APPROACH

We took the framework of an existing crop-agroclimate model developed in the UK (Thomasson and Jones, 1992), which relates crop requirements to soil-climate factors. Initial development concentrated on improvements to the water balance-crop growth module, the erosion module, and the land-use/sustainability module. The second stage concentrated on extension of site-specific modelling to larger areas (a process we term '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's.

The compartments of this approach, and that within ACCESS, 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:

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

The European Community is large and diverse so it was clear that the ACCESS model had to be tested under a range of conditions. For this reason we selected 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:

- central England: cool, humid climate;
- Languedoc-Roussillon, France: Mediterranean climate;
- Andalucia, Spain: very hot, dry summers, limited winter rainfall.
- Lublin Upland, eastern Poland: warm continental, with snow cover in winter;
- Middle Tisza Region (Nagykovács), eastern Hungary: dry continental, cold winters, little snow.

The compilation of the databases concentrated on:

- site factors - topographic maps and/or landform analysis;
- soil factors - soil mapping (survey) and associated databases;
- tillage properties - calculated from the number of days at which the soil is likely to be too wet for mechanical cultivation;
- agroclimatic factors - from meteorological data;
- 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 version of the 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 from 130 stations.

In France (Languedoc-Roussillon), the climate data comprised 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, an extensive sampling program was carried out to determine these

soil properties for the main soil units. The other soil data came from the soil databank for the region (Borland *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 was assembled by the Hungarian Meteorological Office.

The Romanian database came from the archives of the Research Institute for Soil Science and Agrochemistry, Bucharest.

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. Robust pedo-transfer functions originally developed from work in Romania and Hungary, were extended across these diverse datasets.

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. In order to deal with this, we developed the revised model (ACCESS) to work at two scales:

- regional (Level I): large areas form several hundred to several thousand hectares in extent; this part of the model is known as ACCESS-I;
- 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.

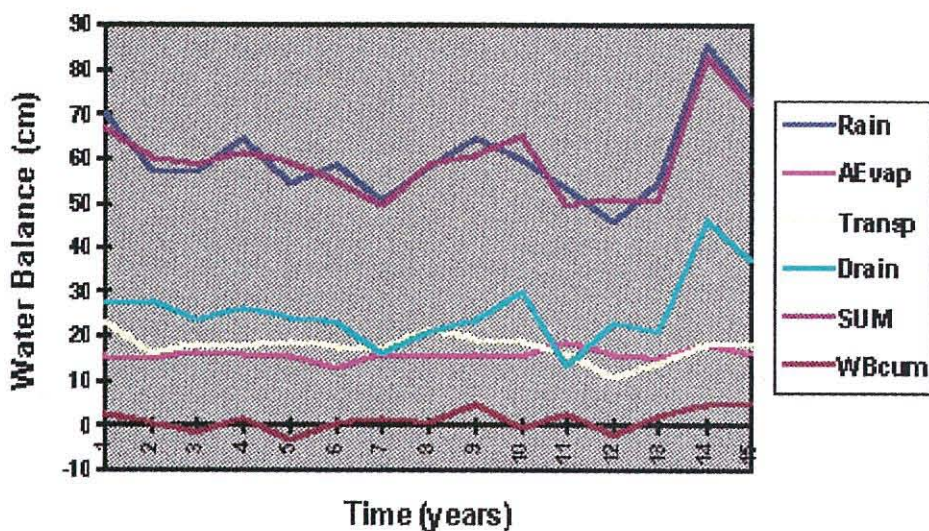
For the purposes of this project and the development of a working model, we concentrated on the strategic crops: maize, winter wheat, sunflower, soybean and potatoes for ACCESS-I; and, winter wheat, maize and sunflower for ACCESS-II.

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. For example, 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 cropping, although such research is in progress.

ACCESS-I

The soil water balance component of ACCESS-I considers evaporation and transpiration separately, as well as defining root front development and root density. Crop yields are estimated using the concept of water use efficiency including the influence of CO_2 on this. Soil hydraulic properties are estimated using pedo-transfer functions from simple soil survey data (particle size distribution, organic carbon content and bulk density).

ACCESS-I also addresses soil workability, which is a significant constraint to crop production in many European regions (Rounsevell, 1993). Soil workability is usually quantified by the number of days suitable for machine operations during the growing season, and these are strongly influenced by the weather (Rounsevell and Jones, 1993). Changes in the climate will affect the number of machinery work-days; (Rounsevell and Brignall, 1994), and this will impact significantly on crop production and land use distribution (Rounsevell *et al.*, 1994).

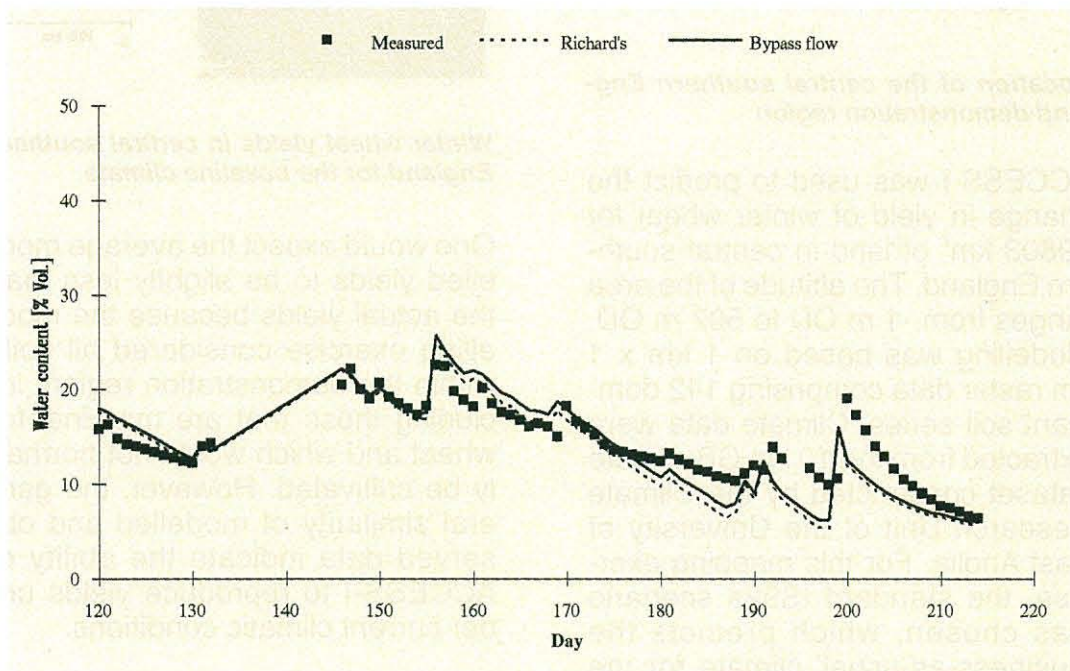


An example of the soil water balance calculated using ACCESS-I for a period of 15 years. The lines on the graph represent rainfall (Rain), actual evaporation (AEvap), transpiration (Transp), drainage (Drain), the sum of the actual evaporation and transpiration (SUM) and the cumulative water balance (Wbcum)

ACCESS-II

ACCESS-II provides a detailed soil water balance model based on a mechanistic description of the processes of water infiltration, redistribution, and crop water uptake. It is derived from the MOBIDIC model of Leenhardt (1991), and contains within it the options to describe soil water movement using the simple ARFEJ model (Rambal and Cornet, 1982) or a full solution of the Richards' equation describing water movement in unsaturated soils.

The growth of the crop is simulated using the crop growth model derived from EPIC (Williams *et al.*, 1983), as modified by Cabelguenne *et al.* (1990) for multiple crop phases. ACCESS-II has the ability to model bypass flow through soil macropores, which is an important component of the water balance in soils with high clay contents under dry climatic conditions (Armstrong *et al.*, 1994).



Water content at 5 cm depth for Grabow, Poland in 1994: measured values compared with ACCESS-II simulations with bypass flow and without (Richards')

DEMONSTRATION

The examples which follow illustrate the use of ACCESS in various modes and in different European regions.

ACCESS-I for the prediction of winter wheat yield in central southern England

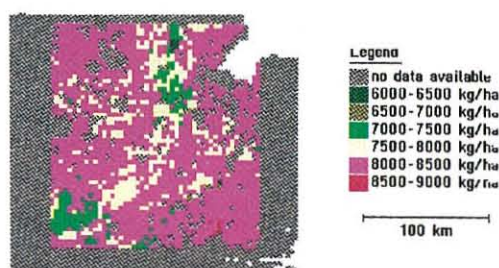


Location of the central southern England demonstration region

ACCESS-I was used to predict the change in yield of winter wheat for 29803 km² of land in central southern England. The altitude of the area ranges from -1 m OD to 507 m OD. Modelling was based on 1 km x 1 km raster data comprising 142 dominant soil series. Climate data were extracted from the 10 km GB climate dataset constructed by the Climate Research Unit of the University of East Anglia. For this mapping exercise, the standard IS92a scenario was chosen, which predicts the 'business-as-usual' climate for the year 2050 with a mean temperature change of +1.15°C and 523 ppmv CO₂, and for the year 2100 with a

mean temperature change of +2.46°C and 733 ppmv CO₂.

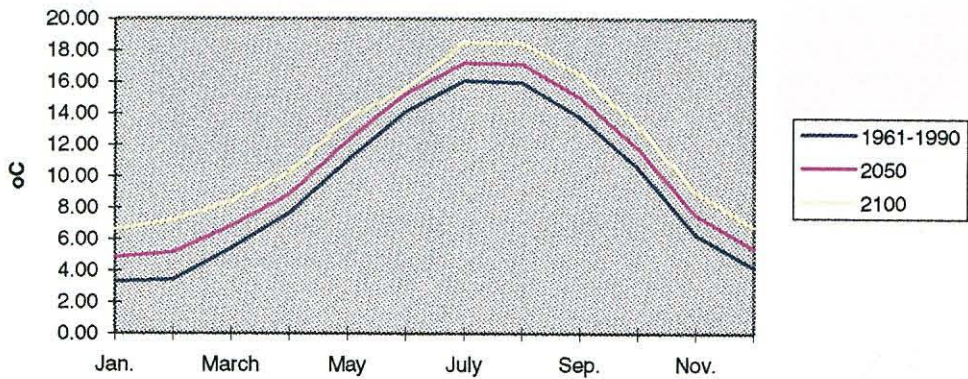
The modelled yield for the baseline climate was found to have an average of 8.1 t ha⁻¹. This can be compared with the historical average for the same region over the same period of time of 6.9 t ha⁻¹. The modelled yield is larger than the observed yield because it does not allow for less than optimum management. Van Lanen et al. (1992) calculate that because of suboptimal management in the UK, actual winter wheat yields are 0.75 of water limited yields. Thus, 0.75 of the average modelled yield is 6.1 t ha⁻¹, a value comparable with the observed data.



Winter wheat yields in central southern England for the baseline climate

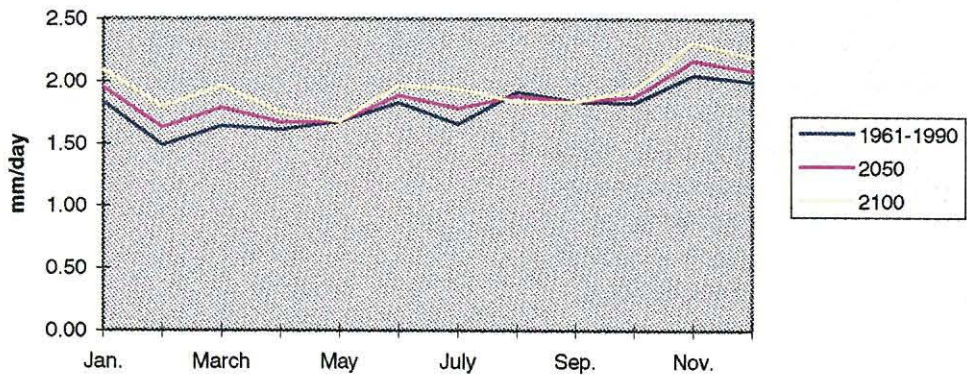
One would expect the average modelled yields to be slightly less than the actual yields because the modelling exercise considered all soils within the demonstration region, including those that are marginal for wheat and which would not normally be cultivated. However, the general similarity of modelled and observed data indicate the ability of ACCESS-I to reproduce yields under current climatic conditions.

Mean Temperature (oC)



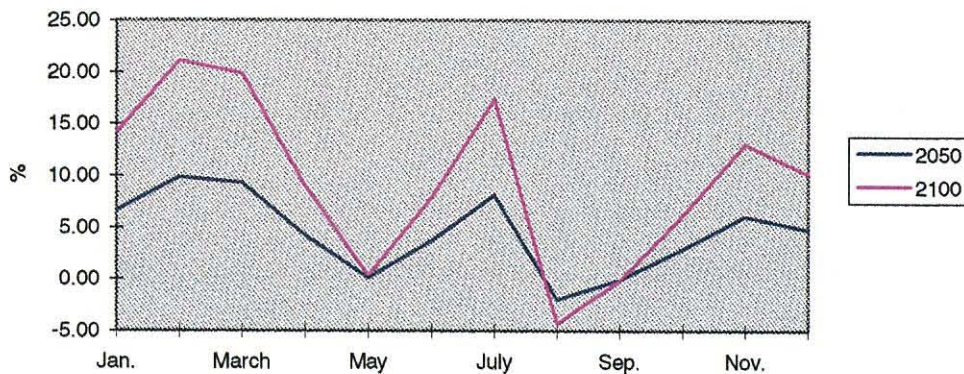
Monthly mean temperature values for the baseline climate and the years 2050 and 2100

Precipitation (mm/day)

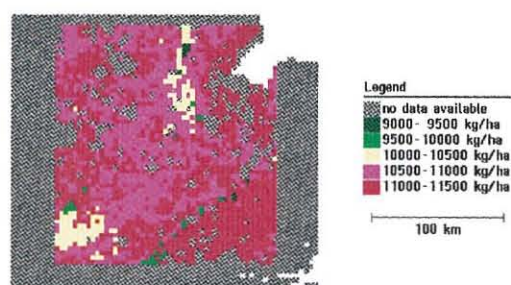


Mean daily precipitation for the baseline climate and 2050 and 2100

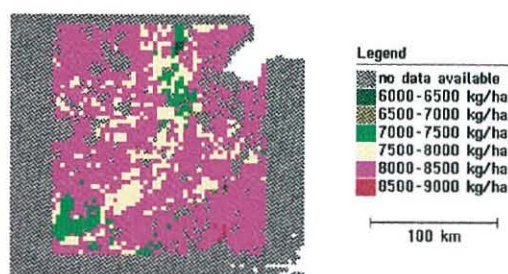
Precipitation (% change)



Changes in precipitation relative to the baseline climate for 2050 and 210



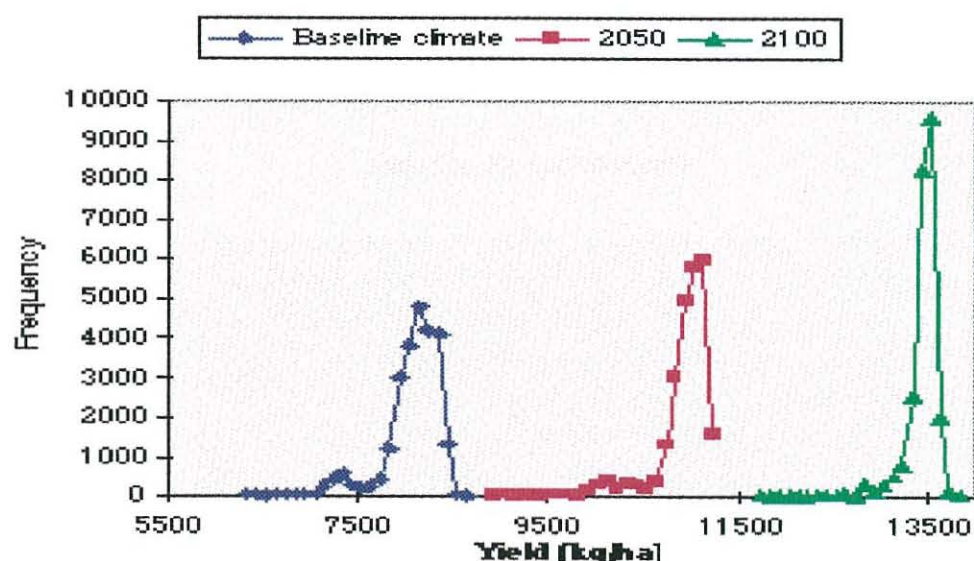
Winter wheat yields in central southern England for the year 2050



Winter wheat yields in central southern England for the year 2100

The average modelled yields for the climate change scenarios were 10.9 and 13.5 t ha⁻¹, for the years 2050 and 2100 respectively. These simulated yields reduced to 8.2 and 10.1 t ha⁻¹ using the management related adjustment factor of van Lanen et al. (1992), assuming that the level of management does not differ markedly from the present to the future. Thus, the simulated average yields are shown to increase by 2.9 t ha⁻¹ (35.5%) at 2050 and by 5.4 t ha⁻¹ (66.6%) at 2100. In addition, as the climate is perturbed, the distribution of yields becomes narrower, indicating optimisation of growing conditions.

The increase in biomass can be attributed to enhanced water use efficiency as a result of elevated atmospheric CO₂ concentrations, and increased temperature and evapotranspiration. However, because of the simplicity of the model, physiological restrictions to biomass accumulation are not considered, and these might result in overestimation of the yield predictions.



Winter wheat yield (kg ha⁻¹) distributions for the climatic baseline, 2050 and 2100 in central southern England

Predicting the effect of climate change on maize in southern France

ACCESS-II was run for maize using current growth conditions based on experiments at INRA-Toulouse during the years 1986 and 1987. ACCESS-II has been shown to simulate the growth of this crop extremely well for this location and for these years.

The imposed climate change was based on a CO₂ doubling scenario: a worst case scenario, with a large increase in temperature. In practice, we successively:

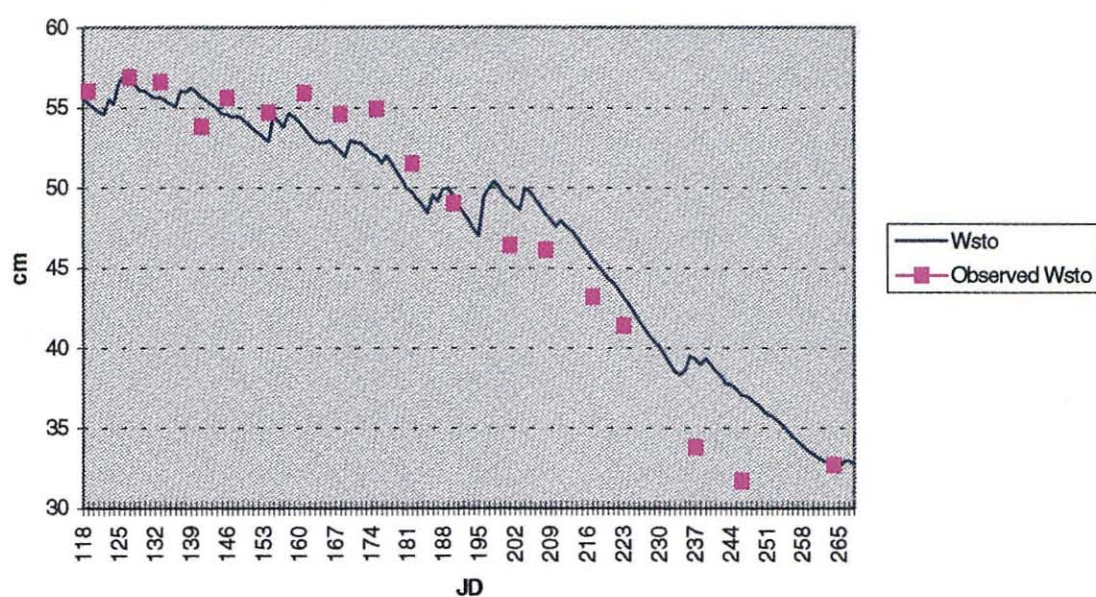
- ran the climatic model starting from ten available years for the region (1966/1975 with daily data),
- used the hypothesis that the atmospheric CO₂ content doubled,
- considered monthly results, smoothing them to avoid small random variations,
- applied, on a daily basis, the transformation of climatic data presented in Table 1 at the monthly level.

Tables 2 and 3 show the results of the simulations made with and without climate modification. To define the current conditions 5% was added to the potential evapotranspiration (for grass), because transpiration of maize is greater than that of the reference crop. All values of the output data given in the tables correspond to the growing period. We must emphasise that the 1987 year was wet, allowing a grain yield near to 10 t ha⁻¹ without irrigation. In contrast, 1986 was very dry and the experiment, also conducted without irrigation, gave poor biomass and yield.

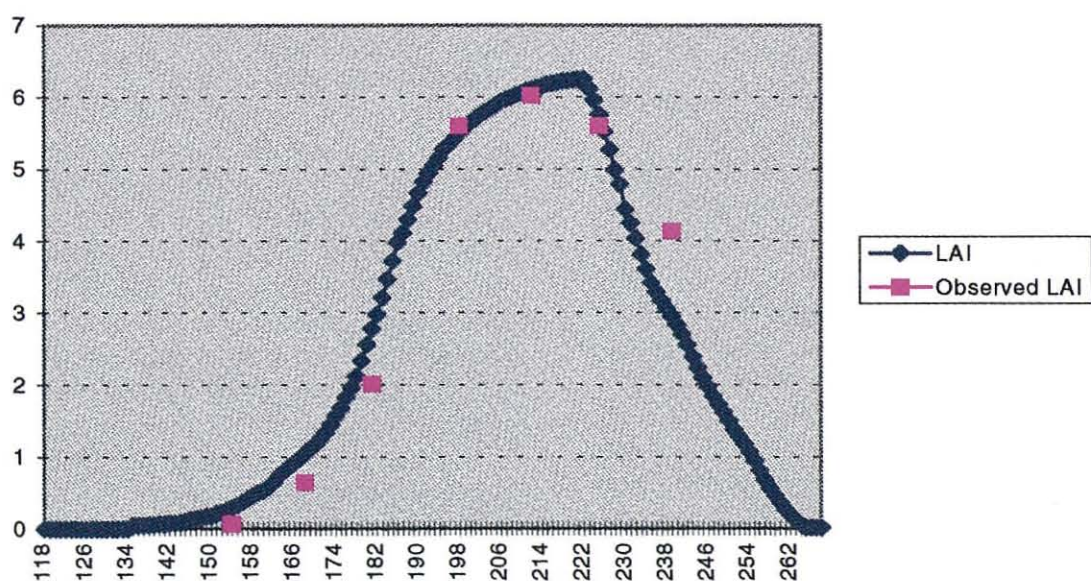
Table 1. Climate change transformations used for maize in Toulouse

	Tmax (°C)	Tmin (°C)	Rain (%)	PET (%)	Solar Rad.
Jan	+0.82	-0.25	-11.6	+10	+4.3
Feb	+1.34	+1.91	+30.7	+10	+13.7
Mar	+4.91	+2.84	+10.7	+10	+17.1
Apr	+0.63	+0.46	-9.4	+10	+6.4
May	+1.47	+1.49	+3.5	+10	+9.1
Jun	+4.17	+2.68	-19.0	+10	+9.6
Jul	+8.31	+3.60	-56.2	+10	-2.9
Aug	+7.00	+4.67	-0.4	+10	-7.5
Sep	+5.96	+4.77	-38.9	+10	+21.8
Oct	+3.19	+2.40	15.6	+10	-5.2
Nov	+2.51	+2.96	+3.1	+10	-4.0
Dec	+2.54	+3.37	+5.5	+10	+2.1

Some of the simulation results are obvious for the year 1987. Firstly, the temperature increase reduces the length of the growing period because this is mainly controlled by the sum of degree-days. The result of this is that the solar energy accumulated is smaller so that the biomass potentially formed from this energy is also small. Secondly, as rainfall decreases, transpiration is reduced and the value of water stress diminishes, i.e. it becomes more severe. For both these reasons, biomass and yield are smaller than the biomass and the yield obtained under current conditions. The yield is approximately halved if no irrigation water is added. Conversely, if the increase in water demand is compensated by irrigation, the yield will not change markedly.



Observed (points) and simulated (curve) soil water contents for Maize; Toulouse experiment in 1987.



Observed (points) and simulated LAI (curve) for maize; Toulouse experiment in 1987.

Table 2. Climate change simulation experiment, Toulouse in 1986.

Output Variable	Actual Climate	Modified Climate
Growing period (days)	130	100
Mean temperature (°C)	18.7	25.2
Rainfall (cm)	8.8	7.0
Irrigation (cm)	0.0	0.0
Drainage (cm)	0.0	0.0
Residual water stock	31.7	35.3
PET (cm)	56.4	46.6
Actual ET (cm)	35.2	29.7
Pot. Evaporation (cm)	28.8	22.6
Actual Evaporation	12.4	8.6
Potent. Transpiration	27.7	24.0
Actual Transpiration	22.7	21.1
Water stress	0.73	0.77
Thermal stress	0.96	0.97
Total biomass (tonnes)	10.2	11.5
Above ground Biomass (t)	8.2	9.2
Yield (tonnes)	2.6	3.6
Degree-days for period	1521	1783
Degree-days for maturity	1500	1750
No. of maturity days	252	222

If we consider 1986, the situation is completely different. The shortening of the growing period, linked with the temperature increase, allows the crop to save on part of its growth because this takes place before the summer dry period. The water stress passes from 0.73 (actual conditions) to 0.77 (climate change hypothesis). The result is an increase in yield even if this yield remains too small.

Table 3. Climate change simulation for maize, Toulouse in 1987.

Output Variable	Actual Climate	Modified Climate
Growing period (days)	151	110
Mean temperature (°C)	18.6	23.3
Rainfall (cm)	23.5	14.0
Irrigation (cm)	0.0	0.0
Drainage (cm)	0.0	0.0
Residual water stock	32.8	36.9
PET (cm)	59.7	46.4
Actual ET (cm)	46.5	33.3
Pot. Evaporation (cm)	26	23.7
Actual Evaporation	14.3	12.4
Potent. Transpiration	33.6	22.7
Actual Transpiration	32.4	20.9
Water stress	0.91	0.86
Thermal stress	0.96	0.98
Total biomass (tonnes)	23.0	13.2
Above ground Biomass (t)	18.3	10.6
Yield (tonnes)	9.2	4.9
Degree-days for period	1764	1754
Degree-days for maturity	1750	1750
No. of maturity days	266	226

However, this interpretation is not absolutely certain because the modelling of the effect of the highest temperatures has not been tested sufficiently as, in general and fortunately, we do not often see this kind of situation in our fields. Nevertheless, if we remember 1976 and 1990, the temperature was so high and water so scarce that maize was severely damaged, with yields <1 t ha⁻¹ everywhere in the region.

However, if irrigation satisfies the water demand, the yield will be identical to 1987 and not far from the maximum actual crop potential.

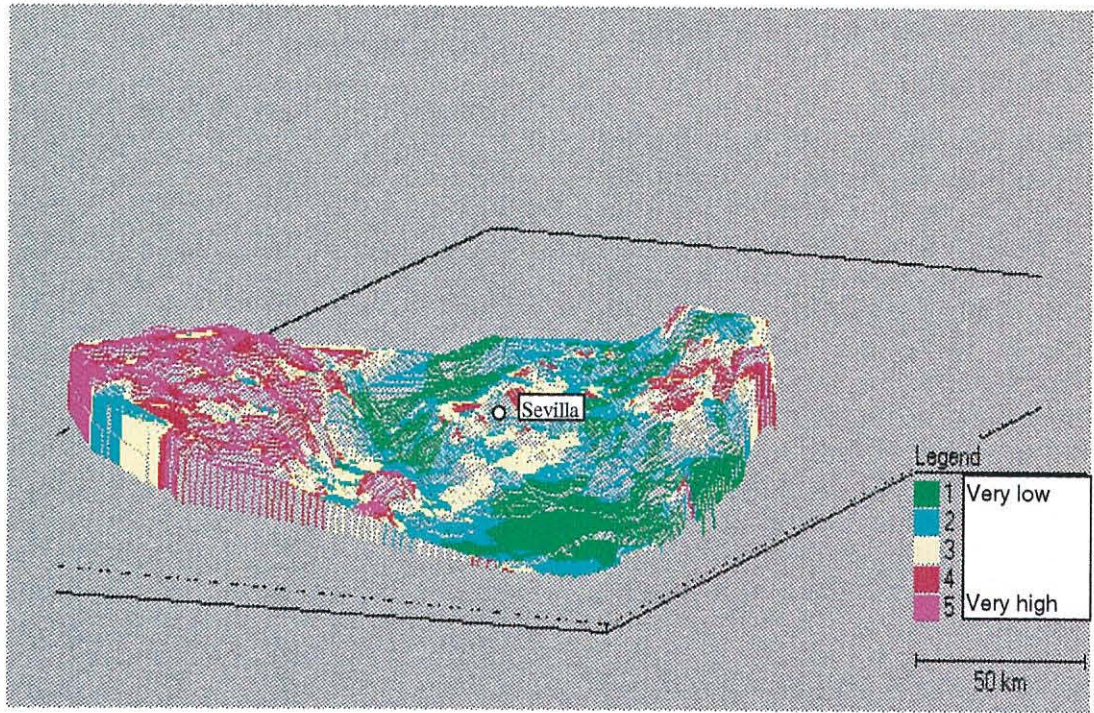
Thus several conclusions can be drawn from these simulations:

- A major climate change scenario, characterised by CO₂ doubling, gives a yield decrease no greater than the decrease we know today when we pass from a normal wet year to a dry one. This allows us to make rather good predictions, because it is possible to calibrate our models on situations that are not very different from those predicted as common or normal for the future, except for the quantity of CO₂ in the atmosphere and for long periods of higher temperatures.
- For maize, the consequences of the change will be linked with annual climatic variability. In the driest years the situation will be no worse than today and, in some cases, it could be better. In the wetter future years (that will always be more or less dry), the growth of maize without irrigation will not be profitable, even if the soils are good and deep.
- Even if water is supplied, the cropping season will be modified by the temperature increase. To benefit from the extra solar radiation the crop must not be too precocious. Thus, the breeding of new varieties must be in a direction opposite to that previous. The new objective will not be to diminish the length of the growing period to adapt maize to northern countries, but to increase this length to make the best use of new conditions. Naturally, the photoperiodic conditions of the country will not be modified.

The erosion vulnerability model for the Province of Sevilla, Spain

The demonstration region of Sevilla Province has a total surface area of 14 001 km². It is located between N 38° 11' and 36° 50' and W 6° 30' - 4° 40'. Soil and climate data were collected from the province, and its border areas, and were used to estimate values at unmeasured locations on a regular grid of 2.5 km x 2.5 km. Soil variables were interpolated using geostatistical interpolation techniques. Long-term (20 year) monthly average maximum, mean and minimum temperature values were interpolated by means of a multiple polynomial regression model using means from 49 precipitation stations. The demonstration in Spain was used to show the erosion risk submodel.





Distribution of attainable erosion risk in the Province of Sevilla, Spai



The effects of climate change on crop yields in Hungary

The ACCESS-I model was applied to different soil types in the test region of Hungary (Middle-Tisza), for the present and potential future climate based on a double CO₂ scenario. Table 4 shows the monthly average imposed changes in precipitation (%), temperature (°C) and evapotranspiration (cm). The changed climate further reduces the already extreme lack of precipitation in the vegetation period (April, July and September) coupled with significant increases in the mean air temperature of 4 °C.

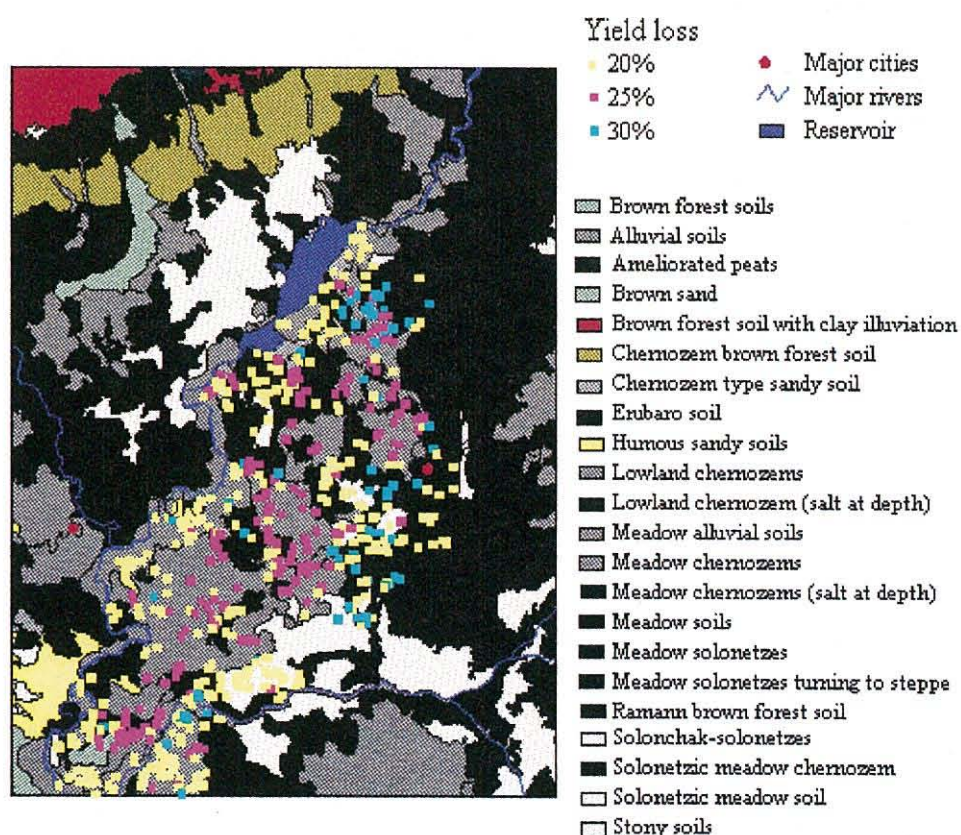
For the current climate, ACCESS-I predicted wheat yields of 4.8 t ha⁻¹ for soils having low hydraulic conductivity's, compaction, and high water holding capacities, mainly due to their salt content. However, the direct effect of salt on wheat yields were not modelled. The other soil types such as meadow chernozems, chernozems with salt accumulation in the deeper horizons, and heavy textured solonetzic meadow soils, show a similar wheat productivity (5.2 t ha⁻¹). Under the changed climate conditions, yields decrease uniformly to 4.6 t ha⁻¹ which is a 10-15% reduction. The lower yield loss of the salt-affected soils is not realistic because they are not suitable for wheat production anyway.

An implication of the predicted yield losses is that there could be a large increase in the use of irrigation water in the central Tisza region of Hungary. It should be noted, however, that the modelling does not allow for the effects of groundwater tables, a subject for future research.

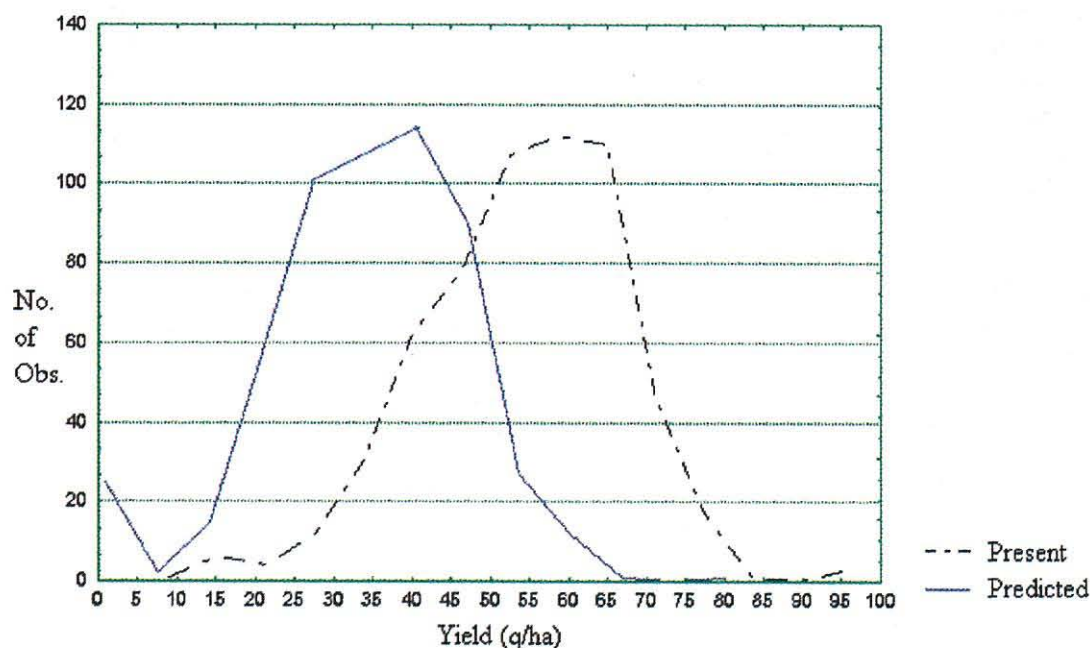
Table 4. Climate perturbations used in the Hungarian demonstration

Month	Rain	Temp	ET (cm)
Jan	1	3	0.13
Feb	19	3	0.09
Mar	16	6	-0.38
Apr	-10	4	0.16
May	4	4	0.11
Jun	0	4	0.07
Jul	-21	4	-0.04
Aug	5	5	0.31
Sep	-17	4	0.18
Oct	18	3	0.12
Nov	2	5	-0.29
Dec	22	6	-0.08





Effect of climate change on wheat yield on different soil types in central Hungary



The distribution of wheat yields in central Hungary for the present and predicted future climates

ACHIEVEMENTS, LIMITATIONS AND THE WAY FORWARD

Achievements of the project

The ACCESS project has brought together a group of researchers from across Europe who have very different experiences of diverse landscapes. Out of this group has emerged an integrated, fully functioning and well documented software product, based on sound scientific principles, that allows a user to model the soil-crop-climate system under conditions of climate change at the regional scale. This is the principal achievement of the project. However, the research has also been responsible for the development of robust approaches to estimate soil hydraulic properties from simple soil survey data using pedo-transfer functions, a framework for the manipulation of spatial environmental datasets and their use with simulation models, and improved understanding of complex soil water balance modelling including the influence of macropore flow. Considerable amounts of data have been collected for the development, validation and application of ACCESS, and in combination with the modelled output, this provides an extensive knowledge base within the study regions selected for the project.

Moreover, ACCESS represents a foundation of some considerable strength upon which future initiatives in land use modelling can be built. ACCESS should be considered as the first phase toward many exciting future initiatives.

Limitations of ACCESS-I

A number of assumptions have been made in the development of ACCESS-I to allow it to operate at the regional scale. These include:

- the monthly time step for physical and physiological processes does not allow accurate simulation of processes having a smaller time resolution;
- free drainage is assumed as the lower boundary condition, which is not realistic in the presence of groundwater or impermeable horizons;
- the soil matric potential below the rooting zone is assumed to be constant for the simulation period;
- the amount of water available for transpiration is supplied by two independent sources: soil available water and rainfall;
- leaf interception of rainfall, surface run-off, lateral water transfer, capillary rise and macropore flow are not considered.
- growth limiting factors other than light, temperature, or water are not considered, and the interactions between these factors are not taken into account;
- the model assumes that the influences of temperature and crop water stress on the water-use efficiency are independent.

Limitations of ACCESS-II

ACCESS-II offers a more detailed and mechanistic model than ACCESS-I, but does so at the expense of requiring many more parameters and a greater computational effort. However, it cannot consider all possible situations and these may be seen as limitations of the model.

- Validated parameters are available for only a limited number of major crops (maize, wheat, soya and sunflower), although users may import their own parameters to define other crops;
- Solution of the Richards' equation for soil water movement requires estimates of the van Genuchten parameters for the soil moisture characteristics. These must be provided externally either by pedotransfer functions or by measurement;
- A range of lower boundary conditions can be modelled, including both free drainage and the sealed condition, but the interaction with a moving regional ground water table cannot be modelled;
- Irrigation scheduling is treated simply, consisting of a 'trigger' deficit, an irrigation amount and a maximum total per year;
- There is no interaction between the soil and crop state and the cropping diary, which is defined *a priori*. Thus, sowing and harvest dates do not depend on either soil or crop conditions;
- As with ACCESS-I, lateral movement of water is not considered. Water reaching the surface in excess of infiltration capacity is assumed to be lost as surface runoff, but no attempt is made to model the fate of such water.
- As with ACCESS-I, the sites are considered to be flat and the solar radiation and rainfall inputs are corrected neither for slope nor aspect, nor are any lateral transfers considered.
- The crop growth model assumes complete plant nutrition. There is no attempt to identify the effects of nitrogen and carbon supply, nor the interactions with other limiting or deleterious soil conditions.

Despite these limitations, ACCESS can predict crop yields within 10% of known values over large regions.

The way forward

ACCESS provides a framework for the linkage of existing environmental datasets with state-of-the-art simulation modelling, for the assessment of regional environmental change impacts on agroecosystems. As such, ACCESS provides a scientifically-sound platform for the further development of integrated land use modelling within Europe.

Climate change research is largely driven by the need to provide policy makers with comprehensive information on the likely consequences of any impact. For agroecosystems, this implies the need to address the impact of climate change on all aspects of the primary production sector. It is becoming increasingly evident that the ability to provide policy-makers with useful information, requires an integrated modelling approach that considers the socio-economic as well as the physical environment. An integrated model could be used to define optimum land use and management strategies in response to the changing environment. It is equally important that these models operate at scales which are useful to planners and others on the ground.

The further developments necessary to achieve an integrated land use model, based on the ACCESS framework, are outlined below. These are divided according to developments directed at an understanding of the physical environment of plants and soils, and those aimed at the wider management and socio-economic aspects of land use systems.

Developments in modelling physical processes

Land use systems are complex, and still not fully understood, nor described. Hence, there is always a need to further develop and improve modelling procedures of physical environmental processes. This need is also influenced by the collection of ever increasing amounts of experimental data. In order for models to represent the true state of knowledge and understanding of fundamental processes, they must respond to new experimental findings. Future developments in the physical components of ACCESS need to consider:

- Modelling of physical processes, by;
 - (a) improving the mechanistic modelling approaches based on up-to-date experimental data,
 - (b) further validation of the model for a wider range of agroclimatic environments,
 - (c) undertaking a model sensitivity analysis, especially of the soil inputs e.g. organic carbon content, and
 - (d) using newly available GCM output data for regional impact assessments.
- The use of digital terrain modelling (DTM) within the ACCESS framework, in order to evaluate:

(a) regional scale surface water flows and drainage patterns, as a component of the soil water balance and land degradation assessments;

(b) energy inputs to a growing crop.

- Further development of spatialisation techniques at the regional scale. This needs to include some refinement of soil and climate data, estimation of the precision of model inputs and outputs and an estimation of the optimal sampling of model run sites.
- The development of mechanistic approaches to evaluate the impact of land degradation processes, e.g. soil erosion and salinisation, on crop production.

Developments in modelling land use systems

Further development of ACCESS needs to widen its ability to consider all components of European land use systems. This can be achieved by:

- Extension of the current range of land uses considered by ACCESS.
- Incorporation of modelling procedures within ACCESS to evaluate the socio-economics of agricultural production. This approach would allow predictions to be made of the actual distribution of land use based on a knowledge of prevailing soils, climates and socio-economic environments.
- incorporation of management aspects into the integrated modelling, e.g. tillage practices, sowing dates, fertiliser applications, including the influence of nitrogen inputs on crop yield, etc.

Use of the model to test adaptation strategies to climate change based on different land use and management options.

REFERENCES

- Armstrong, A.C., Matthews, A.M., Portwood, A.M., Addiscott, T.M., and Leeds-Harrison, P.B. (1994). Modelling the effects of climate change on the hydrology and water quality of structured soils. In: M.D.A. Rounsevell and P.J. Loveland (eds). *Soil Responses to Climate Change*. NATO ASI Series. **23**, 113-136, Springer-Verlag, Berlin and Heidelberg, Germany.
- Bornand M., Legros, J.P., and Rouzet, C. (1994). *Les banques régionales de données-sols. Exemple du Languedoc-Roussillon*. Etude et Gestion des Sols No 1, pp. 67-82, Montpellier, France.
- Cabelguenne, M., Jones, C.A., Marty, J.R., Dyke, P.T. and Williams, J.R. (1990). Calibration and validation of EPIC for crop rotations in southern France. *Agricultural Systems*, **33**, 153-171.
- Carter, T.R., Parry, M.L., Nishioka, S., and Harasawa, H. (eds). (1992). *Preliminary Guidelines for Assessing Impacts of Climate Change*. Report prepared for Working Group II of the Intergovernmental Panel on Climate Change, Environmental Change Unit, Oxford, U.K.
- Commission of the European Communities. (1991). *Soil and Groundwater Research Report 1: Soil Survey - a Basis for European Soil Protection* (ed. J.M. Hodgson). EUR 13340. Office for Official Publications of the European Communities, Luxembourg.
- Csillag, F. (1988). Hungarian Soil Information System (TIR): a thematic geographical information system for soil analysis and mapping. *Bulletin of the Hungarian National Commission for CO-DATA*, **5**, 1-13.
- De la Rosa, D. (1984). *Catalogo de suelos de Andalucía*. pp. 192 (+ maps). Junta de Andalucía, Sevilla, Spain.
- DoE. (1991). *The Potential Effects of Climate Change in the United Kingdom: First Report of the United Kingdom Climate Change Impacts Review Group*. HMSO, London, U.K.
- Hough, M.N. (1990). *Agrometeorological aspects of crops in the United Kingdom and Ireland: A review for sugar beet, oilseed rape, peas, wheat, barley, oats, potatoes, apples and pears*. EUR 13039 EN. 310 pp. Office for Official Publications of the European Communities, Luxembourg.
- IPCC. (1990). *Climate Change: The IPCC Scientific Assessment* (J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds). Report prepared by Working Group 1 of the Intergovernmental Panel on Climate Change. Cambridge University Press, U.K.
- Leenhardt, D. (1991). *Spatialisation du bilan hydrique*. Thèse: Doctorat; Spécialité: Science Agronomiques. Ecole Nationale Supérieure Agronomique, Montpellier, France.
- Mackney, D., Hodgson, J.M., Hollis, J.M. and Staines, S.J. (1983). *The 1:250000 scale National Soil Map for England and Wales*. Harpenden, U.K.
- Narcisco, G., Ragni, P., and Venturi, A. (1992). *Agrometeorological aspects of crops in Italy, Spain and Greece: A summary review for common and durum wheat, barley, maize, rice, sugar beet, sunflower, soya bean, rape, potato, tobacco, cotton, olive and grape crops*. EUR 14124 EN. 440pp. Office for Official Publications of the European Communities: Luxembourg.
- Parry, M. (1990). *Climate Change and World Agriculture*. Earthscan Publications Limited, London.
- Ragg, J.M., Jones, R.J.A., and Proctor, M.E. (1988). The refinement and representation of spatial data in an information system using statistical and DBMS procedures, and trend surface analysis. *Geologisches Jahrbuch*. **A104**, 295-308.
- Rambal, S., and Cornet, A. (1982). Simulation de l'utilisation de l'eau et de la production végétale d'une phytocoenose sahélienne du Sénégal. *Acta Oecologica (planta)*. **3(4)**: 381-397.
- Rounsevell, M.D.A. (1993). A review of soil workability models and their limitations in temperate regions. *Soil Use and Management*, **9**, 15-21.
- Rounsevell, M.D.A., and Jones, R.J.A. (1993). A soil and agroclimatic model for estimating machinery work-days: the basic model and climatic sensitivity. *Soil and Tillage Research*. **26**, 179-191.
- Rounsevell, M.D.A. & Brignall, A.P. (1994). The potential effects of climate change on autumn soil tillage opportunities in England and Wales. *Soil and Tillage Research*, **32**, 275-289.
- Rounsevell, M.D.A., Jones, R.J.A. & Brignall, A.P. (1994). Climate change effects on autumn soil tillage opportunities and crop potential in England and Wales. *Proceedings of the 13th International Soil Tillage Research Organisation Conference*, pp. 1175-1180, Aalborg, Denmark.
- Thomasson, A.J. and Jones, R.J.A. (1992). An empirical approach to crop modelling and the assessment of land productivity. *Agricultural Systems*, **37**, 351-367.
- Van Lanen H.A.J., Van Diepen, C.A., Reinds, G.J., de Koning, G.H.J., Bulens, J.D. and Bregt, A.K. (1992). Physical land evaluation methods and GIS to explore the crop growth potential and its effects within the European Communities. *Agricultural Systems*, **39**, 307-328.
- Viner, D., and Hulme, M. (1993). *Climate Change Scenarios for Impact Studies in the UK: General circulation models, scenario construction, methods and applications for impact assessment* Report for the Department of the Environment. Climatic Research Unit, University of East Anglia, Norwich, U.K.
- Williams, J.R., Renard, K.G., and Dyke, P.T. (1983). A new method for assessing the effect of erosion on productivity. *Journal of Soil and Water Conservation*, **38**, 381-393.

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