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INTEGRATED MODEL TO PREDICT EUROPEAN LAND USE: CLIMATE CHANGE AND LAND USE IN THE VENICE LAGOON WATERSHED

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Integrated Model to Predict European Land Use: Climate Change and Land Use in the Venice Lagoon Watershed

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1. Introduction

IMPEL (Integrated Model to Predict European Land use) is a research project financed by the European Commission, within the Fourth RTD Framework Programme.
The IMPEL project aims to integrate physical and socio-economic models to evaluate the impact of climate change on European land use systems at the regional scale. IMPEL is spatially-distributed, based on a multidisciplinary, modular approach, and comprises:

a) a climate module (Euroscen) to down-scale baseline climate data (gridded to 0.5° Lat/Long) and GCM climate change scenario datasets, using a stochastic weather generator;
b) a soil and crop module (EuroAccess) to evaluate the soil water balance and crop yields for a wide range of European crops at the scale of soil map units (Evans *et al*., submitted); two versions of the model are available at increasing level of complexity and data requirement: EuroAccess I and II;
c) a land degradation module (ImpelEro) to evaluate the impact of soil erosion and changes in soil quality on crop productivity at the scale of soil map units (de la Rosa *et al*., submitted);
d) a socio-economic module (Sfarmod) to evaluate optimal land use allocation and management requirements at the scale of individual (generic) farms.

The Italian group of the Impel Project has two main tasks:

a) to contribute to the development of the socio-economic module, in particular as concerns the modelling of risk perception by farmers in farm management;
b) the experimental application of the integrated model being developed by the research project to the territory of the Venice Lagoon Watershed (VLW). For this purpose a general framework of the activities has been drawn up, as shown in figure 1.

This paper presents a brief report on simulations, carried out at a farm level, of climate-change scenarios as proposed by the IMPEL project.
Simulations were carried out by integrating EuroAccess software with simulation farm models. The tests were done with linear and non-linear programming farm model.

2. Methods

2.1 Building of environmental data bases

The GIS utilised as a basis for the research done on the Venice Lagoon Watershed derives from previous research projects on agricultural pollution at a territorial level. Consequently, the available data base at the start of the project already contained a large amount of information on the environment and agriculture of the area, but had anyway to be integrated to update the information and fill in specific blanks with respect to the informational requirements of the elaboration and simulation instruments developed within the ambits of the Impel Project.
Given the subjects tackled in this Project, the attempts to improve the data bases have mainly been concentrated on the soil and meteorological data bases.
An ongoing effort that involves the entire information base is that of supplying it with adequate documentation in the form of metadata, to render the data as far as possible utilisable by others as well as the current working group.
The database of the soil profiles has been created *ex novo* within the ambits of the Impel project, as previously only a representative set of profiles was available referring to the map of agricultural soils of the area. The indications proposed by the Spanish partners[2] have been followed and based on the standard FAO formats, to allow the adoption of the approaches proposed for the identification of the representative profiles on a statistical basis (see following section). The software used for constructing the data bases is an application of Microsoft Access.
The meteorological data base was built on the basis of a preceding data bank containing monthly rainfall and temperature values for a network of stations that covers the entire Veneto plain. To satisfy the requirements of the models adopted, the temperatures data base has been completely rebuilt, substituting average monthly temperatures with pairs of values formed by the average of the maximum and minimum temperatures. All the data from the above-mentioned weather stations in the VLW have been updated and some new stations have been included. The software adopted for building the databases is Microsoft Excel.

2.2. Fuzzy clustering of site records

In two cases we had to classify geographical point observations for clustering and selecting representative sites:

- for weather stations
- for soil profiles.

[2] MicroLEIS (Microcomputer-based Land Datatransfer & Agro-ecological Land Evaluation System), Ed. by Diego de la Rosa, CSIC-IRNAS, Sevilla, Spain, 1996.

The approach adopted to classify punctual data derives from that proposed by the French partners[3] and is based on the theory of fuzzy sets. The tool adopted for fuzzy clustering was the software Fuznlm[4], based on the fuzzy c-means clustering algorithm partly based on the original version by Bezdek *et al.*[5].
Fuzzy logic is a suitable method for the classification of sets of multivariate data characterised by a high level of imprecision, like data describing soil profiles. Within a binary system a set is defined in an unequivocal way; each element either does or does not belong to that set. A logical system like the fuzzy one, instead, is far more flexible as it allows the sets to be defined in a less rigid and precise way. In this case the attribution of an element to a set, or cluster, is not always univocal; an element may in fact belong to more than one set contemporarily. The different measure with which an element becomes part of a set is expressed in terms of "grade of belonging of the element to that set".
Fuzzy c-means (FCM) is a technique of clustering that derives from the more elementary hard c-means, that provided for a binary type grade of belonging. The step forward is in the reduction of distortion in the results, caused in the hard c-means by the forced inclusion of the intermediate elements in a single class. In fact FCM allows intermediate elements to be attributed to more than one cluster according to the grade of belonging. Moreover the contribution of external elements (extragrades), being equally split between the different clusters, produces less disturbance to the result of the elaboration.
The programs that operate this type of multivariate grouping require the number of clusters to be defined in advance. The elaboration is done according to an iterative procedure that starts with the generation of a series of random values of belonging.

2.3. Selection of representative sites

Once the fuzzy clusters of soil profiles and weather stations were obtained it was necessary to define the set of representative values to be adopted in the simulations. Instead of adopting the centroids of the clusters as calculated by the clustering routine it was preferred to select an existing representative site for each cluster by comparing the values of each individual (soil profile or weather station) with the centroids.
This approach is similar to a comparison of a given set of values with various possible sets of estimated ones, such as when comparing simulated versus observed values. In this case centroids can be assimilated to observed values while the values of every site can be the simulated ones.
Many statistical indices have been proposed to evaluate the fitting of a model with a series of observed data; in general these are dispersion indices based on elaborations of the differences between pairs of values, one deriving from field observation and the other from the model simulation. In this study the index called Model Efficiency (EF) was used. The EF measures the scatter of the simulated data with respect to the observed, with optimal values equal to 1:

$$EF = \frac{\left[\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{n}\left(O_i - P_i\right)^2\right]}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}$$

where: P_i = Predicted value;
O_i = Observed value;
$\overline{O}$ = Mean of observed values;
n = Number of pair.

2.4. Crop modelling with EuroAccess

Some months of work have been needed to begin to use the model profitably, mainly because of the incompleteness of some parts of the manual and of the presence of errors in both the manual and software. Moreover, as often happens in similar researches, tools evolved throughout the project. For these reasons, the results presented in this paper have to be considered temporary; final results will be available by early autumn 1998, when a new modelling session is scheduled with the final version of the integrated model.
For running the first trials the demo files were used, and the behaviour and sensitivity of the model were tested. The next step was that of setting up new simulations, using weather and soil data referring to the area of the Venice Lagoon Watershed. Initially only the EuroACCESS I model was used so as not to over-complicate the work. The necessary data were taken from previous studies carried out in the area, integrated with the specific information necessary for implementing the model in question.
Once the preliminary trials with EuroACCESS I were completed, work began with EuroACCESS II. The close analogy between the two models and the experience gained made this second phase relatively simple. The study went ahead

[3] P. Lagacherie and J.P. Legros. Selection of representative sites and extrapolation of AccessII outputs by fuzzy clustering. Development note presented at second CEE - IMPEL Project meeting, 18-19/10/1996, Mitilini, Greece.
[4] P. P.F.M Van Gaans and S.P.Vriend (1995), FUZNLM freeware software, Utrecht University, The Netherlands.
[5] J.C. Bezdek, R.Erlich and W. Full (1984), Computer and Geosciences, (10) 191-203.

according to what had been done previously, i.e. modifying the existing data sets and then constructing a new one, and comparing the effects of changes. New difficulties presented themselves in the compilation of the input files because of the larger number and greater specificity of the required data.

The final setting of model simulations for both versions of EuroAccess was as follows:
meteorological data ⇒ 3 representative weather stations (Mestre, Castelfranco, Cona)
soil data ⇒ 6 representative soil profiles (in different locations within the VLW)
crops ⇒ 4 two-year monocultures (maize, wheat, sunflower, soybean) and 12 rotations of two crops each
soil-weather-crop combinations ⇒ 288.

The results presented herein derive from two complete sets of simulations referring to the present climatic conditions and those proposed by the global change model (GCM) of the Hadley Centre (UK) and chosen by the Impel Project as a reference estimate of possible climate change with reference to the year 2050 (HadCM2), it's selection being justified by the high confidence level of the HadCM2 GCM.. The HadCM2 GCM adopted by IMPEL is also defined by mean sensitivity and emission (IS92a), as defined by Euroscen[6] the tool for identifying possible future climate perturbations.

2.5. Geographical management of environmental information

The environment for applying the geographical part of the research, in other words for the distributed modelling and spatialisation of the information was an already available GIS, mainly based on the software Idrisi for Windows. Suitable programs were written to interface the modelling components and the database with the geographical data. Two alternative approaches were developed for the spatially distributed integrated model:

- multilocal
- typical site

In the first case a map was drawn up containing the information for the building of the region file of EuroAccess ("region map"), made by intersecting the map layer of soil and climatic units. A procedure was then written for converting it directly into a region file for running the model on all the grid nodes (in this case, with 1 km sides).
In the second case all possible combinations of soil and climate were identified and the model was run only in these situations, leaving the geographical location out of consideration. A procedure was then set up that extracts the necessary pieces of information from the model outputs and creates a database to connect with the "region map" (describing all the observed soil and climate combinations) for representing the results in a geo-referenced way.

2.6. Integration of environmental results with the socio-economic approach

From what is reported on the flow chart in figure 1, it appears evident that the simulations with EuroAccess are useful for supplying the economic module with information on crop yields and the workability of the soils. In the light of the developments of the eco-physiological modelling component it is not currently possible to fully rely on model outputs. Consequently, until now attempts have been made to prepare alternative sources of information to satisfy the farm model inputs, planning to entirely substitute them as reliable results of the simulations become available.
It can therefore be stated that the architecture of the entire system has now been built and tested, but with basic information and tools still being finalised.

2.7. Socio-economic farm modelling

The farm models have been developed using two different approaches:

- mixed integer programming (Sfarmod);
- non linear programming (RiNO).

2.7.1. Sfarmod

Sfarmod, developed by Silsoe Research Institute[7], is based on a mixed integer linear programming (MIP) model that evaluates optimum agricultural land use (at the farm scale) for a range of European environments, including the need for machinery and farm labour and the timing of machine operations. The model estimates land use decisions by considering non-significantly different near-optimal solutions and the cost of change: increasing the area of an existing crop will have no penalty, but introducing a new crop would have a start-up penalty.
Sfarmod requires a number of inputs, including crop yield and its variability, and soil workability, which are derived from ACCESS. A summary of the input variables is given in Table 1. Sfarmod also accounts for farm sizes, existing farm systems, and other demographic factors to enable predictions to be made of the likely rate of change of land use,

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[6] CRU-SES (1977), Euroscen, University of East Anglia.
[7] Audsley, E. (1993). Labour, machinery and cropping planning. In: Farm planning. Labour and labour conditions. Computers in agricultural management (edited by Annevelink, E., Oving, R.K. and Vos, H.W). Proceedings XXV CIOSTACIGR V Congress Wageningen, Netherlands. Wageningen Pers, pp. 83-88.

based on the difference in profit between existing and proposed systems. The variability in yield and prices are used to determine a profit risk profile. The module can be used to assess the capacity of different agricultural systems to adapt to climate change and, more importantly, identify which systems will be slow or unable to adapt.

Table 1. Summary of input variables for Sfarmod

Decisional variable	Parameters
Crop	Gross margin: yield (primary and secondary), prices, seed rate, fertiliser rates, sprays and costs Husbandry operations: list of operations and their feasible timing *e.g.* plough, cultivate, drill, spray, fertilise, harvest, bale Timeliness penalties: extra cost or loss of yield of doing operation at other than the optimal timing Rotational penalties: reduction in yield from one crop following another, including impossible
Operations	Workrate as a function of size of machinery and amount of *e.g.* yield or fertiliser or soil type Workable hours as a function of soil type, rainfall and time of the year Machinery needed (*i.e.* size, power)
Machinery and labour	Cost: capital, repairs, fuel, resale value Replacement interval

2.7.1. Risk and Nitrogen Optimiser (RiNO)

RiNO is a non-linear programming model on a farm level. The model, even though it only approaches the decisional process of the farmer and the productive techniques, has the merit of treating certain important questions of business management in quite a sophisticated way, such as the aversion to risk on the part of the farmer and the optimal use of fertiliser.

Aversion to risk has been incorporated into the decisional process through the "expected gain confidence limit" approach, proposed by Baumol[8] by means of which the farmer tends to optimise an income with a certain probability of achievement.

In brief:

$$\textit{Maximise } L = E - \phi \cdot \sigma$$

where: E = expected average income $\Sigma_i(X_i p_i)$;

ϕ = parameter for aversion to risk;

σ = standard income deviation[9] given by $[\Sigma_i \Sigma_h X_i X_h \sigma_{ih}]^{1/2}$;

with: X_i = area allotted to umpteenth crop;

p_i = average income of the umpteenth crop;

σ_{ih} = matrix for the variance/co-variance of the income of crops.

The aversion to risk factor (ϕ) has been fixed at 1 which corresponds to the probability of realising a profit of about 66%. The literature[10] concurs with this value which, besides, makes it possible to obtain from the model a crop distribution very much like that which is presently being practised by farmers in the Venice Lagoon Watershed. Besides, a corrective factor of the matrix of the variance/co-variance was introduced into the model in order to adjust the estimated variability to the calculated optimal yield according to the production functions used (see Figure 2). Indeed, standard deviation of farm profit depends on the variance/co-variance of income from the various crops over a period of time and is the summation of the variances and co-variances of all the crops, weighted by the respective agricultural area. Since the variance/co-variance matrix was calculated on current average yields, each addend was multiplied by a corrective factor given by the relationship between estimated yield of the model and actual yield. This adjustment enables one, if only approximately, to adapt variability to optimum yield. Otherwise, attributing the same variability values to points on the curve with different yields would not provide a realistic result: indeed, more limited

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[8] Baumol, W.J. (1963). An expected gain-confidence limit criterion for portfolio selection. Management Science, 10. pagg. 174-182.

[9] Markowitz H.M. (1959) Portfolio selection: efficient diversification of investments. Wiley, New York.

[10] Hazell , P.B.R., Norton, R.D. (1986) Mathematical programming for economic analysis in agriculture. Macmillan Publishing Company, New York. pag. 93.

intervals of variability correspond to inferior yields and vice versa. In short, it was assumed that variability in profits from different crops is proportional to expected average profit.
The optimisation of fertiliser use, on the other hand, was realised by modelling crop production functions, such as exponential functions, which allow one to determine the exact dose of fertiliser which is most advantageous with respect to the objective function previously illustrated.
The general formula of the functions used is the following [11]:

$$\mathrm{Re} = Rm \cdot \frac{\left[1 - 10^{-Ca\cdot(Nt+Nc)}\right] \cdot 10^{-Cd\cdot(Nt+Nc)^2}}{1 + 10^{\left[1 - Ca\cdot(Nt+Nc)\right]}}$$

Where: Re = yield (t ha^{-1});
Rm = maximum yield (t ha^{-1});
Ca = activation coefficient;
Cd = depression coefficient;
Nt = nitrogen carried by the soil (kg ha^{-1});
Nc = nitrogen introduced with fertilisation (kg ha^{-1}).

The model was designed to give the farmer's net income, after taxes. To this end, certain accounting equations to calculate general farming expenses and certain farmland fees were included in the function that expresses said income. The programming model was developed by means of the CONOPT[12] procedure, included in GAMS[13] software.

2.7. Farm typology

The farm typology used for the simulations was chosen on the basis of the results of the socio-economic study expressly carried out on the VLW farmland[14].
One of the most common farm typology in the aforementioned area, according to the study, is the small family farm, engaged in the cultivation of arable crops, which relies on contractors to help with certain farming operations. Having said as much, and keeping real-farm data in mind, the following outline was drawn up.
The farmland is at an average altitude of 15-20 m a.s.l. There is an average of 10 ha of utilisable farmland (UAF), divided in two or three tracts of land. The farmer owns the land and works it himself also providing the manual labour necessary. The farmland is irrigable with a sprinkling system. Irrigation is usually limited to the summer months (July). Production focuses on the cultivation of seeds, especially maize, soybean, wheat and sugarbeet. Cultivation is mainly carried out by the owner, with recourse to contractors to sow, weed and harvest.[15] The fleet of farm machinery used for the remaining farming operations, on average, includes a 50-70 Kw tractor, a plough, a weeder, a harrow, a mechanical hoe, a tow and other tools of less consequence[16].

2.8. Farm simulations

Three basic series of simulations were carried out. The first simulation was based on the present situation from both a climatic and political-economic point of view. This simulation became the point of reference for the other scenarios. The present situation was simulated by adopting the prices of the products registered on the Padua market during harvest time over the last two years. The data relating to compensation given by the European Union to farmers for the cultivation of maize, wheat and oil-producing seeds are those estimated for the province of Venice. The average yield per crop was found through farm surveys.

[11] Giardini L. (1989) Aspetti agronomici e fisiologici della concimazione azotata in relazione con l'ambiente. Rivista di Agronomia, 23, 1, pagg. 3-22.
[12] CONOPT 386/486 DOS version 2.042D-001-031 Copyright (C) ARKI Consulting and Development A/S Bagsvaerdvej 246 A DK-2880 Bagsvaerd, Denmark.
[13] Brooke A., Kendrick D., Meeraus A. (1988) GAMS A user's guide. The Scientific Press, Redwood City, CA.
[14] P. Rosato, F. Azzolin (1997) Agriculture in the Venice Lagoon Watershed. CEE-IMPEL Report, Dipartimento Territorio e Sistemi Agroforestali, Università di Padova.
[15] Dependence on contractors for these important farming jobs creates certain problems in timing which, in turn, means somewhat less yield and more variables than in larger farms which are able to do all the work themselves and which have greater contractual power with regard to contractors.
[16] For a more detailed description of the structural characteristics of a simulated farm see L. Fantinato, C. Giupponi, P. Rosato (1997) The Italian Test Area of the Impel Project. CEE-IMPEL Report, Dipartimento Territorio e Sistemi Agroforestali, Università di Padova.

The simulations of the future situation were carried out on the basis of the forecasts on future scenarios, on prices and on farming policies[17] as well as the expected alterations brought about by climate changes, estimated on the basis of EuroACCESS data.
In particular, the expected scenarios for the year 2050 were drawn up on the basis of the following hypothesis. As regards the market for produce, it was hypothesised that the entire internal protection system will be dismantled in favour of joining world markets. These, encouraged by the growing demand for foodstuffs generated by an increase in population, and with the supply unable to fully satisfy demand, will establish substantially higher prices. The rise in prices will, above all, affect wheat and maize; the rise in price in sugarbeet and oil-producing seeds will be more contained as they are more liable to competition as produce typical of developing countries. Finally, the reference of internal European Union prices to world markets foresees, for the prices of the main farm products, a general increase in price fluctuation. Such an increase seems to affect cereals more than other farming produce since cereal production is limited to temperate zones and is more sensitive to climate changes.
Keeping this in mind, two price adjustments were hypothesised.

A. a 10% increase in the price of farm produce (15% for cereals) and 50% for nitrate fertiliser;
B. a 30% increase in the price of farm produce (50% for cereals) and 150% for nitrate fertiliser;

The big estimated increase in the cost of nitrate fertiliser is linked to the greater attention given to environmental pollution problems; the release of nitrates by cultivated soil into surface and deep waters being an important element.
In the simulations of the scenario of the year 2050, no compensation was calculated since it is felt that any economic support given to the farmer will tend, more and more, to be given directly through services offered by the agricultural sector rather than for produce.
As far as set-aside is concerned, forecasts were based solely on aspects regarding the future development of national and international markets, excluding any considerations concerning the environment. Accordingly, the abolition of set-aside was hypothesised, due to an increase in demand and to the consequent reduction of stockpiling with market globalisation.

Table 2. Price scenarios

	Scenarios						
	1995-2000			2050			
				A		B	
	Ecu ton^{-1}	CV %	Ecu ha^{-1}*	Ecu ton^{-1}	CV %	Ecu ton^{-1}	CV %
Maize	120	8	490	138	12	180	15
Wheat	135	12	308	155	20	202	18
Soybean	190	15	720**	209	20	247	22
Sugarbeet	50	2	-	55	5	65	8
Set-aside	-	-	578	-	-	-	-
Nitrogen c/kg	54	-	-	81	-	135	-

* Direct payments (Reg. UE 1765/92); ** Corrected with overproduction penalties.

Table 3. Yield scenarios

	Scenarios			
	1995-2000		2050	
Crop	Yield (t ha^{-1})	Yield VC %	Yield (t ha^{-1})	Yield VC %
Maize	11.0	10.0	10.2	15.0
Wheat	6.5	10.0	6.8	7.0
Soybean	4.5	5.0	4.2	7.0
Sugarbeet	55.0	12.0	52.0	18.0

VC: Variation coefficient

[17] P. Rosato (1997) Some Future Scenarios on Prices and EU Agricultural Policy. CEE-IMPEL Report, Dipartimento Territorio e Sistemi Agroforestali, Università di Padova.

The parameters adopted to set up production functions (see also fig. ???) are the following:

Table 4. 1995-2000 Production functions

Crop	Rm (t ha^{-1})	Nt (kg ha^{-1})	Ca	Cd
Maize	13.0	50.0	5.5.E-03	1.0.E-07
Wheat	7.5	50.0	1.1.E-02	8.0.E-08
Soybean	4.7	100.0	1.5.E-02	1.0.E-06
Sugarbeet	62.0	10.0	2.0.E-02	1.0.E-07

Table 5. 2050 Production functions

Crop	Rm (t ha^{-1})	Nt (kg ha^{-1})	Ca	Cd
Maize	12.0	50.0	5.5.E-03	1.0.E-07
Wheat	8.0	50.0	1.1.E-02	8.0.E-08
Soybean	4.4	100.0	1.5.E-02	1.0.E-06
Sugarbeet	58.0	10.0	2.0.E-02	1.0.E-07

3. Experimental implementation of modelling tools in the Venice Lagoon Watershed

3.1. Building of environmental databases

The soils database now contains 111 profiles gathered in the study area. These specially gathered data have been added to already available information, in particular to the agricultural land map (ESAV, 1987).
The meteorological database consists of 55 files with monthly records of rainfall and minimum and maximum temperature. Also in this case a map of the weather zones was already available.

3.2. Fuzzy clustering of site records

The program FUZNLM was used in this task to divide the multivariate databases of the soil and climate into groups of similar profiles and stations, respectively. While for the weather data the distribution of the network of stations can be considered more than sufficient, the same cannot be said for the soil. For this reason, applying clustering to the soil profiles was aimed at testing the methodology and contributing towards improving what was already available (a map of agricultural soils in 6 classes with the same number of representative profiles identified by experts). As previously mentioned, 6 clusters were adopted for soils, to be consistent with the existing map of agricultural soils that identifies 6 main types in the area, while for the weather it was decided to divide the stations into 3 groups, given the lower spatial variability of these variables, also in this case in analogy with previous works on the area.
The results for the soil profiles gave the following division of the 76 complete samples of all the variables to be analysed among the 6 clusters. In the light of the values of the centroids for the variables sand, silt, clay and organic C, a definition was also attributed:
CLUSTER 1 – 13 elements; loamy-clay-organic soils
CLUSTER 2 – 12 elements loamy-sandy soils
CLUSTER 3 – 19 elements; sandy-silt soils
CLUSTER 4 – 9 elements; loamy-sandy clay soils
CLUSTER 5 – 12 elements; loamy-clay soils
CLUSTER 6 – 11 elements; loamy soils
EXTRAGRADES – 0 elements.
The classification thus obtained, representing the different soil types in the area of the Venice Lagoon Watershed, was compared with that done for drawing up the *Agricultural Soils Map of Veneto* (ESAV, 1987). The types obtained with the application in the FUZNLM program appeared to be sufficiently close to those represented in this map; the result than therefore be considered adequate for at least partly improving the previously available information.
The fuzzy c-means approach for the climate database produced three clusters for three areas with relatively dry-and-warm, intermediate and relatively wet-and-cool climate, including 15, 23 and 17 weather stations respectively.

3.3. Selection of representative sites

A further step was to identify, among the soils and weather stations belonging to the different groups, those which most resemble the characteristics of the respective centroid and that, as well as the centroid, can be considered “representative” of that determined cluster. This was done in order to have available 6 representative soils and 3 weather stations actually existing and not derived from mathematical calculations, as the centroids of the clusters are. To verify which elements would present the greatest similarity to the centroid a statistical index devised for the evaluation of the results of the above-described simulations was used.

3.4. Crop modelling with EuroAccess

Two complete sets of simulations were carried out for the present and hypothetical future climate.
Figure 3 presents the results in terms of yield (t of dry matter) of EuroAccess II in the version available at the beginning of summer 1998 for the present climatic conditions. Maize and soybean are grown with irrigation.
Orders of magnitude of results in terms of simulated average yields are very much comparable with available information from statistical sources.
The model estimates both water stresses due to water shortage during summer and water excess during winter and autumn. For this reason it tends to overestimate yield on well drained soils, especially for irrigated crops.
Problems are still present for the simulation of sugarbeet which shows excessive sensitivity to climatic variations.

3.5. Geographical management of environmental information

The current state of the refinement of the modelling tools and their implementation does not yet provide results that can be discussed. It has, however, been possible to test the entire procedure as far as obtaining final maps, two examples of which are presented in figures 4 and 5.

3.6. Results of farm simulations

The simulations carried out with the data on the current economic-environmental context provided fairly satisfactory results. Both models (RiNO and Sfarmod) propose programmed farming based on sugarbeet (25% of the farmland), maize (25-40%) and soybean (30-45%) (Tables 6 e 7). The distribution proposed here is mirrored by the choices made on average on the farms of the watershed[18]. The average profit with this crop distribution is about Ecu 9200 with Rino and 9100 with Sfarmod. Worthy of note is the fact that Sfarmod underestimates, with regard to RiNO, the advantage of growing maize as opposed to soybean. This may be due to the fact that Sfarmod also includes in its economic calculations the beneficial effects of leguminous crops on rotations. Another possible explanation may lie in the inclusion of risk aversion when programming. The “Random” distribution used in this first phase by Sfarmod may provide an incorrect assessment of the co-variance and consequently distorted solutions[19].
The first climate-change scenario (2050-A) forecasts the arrival of wheat in the cropping plan. There are essentially two reasons for this. The first is that the changed environmental conditions, with more intense spring rainfalls and drier summers, favour this crop more than the others. The second is the reduced level of competitiveness of maize and even more so, of soybean, a crop that, according to what was hypothesised, will not benefit from the present high subsidies in the future.
According to the model forecasts, the average profit to be realised in this context is Ecu 5700 with RiNO and Ecu 5400 with Sfarmod.
This demonstrates that subsidies are an important component of the farmers’ income. In fact, despite the price increase of the product, the absence of subsidies causes a reduction in earnings of around 38%.
Through RiNO, the effect of the introduction of a maximum limit of nitrogen to be distributed per hectare, per year, was also assessed. Taking 200 kg ha^{-1} as the maximum limit and with price levels fixed, there is a further slight reduction in the land growing maize in favour of that growing wheat. This can be explained by the lowered maize yields caused by an insufficient supply of nitrogen, which determines lower profitability.
It is worth noting that this trend may cause greater environmental problems than those which were to be kept in check with the introduction of the limit. Indeed, some studies seem to show,[20] that the substitution of maize with wheat, although responsible for a substantial reduction in the supplies of nitrogen in the soil, causes an increase in release, as fertilisation takes place in a very rainy period (end of winter) with elevated phenomena of flooding and flowing of surface water. These phenomena are destined to increase with the anticipated climate changes.
A greater price increase (Scenario 2050-B) involves a slight modification in crop distribution. Sfarmod proposes the same crop distribution while RiNO predicts the reduction in land surface area growing soybean in favour of wheat. This

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[18] RiNO forecasts the following optimal yields: 11 ton. ha^{-1} for maize grain, 4.4 ton. ha^{-1} for soybean and 61 ton. ha^{-1} for sugarbeet roots.

[19] In the simulations with Sfarmod, a coefficient of 0.3 was attributed to the risk factor given by total absolute deviation (TAD) proposed by Hazell (cited above) in the Motad approach.

[20] C. Giupponi, P. Rosato (1995) Simulating Impacts of Agricultural Policy on Nitrogen Losses from a Watershed in Northern Italy. Environment International, 21, 5, pp. 577-582.

can be justified by the increasing differences between the prices of the two crops[21]. The profit that can be achieved under these conditions is around Ecu 8500 according to RiNO and 8100 using Sfarmod.

Table 6. Land use (RiNO)

Land Use (%)	Scenarios		
	1995-2000	2050	
		A	B
Maize	40	30	30
Wheat	-	30	35
Soybean	30	15	10
Sugarbeet	25	25	25
Set-aside	05	-	-
Profit (Ecu ha^{-1})	920	570	850

Table 7. Land use (Sfarmod)

Land Use (%)	Scenarios		
	1995-2000	2050	
		A	B
Maize	25	22	22
Wheat	-	32	32
Soybean	45	22	22
Sugarbeet	25	25	25
Set-aside	05	-	-
Profit (Ecu ha^{-1})	910	540	810

4. Concluding Remarks

In general the simulations appear to demonstrate, even with the application limits and the preliminary simulation models, that the integrated approach works, providing results that are reasonable and coherent with the assumed hypotheses. The results must, however, be taken as purely indicative as they were obtained with models that incorporate only to a limited extent the information and algorithms necessary to fully evaluate the effects of climate changes. Further efforts should be oriented towards a better understanding of the sensitivity of the soil-crop system to climatic changes, to better identify the major forcing variables, thus focusing the efforts more on data gathering and implementation. In general it is possible to identify some major sources of implementation problems for future application: a) availability of long-term weather records and in particular daily measures of solar radiation; b) availability of spatially detailed soil information and in particular data on hydrological parameters; c) the possibility of designing "reasonable scenarios" for future a macro-economic parameter.

In any case, it seems reasonable to affirm that suggested climate changes, together with the political and economic trends underway, will produce a drop in the farmer's income. This drop, however, is only marginally due to the climate since it is linked to a decrease in the commitment of European Union to support agricultural production because of the probable lack of attention given to the closely connected social question and/or modified social policy.

The climate seems, on the other hand, to have a quite clear-cut effect on land use. The change in the distribution of rainfall seems to favour autumn-winter crops (wheat) at the expense of summer crops (soybean and maize).

As regards the competitiveness of maize as opposed to soybean, both hypothesised variation factors (climate and prices) appear to play their part. On the one hand, the climate scenario seems to favour soybean since it needs less water, on the other, the hypothesised fluctuations in prices increase the income differential in favour of maize. The synthesis of these opposing tendencies appears to favour maize in as far as, in both models, the reduction of the area cultivated with maize (25% RiNO, 12% Sfarmod) is always inferior to that cultivated with soybean (50-60% RiNO, 50% Sfarmod).

[21] In this scenario, using RiNO, a further reduction in the maximum quantities of nitrogen per hectare (150 kg ha^{-1}) was simulated. This reduction does not cause changes in cultivation, only a decrease in the amount of nitrogen spread on summer cereals.

Figure 1: General framework of the spatially distributed Integrated Model to Predict Land Use in the Watershed of the Lagoon of Venice

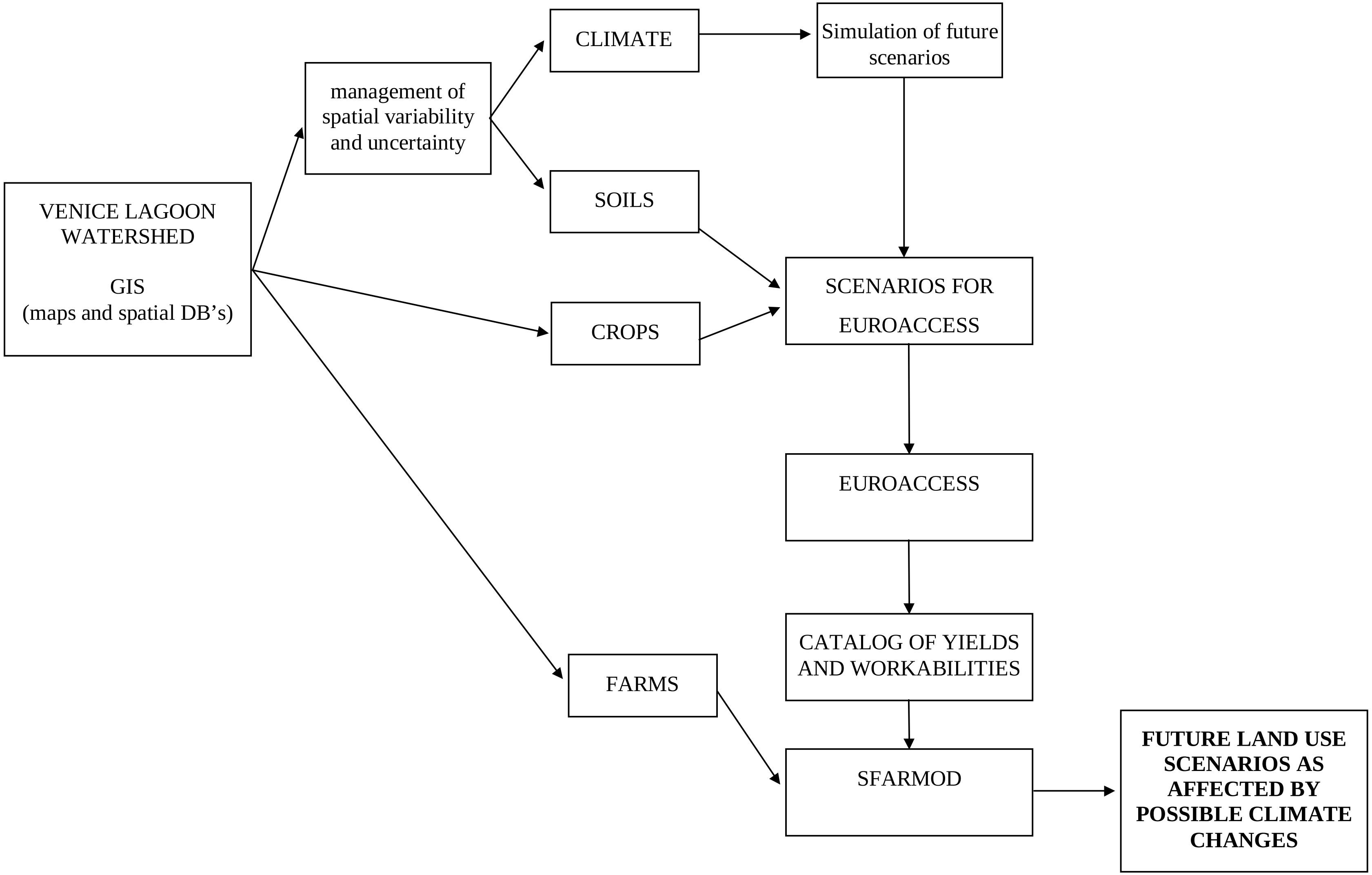

Figure 2. Production functions included in the RiNO model.

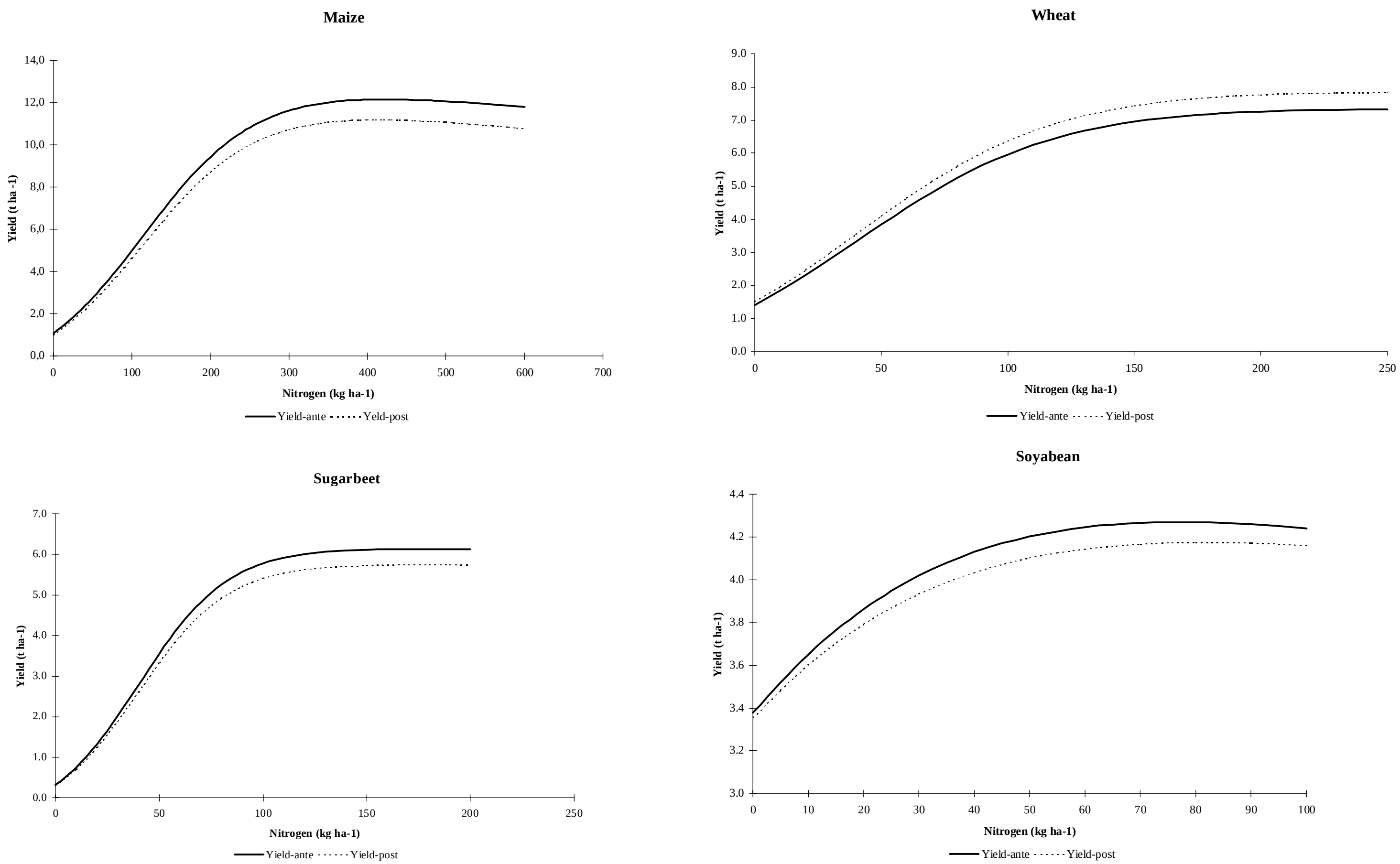

Figure 3: Output of the EuroAccess II model: crop yields ($t_{dry\ matter}$ ha^{-1} $year^{-1}$).

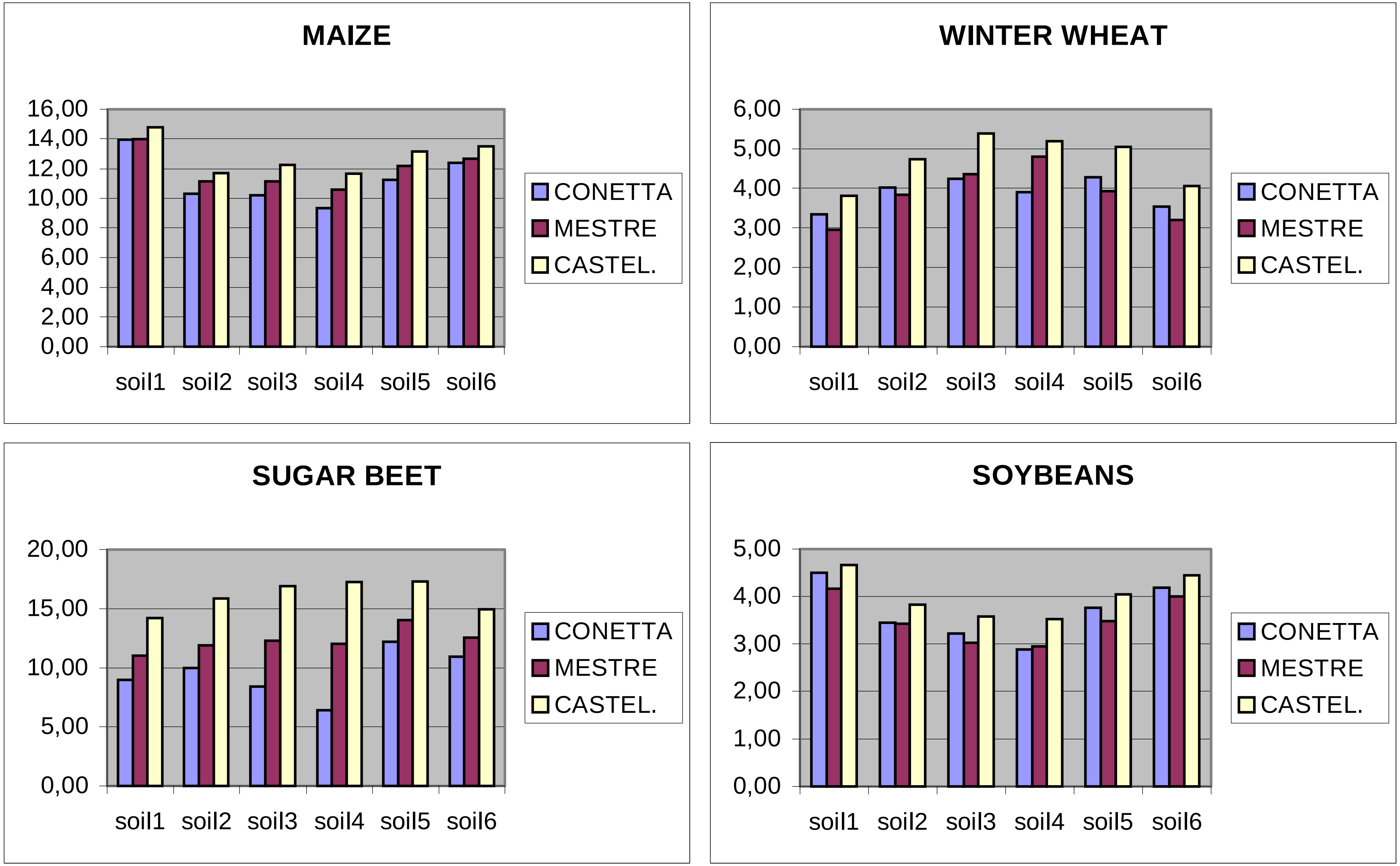

Figure 4: Maps of maize yields with actual climate (a) and with climate change scenario HadCM2 (b)(increasing yields from brown to pale green).

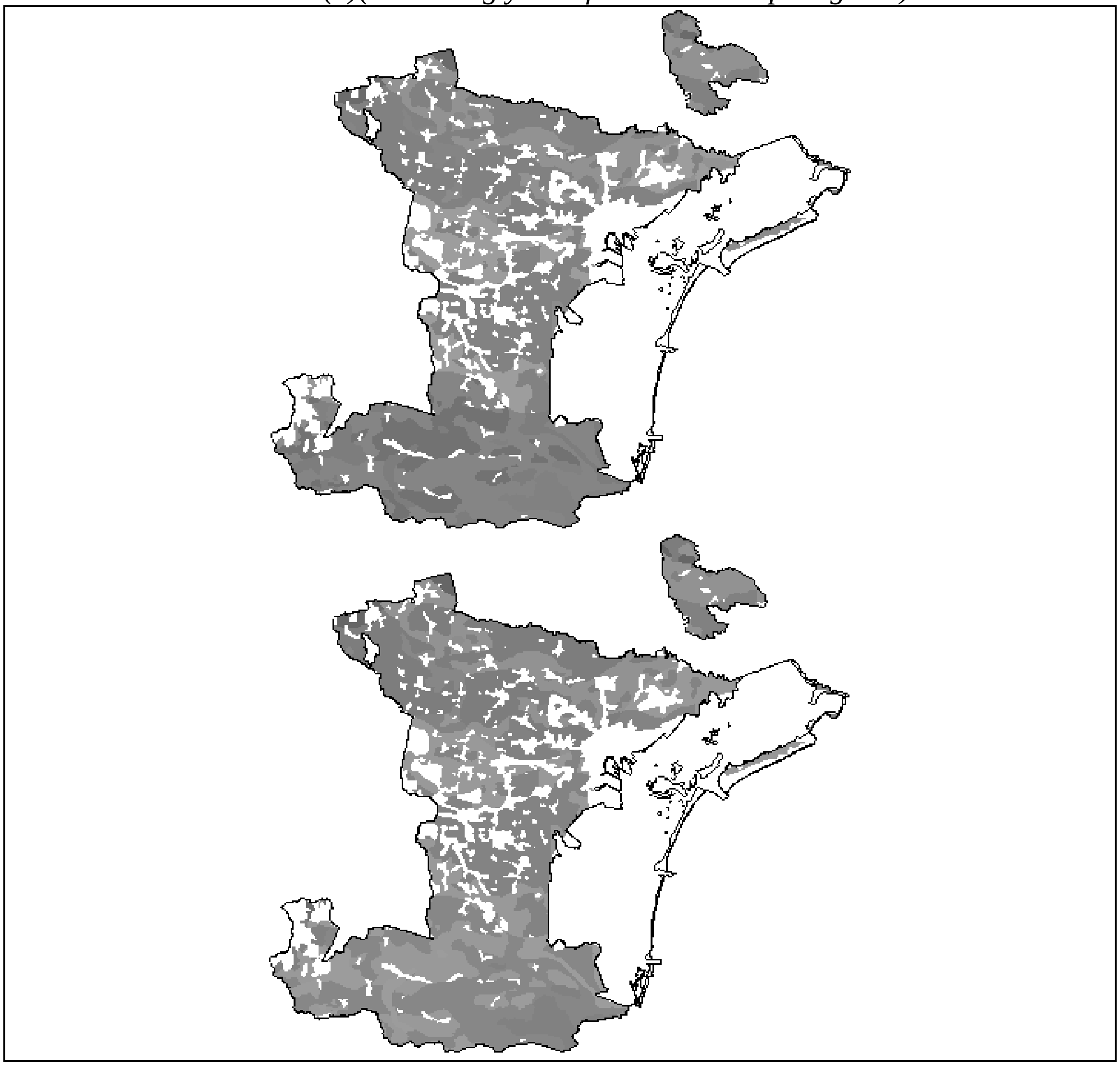

Figure 5: Map 4a minus 4b (differences <0 to >0 from red to green).