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[1]What can scenario modelling tell us about future European scale agricultural land use, and what not?

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Abstract

Given scenarios describing future climates and socio-techno-economics, this study estimates the consequences for agricultural land use, combining models of crop growth and farm decision making to predict profitability over the whole of Europe, driven solely by soil and climate at each location. Each location is then classified by its profitability as intensive or extensive agriculture or not suitable for agriculture.

The main effects of both climate and socio-economics were in the agriculturally marginal areas of Europe. The results showed the effect of different climates is relatively small, whereas there are large variations when economic scenarios are included. Only Finland's agricultural area significantly responds to climate by increasing at the expense of forests in several scenarios. Several locations show more difference due to climate model (PCM vs HADCM3) than emission scenario, because of large differences in predicted precipitation, notably the Ardennes switching to arable in HADCM3.

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Scenario modelling has identified several such regions where there is a need to be watchful, but few where all of the scenario results agree, suggesting great uncertainty in future projections. Thus it has not been able to predict any futures, though all results agree that in central Europe, changes are likely to be relatively small.

Keywords
climate change, agricultural land use, scenarios, crop model, farm decision model

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1. Introduction

Agriculture is the primary land use across Europe, hence future European land use is largely a function of the activity chosen for this sector. The main driving factor that determines how agricultural land is managed is profitability (Rounsevell, et al., 2003). A low profit can lead to land abandonment. Conversely a large profit can lead to forest and land that is otherwise unsuitable, being converted to agriculture. The changes in relative profit between enterprises (whether due to technology, subsidy or economics) can lead to large areas of single crops, landscapes of brightly coloured crops, and arable crops replacing permanent grassland on slopes. All these changes in agricultural land use have profound impacts on the quality of the landscape and the environment through, for example, nutrient dynamics, soil erosion, ecological diversity and food resources for birds and other wildlife. In the second half of the 20th century technology and socio-economic change have driven rapid changes in land use (Ewert et al., in press; Rounsevell et al., in press). In the future these two driving forces will remain, but the trend of land use change is likely to be enhanced by additional drivers that now exist; climate change and subsidy structures favouring environmental protection. This leads to questions about what type of land use change is likely to result from all these drivers. Will the same type of changes continue, be reversed, or be replaced by different types of land use?

Predicting the future is regarded as impossible. A common approach to studying the future is to attempt to define a number of possible futures, called scenarios, which span the space of all futures. Abildtrup et al (2005) describe a procedure for defining such scenarios for agriculture in terms of population, economic, technical, climate and social changes. In general, scenarios are a product of their time and so they consider drivers that are important for that time. Unknown drivers that will become important in the future are by definition not included, and it can be instructive to consider how one would have predicted today's world from 1950. Within that caveat however, modelling the land use that is implied by a scenario permits the study of possible impacts and, by including possible policy responses in the scenarios, the study of the means to prevent undesirable impacts. One question is whether the impacts are simply a function of the particular scenario or whether the collection of all scenarios provides useful information about future impacts and their mitigation. An outcome that is affected by the scenarios may be:

1. similar for all scenarios. This implies this aspect of the future is not as uncertain as the scenarios. While policy makers can expect this outcome to happen, it also implies they cannot control it.
2. similar for all scenarios except one or two, or split into groups of scenarios. This implies that a certain aspect of these scenarios has a large influence, for example rainfall distribution differences between climate models. This aspect is thus an indicator for policy makers concerned with outcomes.
3. different for all scenarios. This is least informative, although it may be possible to identify an observable trend with some aspect of the scenarios. This aspect is thus an indicator for policy makers concerned with outcomes.

Decisions about agricultural land use are actually made by farmers, with the general aim of maximising the profit they achieve from the land, within the plethora of subsidies, support payments, grants and restrictions that attempt to drive their decisions in particular directions. Their primary constraints are the soil and the climate. Many models have been developed to consider the problem of predicting future land use (Rounsevell et al., 2003; Thornton, 1998; Hossell et al, 1996; Klocking et al, 2003; Zander, 1999; Veldkamp, 2004). They differ in the level of detailed choices they consider, whether the individual decision maker is modelled and the specific region of Europe within which they can be applied. Lambin et al., 2000 reviewed the different modelling approaches that have been used in land-use change research. Their case studies highlight the importance of modelling the decision-making process that drives land management. LP optimisation methods (Annetts, 2002) are thus suitable because they describe the core of this process. Thornton, 1998 and Lambin et al. (2000) highlight uncertainty, whereas Murray-Prior (1998) highlights farmer behaviour as the important aspect, which leads to a range of land uses being chosen for a similar circumstance. This is accommodated in a LP approach by using a range of objective functions to simulate a range of behaviours (Rounsevell et al., 2003) and the concept that the purpose of the model is to simulate the aggregate behaviour of farmers in a region, not generate a land use pattern. Hossell et al. (1996) determined prices from world food market demand and consequent gross margins to determine land use. As LPs are partial equilibrium future land use models, they need a price adjusting mechanism to prevent over- or under-estimation of the production of any commodity. This is particularly important where future scenarios define increased demand and/or increased productivity. Within an individual based approach it is necessary to aggregate the new optimised production, compare it with demand and adjust prices appropriately, taking account of world supply and prices.

The objective of the model used here is to estimate land use change at the European scale. Regional models have implicit assumptions about agriculture due to the region in which they are created. These manifest themselves in the constraints, which are included and omitted. This model predicts the actions of the collections of individual decision makers using the same model over the whole of Europe – that is from the north of Finland to the south of Spain and Greece and from the west of Ireland and Portugal to the east of Poland and Romania. One of the questions to be addressed in this study is how far this model is capable of simulating all European land managers and which areas need further development.

2. Method

2.1 Overview of the modelling approach

The concept of the agricultural land use analysis is that farmers seek to maximise their long-term profits, within the constraints of their situation, taking account of uncertainty in prices and yields, which causes otherwise identical farms to perceive different crop gross margins. (Annetts, 2002). Land use on a regional scale is the sum of the results of decision-making at the farm level (Rounsevell et al., 2003). A farm is constrained by its physical situation, which can be summarised as soil, climate and slope. These define the cropping options available to the farmer. Given a particular economy, farmers will choose the cropping which they individually consider most profitable.

The procedure determines the profitability of a soil/climate unit. If the land is sufficiently profitable, it will be used for intensive agriculture – which is defined either as annual arable cropping or dairy farming. Below this level, land that is marginally profitable is assumed to be used for extensive agriculture – in the UK this would typically be grazing of beef or sheep. Land that is not profitable for use is classified as abandoned, although this could include for example forestry. Given any future scenario of climate, economics or technology, the procedure determines where land will change use between the three classes of intensive, extensive and abandoned. Note that this study does not consider the timescale over which changes will occur, effectively assuming that by 2050 significant changes will have occurred, since this is ample time for several economic cycles. Clearly the impetus to change will depend on the difference in profit and the capital needed, and policy incentives to accelerate or decelerate change, identifying the need for which is one purpose of this study.

Annetts (2002) describe the optimising farm model to determine crop choice in detail, but the underlying concept of linear programming model can be summarised as:

$$z = \sum_i (P_i Y_i - V_i) a_i - \sum_m C_m n_m - \sum_{ijk} T_{ijk} x_{ijkm} \qquad (1)$$

subject to

$$\sum_{ij} L_{ijm} x_{ijkm} \leq H_{mk} n_m \forall k, m \qquad (2)$$

$$\sum_k x_{ijkm} = a_i \forall i, j, m \qquad (3)$$

where

- the variables (lower case) represent profit (z), crop area (a_i), number of men and machines(n_m), and area (x) of an operation ($_j$) on a crop in a period of time ($_k$)
- the constants (upper case) represent the crop price(P), yield(Y), variable costs(V), cost of men and machinery(C), timeliness penalty(T), labour and machinery requirement(L) and workable hours in a period(H)

The model uses a flexible approach when choosing crop rotations, using planting and harvesting timeliness, rotation penalties and workable hours as a function of precipitation and soil data, making it ideal for selecting future cropping systems, which may not exist now. It also includes dairy cows with grazing, silage making and feed constraints. The model takes account of the variable perception by farmers of prices and yields by determining the average cropping of 10 price and yield sets for each soil.

Farm size is often considered an important variable. A study of Danish farms comparing the cropping on small and large farms, found that the average cropping was not different (Albidtrup 2002). In Greece, we found that the definition of a farm was not a useful concept for land use, as the main agricultural areas were farmed by large-scale machinery by land managers. A similar situation was found in Italy although it was less clear how much input to the crop choice the land owner had. Therefore the model was defined to be independent of farm size and uses workrates for machinery sizes typical of 200ha farms. Increasing future farm sizes was modelled by reducing labour per hectare.

Different regions and climate scenarios were modelled by changing the values of the farm model’s constants as a function of soil and climate. These were calculated as the first step in the modelling process using a crop/soil/climate model. In addition to calculating the yield of each crop, possible sowing dates, harvest dates and soil workability were calculated.

2.2 Data available

The key spatially-explicit biophysical variables are:

a. *Soil Geographical Data Base of Europe at the scale 1:1,000,000 version 3.2.8.0, 19/07/1999*. The database divides Europe into Soil Mapping Unit (SMU) polygons, each of which contains a number of Soil Typological Units (STU). STUs are described by variables (attributes) specifying the nature and properties of the soils, e.g. texture, water regime, stoniness, etc.

b. *Climate data*. These data were based on a 10’ grid for Europe with monthly time steps using observations for 1961-2000 (Mitchell et al., 2004)

c. *Land cover data*. Pelcom (Pan-European Land Cover Monitoring) contains land cover information for the whole of Europe at a 1 km resolution based on Earth Observation data.
d. *Administrative boundary data*. Data at the NUTS2 level were obtained from ESRI in shapefile format.

2.3 Models

2.3.1 Crop yield model (ROIMPEL)

General description

An agro-climatic simulation model (Mayr et al., 1996) was developed based on the soil/terrain information and weather/climate variables to predict the water-, air temperature-, nitrogen-limited crop yields, sowing and maturity days and the number of workable days (providing constants Y, T and H). The minimum requirement for soils data are the soil texture and organic matter classes. The minimum weather data needed by the model are monthly values of the average daily air temperature and the monthly-cumulated precipitation. For this study nitrogen is assumed not to be limiting.

Algorithms

The soil is considered as a single reservoir partially filled with water. The zero level of the reservoir corresponds to the total soil water content at the wilting point for a soil layer corresponding to the maximum root depth. The maximum volume of the reservoir is the maximum soil available water. Therefore, the actual water volume in the reservoir is the actual soil available water. The reservoir is filled with water from precipitation and discharged by crop transpiration. Should the water in the reservoir exceed the maximum reservoir volume, a second reservoir starts to fill. The water in this reservoir is the soil drainable water. The second reservoir is also discharged by drainage flow and evaporation and a threshold defines the wet water content limit at which the soil is defined as not workable.

The dynamics of the water budget elements (evaporation, transpiration, drainage) are computed using the Thornthwaite-Mathers approach (Thornthwaite, 1957) if the soil water content is less than the maximum available water, and the travel time approach (Lane, 1989) for drainage flow calculations for soil water contents greater than the maximum available water. The algorithm shares total actual evapotranspiration between evaporation and crop transpiration using Ritchie’s formula (Ritchie, 1972). Thus, the dynamics of the leaf area index (LAI) is the central driving process for soil water dynamics during the vegetation period and for biomass calculations. The dynamics of LAI is computed using the maximum LAI and an analytical function (Wight, 1987, lairgc(i)) relating the relative LAI (LAI/maximum LAI) to the values of the development stage. Maximum LAI is estimated using an iterative technique matching the values of total cumulated crop transpiration with the water supply during the vegetation period (available water at emergence + precipitation during the vegetation period). Maximum LAI is first changed by a fixed step. The evaporation and transpiration are computed for the new value of LAI and the water balance evaluated. If water supply is different from water extraction (evaporation + transpiration + drainage) then a new value of maximum LAI is considered until the difference is less than a threshold. Therefore, an overall water balance is achieved.

Each SMU polygon is associated with the climate data corresponding to the closest grid point to its label point (weight centre of the polygon). ROIMPEL dynamically calculates the state variables with a time step of 1 day. The data available from the European scale grids have a time step of 1 month. Therefore, ROIMPEL uses functions to derive daily weather data (air temperature, precipitation, radiation) from monthly values. These are either trend functions for temperature and radiation derived from monthly values and a distribution of rainfall events based on the average days with rain for each site, or the LARS weather data generator (Semenov, 1997) for site specific simulations where a long series of daily weather exists for calibration.

A screening of soil/climate conditions to evaluate the land suitability for a given crop is first performed. For suitable land, the daily dynamics of the crop development stages up to harvest, are simulated for each crop. The accumulation of biomass is based on the radiation use efficiency and the net photosynthetic active radiation. The radiation use efficiency is CO_2 concentration sensitive. This potential daily biomass increase is corrected by temperature, water and nitrogen stresses. Additional penalties on crop yields are included through alarm criteria (unfavourable weather parameters during the most sensitive development stages) based on the crop specific physiology. Unfavourable weather is linked mainly to temperatures: for each development stage temperatures lower/higher than a threshold. The values of these parameters are derived from MARS series of works (1990-1992). Grass crop yields are calculated for each fortnight.

The model was derived against data from Romania and then validated against data from Bulgaria for 1980-1993 and Czech Republic for 1995-1998, in comparison with CERES which uses more detailed input data. Figure 1 shows the comparison of data for the Bulgaria case. The results show ROIMPEL performs adequately and as well CERES, but illustrate that some experimental data contains other issues than just soil moisture.

[Figure 1]

Calculation of sowing dates is crucial. The algorithm for calculating sowing dates has two stages. First for each year of simulation, the latest/earliest possible day is computed from weather data for winter/spring crops based on threshold temperature and the accumulation of degree-days between sowing and emergence. The emergence day needs to be before freezing for winter crops; for spring crops a threshold temperature drives the possible day. The sowing date (which is the same for all years of simulation) is then defined as the 9th decile of the ordered set of simulated possible dates.

2.3.2 Farm model (SFARMMOD)

Input data

The model uses input from three sources: details of husbandry provided by a farm database, details which are a function of the soil and climate provided by ROIMPEL, details of future economics provided by the scenario database.

A common farm database is used for all countries in the EU (the countries are defined in table 1). An analysis of the operations to produce a range of crops throughout the EU showed that all countries use largely the same methods. The database includes crop characteristics, standard crop yields as a function of soil type, soil workability requirements of operations, machinery/labour requirement as a function of soil type, rotational constraints and irrigation requirements, crop prices, variable inputs and costs (seed/fertiliser) and subsidies/area payments as a function of the regional base yield. In order to speed up the analysis, the list of crops was reduced to crop 'types' by eliminating crops that have similar characteristics of sowing, harvesting or rotational benefit. The constants in the model were calculated as follows:

- crop price (P) was taken from the database for the baseline. A study of prices across the EU showed that differences were small and inconsistent. In some cases there were differences between regions in production surplus versus in production deficit, and in regions near to population centres, but not in others. Thus no differences were used.
- yield (Y) for each soil (and its variation between years) was taken from the crop model, after eliminating polygons on the basis of slope and climate and those with insufficient degree days. Tests indicated problems caused by high yields of cereals in wet areas and grass in dry areas where they would not be expected. This was attributed to the crop model being only a soil moisture model and not considering factors such as disease in cereals and the unreliability of summer grass growth in dry areas. Therefore adjustments were made by reducing yields where the summer precipitation was greater than the summer evaporation and where the standard deviation of yield was high. Analysis of Greece showed that yields of crops such as unirrigated maize were low and the water management settings in the soil database were used to select irrigated soils. In spite of these changes, the yields, and comparative yields such as barley versus wheat, generally did not agree with the average crop yields for the NUTS2 regions reported in the REGIO database (REGIO, 2001). Therefore a regional scaling factor was determined by comparing the average yield of each crop on likely arable soils to the REGIO yield. Care is needed where the REGIO average represents more than one type of crop (e.g. spring and winter cereals). Typically the factors were found to be close to 1.0 for northern countries, but 0.8 for barley, 0.7 for oilseed rape, and lower for other countries.
- variable costs (V) were adjusted to take account of yield and irrigation.
- cost of men and machinery (C) were modified by country as labour costs are much lower in southern than northern European countries. In CEECs, labour costs and input and output costs are lower than in the EU15. Three factors were defined therefore for all countries and used to modify the costs. In the future scenarios, only labour cost differences remain and are reduced by the scenario convergence parameter.
- timeliness penalties (T) reflect the timing of sowing and harvest. A detailed sowing date analysis led to a procedure to calculate climate and region specific sowing windows for individual spring/winter sown crops, based on the date after/before which low temperatures rarely occurred. The analysis (Fig.2) showed differences of up to two months between individual countries, which were strongly correlated with the severity of the winter conditions. Countries with a more severe winter such as Northern European countries and those with the pronounced effect of a continental climate (typically Czech Republic or Hungary) tend to close the sowing season of winter crops by the end of October whilst the spring crops are generally sown from March till May. On the other hand in southern countries or those with maritime climate (typically UK) the sowing of winter crops is possible until the end of December whilst some spring crops are sown as early as January. Note however that in countries such as southern Spain, 'winter' wheat is in fact 'spring' wheat (no vernalisation requirement) grown over winter. In the case of some crops (e.g. sugar beet or potatoes) the recommended sowing dates are similar throughout the EU. For winter-sown crops, the crop model defined the latest sowing date, and the start date was defined by the database. The length of the operation and the timeliness penalties were reduced to this range so that there were high penalties for sowing close to the

latest date. For spring-sown crops, the crop model defined the earliest sowing date and the database the latest. The start of the harvest operation in the database was moved to the date of maturity calculated by the crop model, plus a fortnight. An analysis of actual harvest dates was used to verify the crop model performance.

[Figure 2]

- labour and machinery requirements (L) were modified for yield and soil type. Thus for harvesting there was a minimum requirement and an increase proportional to yield. Most other workrates were fixed as a function of soil type.
- workable hours in a period (H) were calculated by the model's soil workability formula (Tillett, 1987, originally derived for England) which requires a soil index value and annual precipitation. The soil index value was derived from the soil textures over the profile including impermeable layers as specified in the soil database. Precipitation, mm in the original formula, which implicitly includes the average evaporation in England, was modified to be 435+Annual (Precipitation-Evaporation). This method was preferred to the output of the crop model.

Several crops (such as forage maize) were not modelled by the crop model. Equivalent crops (e.g. spring wheat) were defined and sowing, harvest and yield values modified for other sites and climates by the same amount as the equivalent crop. For sowing and harvest, the 'same amount' was based on temperature level. A temperature sine wave was fitted for East Anglia and used to convert the database dates to temperatures. Thus if the latest sowing date changes according to the crop model, from the database value of day 360 to the site value of day 300, then, for the equivalent non-modelled crop, if the database value is 330, then the site value is 287. Thus a month's delay in sowing in February of the equivalent crop equates to a shorter delay in April.

Output data

The output of the model is the optimum cropping percentage for each soil in each soil polygon and the profit. Each soil must then be classified as intensive, extensive or abandoned. Data from REGIO lists the area of each NUTS2, the area that is agriculture, permanent grass, arable land, and arable land-green fodder, mostly at the NUTS2 level. Comparing the output profits with this REGIO data, it was clear that a single profit threshold for all countries is not satisfactory and that there are large areas of low-profit land classified as agriculture because they are grazed. In some countries, such as Belgium, there was no suitable threshold and the area of high profit soils apparently available to agriculture was considerably greater than the actual area of agriculture. In these cases a standard threshold of €350/ha was used, and a proportion of the land was defined as not available for agriculture (termed "pseudo-urban"), both now and in the future. Each country was therefore analysed as follows:

1. Determine the proportion of each polygon in each NUTS2 and of each Pelcom land type.
2. Remove the urban proportion in each NUTS2 pro-rata from all soil polygons.
3. Define areas with a profit above the threshold e.g. €350/ha, as intensive agriculture and calculate the total grass/fodder and arable areas.

[Figure 3]

4. If there is too much agricultural land, define the surplus to be 'urban' and remove pro-rata.

5. If there is too little agricultural land (e.g. UK), calculate a second threshold above which land is grazed and, which minimises the error in the arable percentages in each NUTS2.
6. Define all other land as ‘abandoned’. Note that this does not mean not used and could be forestry or grazing such as sheep on moorland or goat herds.
7. For the future climate change and socio-economic scenarios: remove the increased urban land defined by the scenario and then allocate non-‘urban’ soils to the three classes based on their profit. Compute the percentage change between classes and percentage arable versus grass.

2.4 Future scenarios

2.4.1 Climate

Climate scenarios for 2050 were derived from the recent HADCM3 and PCM climate model outputs for 2001-2100 (Mitchell et al., 2004). Rounsevell et al. and Harrison et al. describe how the scenarios were constructed and describe the patterns for temperature and precipitation. HadCM3 and PCM were the extremes of the 4 climate models in terms of both temperature and precipitation change. Four SRES (Special Report on Emission Scenarios; Nakićenović et al., 2000) emission scenarios were used within the HadCM3 climate model: A1FI, A2, B1, B2 and one – for the PCM climate model - A2. The most severe changes in climate occur under the HadCM3 model simulations. As illustrated in table 2, the differences are much greater between climate models than between scenarios within models. The PCM A2 climate model shows lower increases in air temperature and precipitation changes are smaller. (See figures 4 and 5).

[Table 2]

[Figure 4]

[Figure 5]

2.4.2 Socio-economics

Socio-economic data for the future are derived and detailed in Abildtrup et al. (2005). Four scenarios were created, which are based on A1, A2, B1, B2 respectively, but contain much more agricultural detail:

- World Market (WM),
- Regional Enterprise (RE),
- Global Sustainability (GS),
- Local Stewardship (LS).

These define percentage changes in: a) costs of the most important production inputs; b) prices of agricultural commodities; c) subsidies; d) yields due to technology; e) natural resources available for agricultural production; f) efficiency of natural resource use; g) chemical input restrictions. Variable costs (V) were adjusted for scenarios. Changes to the input costs relative to crop price affect the amount used. Increasing the price of pesticides by 100% reduces use to 60% and yield by 2.5%. In the environmental scenarios it was assumed that this yield reduction would be eliminated by technology. Increasing the price of N by 100% reduces the amount of N applied by 9% and yield by 1.6%.

Land use change was estimated for the climate scenarios alone, with only the prices changed to correct production (+FP), and for the combined climate with socio-economic scenarios. The SRES framework allows the climate and socio-economic scenarios to be combined in an internally-consistent way, as the underpinning socio-economic assumptions drive GHG emissions and therefore climate change. Where a climate change scenario was coupled with its corresponding socio-economic scenario, these are given as A1FI+WM, A2+RE, B1+GS and B2+LS.

Directly modifying the prices as specified in the scenario analysis led to wild variations in the total production of commodities. With a future scenario, a subset of the database was run iteratively and the commodity prices adjusted to generate increases in total production similar to those required by the SRES storyline. This approach was satisfactory in most cases, except in the A1FI+WM scenario, when the full run had too many potatoes. As a result, this scenario also shows high levels of arable rather than grass, but due to the very high productivity, less agricultural land is required. In all cases, soya increases enormously from a low base level due to increasing suitability. The resulting production increases are given in Table 3.

[Table 3]

The scenario data were based on countries in the Common Agricultural Policy (CAP). For Central and Eastern European Countries (CEECs), a separate database for current socio-economics was used with the current climate, but the common EU data were applied to all countries in 2050.

3. Results

3.1 Baseline

Figure 6 compares the proportion of arable cropping listed in the REGIO database for the EU15 versus that predicted by the model, plotted by NUTS2 region. Not all countries have data at the NUTS2 level and some have been reorganised so that the location on the map does not match the REGIO data. Overall the prediction is satisfactory, although some NUTS2 regions such as NUTS2=13 (Antwerpen) in Belgium, southern France and Italy are problematic.

[Figure 6]

For the Czech Republic, a qualitative comparison evaluated the capability of the model to depict the productive capacity of individual regions within the country (Fig. 7a and Fig. 7b). The overall profitability simulated by the SFARMMOD model expects that higher profits will be generated in the north-central and eastern part of the country. It also indicated profitable agriculture at the south-west close to the Bavarian border. These results were compared with the map of the official prices of agricultural land in the Czech Republic (designed for taxation purposes). The price map was developed for each cadastral unit and the official price was calculated as a function of the expected profitability of crop production on individual soil-climate units within each cadastral. The potential profitability of each soil unit was corrected by factors including e.g. aspect, slope or soil depth. The final price for each cadastral was defined as the mean of prices of all soil units present within the cadastral weighted according to their proportion in the area. (Němec, 2001). The expected profitability was based on an extensive statistical survey of the individual farms in combination with very detailed soil surveys and represents the agricultural potential of individual plots rather well. It should be noted that Fig 7b does not take account of other factors affecting prices, e.g. distance from urban centres (which increases the official price), restrictions due to environmental pollution or the location of the cadastral within protected natural reserves or drinking water reservoirs etc.

[Figure 7a]
[Figure 7b]

When Fig. 7a and 7b are compared, it is apparent that the model depicted the most productive regions well (i.e. those with the highest official price in Fig 7b). Part of the differences between the model and observation can be explained by the much lower spatial resolution of the European-level soil map, which did not include all factors that limit agricultural production (e.g. high groundwater levels, unsuitable slope and aspect etc.). It should also be noted that the crop yields simulated by ROIMPEL do not always correlate closely with the observation. Given these caveats, the results of the model are surprisingly good and qualitatively comparable to those obtained with the significantly more detailed map of official prices.

At the same time the percentage of arable land predicted in individual Czech NUTS2 regions compared well to the real world data (with the exception of a few SMU polygons), as well as the overall percentage of cereals, forage and technical crops. However the model showed a relatively high area of soybeans in the Czech Republic of which there is currently a very limited area (2700ha, Czech Statistical Office, 2002), despite the fact that the crop has been grown for a quite long time in Austria. This time lag between a new crop becoming profitable and being accepted is typical as there is a need for experience, technology and farmer-buyer links. Such a time lag also occurred when sunflowers began to be grown in 1982, but took over 10 years to reach their present acreage (Žižlavská, 1998). The model is a steady-state and not a dynamic model and therefore is unable to distinguish between crops that are profitable and well established and crops that are profitable and new. It indicates the situation after profit-driven changes have occurred. Some changes could take decades to be realised if they require large amounts of capital expenditure.

3.2 Future yield changes

Table 4 shows changes in the average simulated yield of crops in representative NUTS2 regions of the EU15 between the current and the HadCM3 A2 climate in 2050. Although broadly an accurate representation of the results, it must be borne in mind that these averages include low yields in areas where the crop would never be grown. As might be anticipated crop suitability increases in the north, and thus in some northern regions, attainable yield increases are large. Crops currently grown in the south also become suitable further north. The results are too numerous to list them all, but they follow what one would expect from the given climates. Crop yield changes in the CEECs show similar patterns to the EU15. Increases in yield are observed in the northern latitude CEECs, with decreases in the Mediterranean regions and the south west Balkans. Crop yield decreases in southern Europe are greater for spring-sown crops such as maize, sunflower and soybeans. The different climate scenarios produce different ranges of crop yield changes. The largest changes (both decreases in the south and increases in the north) are for the A1FI scenarios. The A2, B1 and B2 scenarios have similar effects on crop yields.

[Table 4]

3.3 Scenario Output

Table 5 shows the total area of agriculture in each country for the different scenarios. It is evident that the effect of different climates (+FP columns) is relatively small, whereas there are large variations when the socio-economic scenarios are included. Only Finland responds significantly to climate by increasing the agricultural area. One climate consistently shows a different level of response - PCM A2 climate change scenario. In several countries there is more difference due to the climate model than due to the emission scenario. The WM scenario causes a general reduction in agricultural area due to the large increase in yields. The LS scenario is perhaps the most interesting as it cancels out the climate increases in Finland and Sweden. The main features of this scenario are that input costs are high and yield increases are low so, although prices are high, marginal areas have low gross margins compared to highly productive regions and the profit level is not sufficient to justify a switch into agriculture.

[Table 5]

One might think that Sweden and Finland would show comparable behaviour. However studying the climate and thus the crop yields, the south of Sweden is very similar to Denmark and good for agriculture whereas the north is cold and remains quite cold even in the A1FI scenario. Finland although appearing well north of much of Sweden has a much warmer summer and, although barely suitable for winter wheat currently, a huge area of Finland gives higher yields of wheat than the south of Sweden in the A1FI climate. Therefore whereas the agricultural area in Sweden doubles, the area in Finland increases ten-fold.

Figure 8 shows how the proportion of arable cropping within the agricultural area changes with a future climate, and compares the output from the two GCMs HadCM3 and PCM for the A2 emission scenario with no change in socio-economics. There are considerable differences, usually associated with precipitation. For example in the HadCM3 climate, precipitation in the Ardennes is reduced and with increases in air temperature the area becomes arable whereas in the PCM climate, precipitation is high and the area remains grass. The difference between the PCM and HadCM3 climate change scenarios is visible in several countries, with PCM generally having lower changes and thus less change to arable agriculture. The Republic of Ireland is probably the only exception to the increasing proportion of arable agriculture, but this is due to the increased area in viable agriculture - the arable area still increases.

[Figure 8]

The main cropping changes are the relatively large proportion (6%) of soya in Austria with all 2050 scenarios and similarly in Germany, cropping switches to grain maize with some soya. In Denmark, grain maize becomes a minor crop and in A2+RE and B1+GS there is a huge switch away from arable to forage maize. In the Netherlands, the PCM climate change scenario has notably less grain maize due to the lower increases in air temperatures in this scenario compared with HadCM3.

The model assumes irrigation is available where the soils database indicates that soils are irrigated. In several scenarios in Spain, there is no reduction in land use, although there is a general reduction in livestock and grass in all scenarios. Because the model did not impose any limit on water use, this may represent unsustainable level of extraction of water for irrigation, and needs further study.

For the A1FI emission scenario, intensive land use increases at higher latitudes (i.e. in Scandinavia, especially southern Finland) and also at higher altitudes (i.e. Trentino, Italy) due to the beneficial effects of warming. Decreases in intensification occur at lower latitudes (i.e. south west France, Spain, Portugal and Italy), where higher air temperatures and increased aridity have a negative effect on farm profitability. Some mid-latitude regions (i.e. the southern UK, southern Belgium, Luxembourg and parts of Germany) also show strong decreases in intensification. The trends for the A2 emission scenario are similar to A1FI, with high latitude and altitude areas becoming more intensive. However, A2 shows more intensification everywhere, which can be explained by the higher prices, subsidies and much lower labour costs assumed for the RE scenario compared with the WM scenario. Parts of southern Europe (notably southern Italy and Portugal) even become more intensive compared with the baseline, which is the opposite situation to the A1FI emission scenario. This can be explained by the different spatial patterns of climate change in the A2 emission scenario. Abandonment again tends to occur in marginal agricultural areas and is at its greatest in the A2 emission scenario.

Table 5 shows that intensification in the B1 emission scenario increases slightly almost everywhere, including southern Europe, although southern Finland and southern Italy again show the biggest increases. This probably reflects the slightly higher levels of commodity prices, the less severe climatic change and the technological gains for crop yields. As a consequence abandonment is less important for the B1 emission scenario compared with the other scenarios and farmers on the whole would enjoy relatively good levels of profitability.
Intensification in the B2 emission scenario is quite different from the other scenarios. Scandinavia no longer has increased intensification, whereas southern Europe (with the exception of northern Italy) does. Southern France, Portugal and the north and west of the UK show the greatest increases in intensification. This reflects the patterns of climate change for the A2 emission scenario with northern latitudes not becoming sufficiently warm for intensive agriculture to be profitable. Yield gains due to technological development are assumed to be the lowest for this scenario, and this strongly affects profitability.

4. Discussion

4.1 Present

This analysis has brought together several models and attempted to apply them over a very wide range of situations in terms of soils, climates and economics. This very severe test has indicated a number of areas where further work is required to explain observed differences in farmer behaviour.

The crop model is a soil moisture model and thus does not include the impact of pests and diseases on yield and thus without the regional adjustments, appears to over-predict yield in western maritime regions (Landau et al, 1998). The suitability section under-predicted the areas of Finland that currently can grow crops to maturity. This suggests a need to adapt varieties of all crops to regions and not just for grain maize. A detailed study of Greece also suggested there were problems with predicting where grain maize could and could not be grown successfully. Comparison with statistics on grain yields suggested that many crops' yields were not correct. This was particularly true of spring cereals and oilseed rape. Grass yield also seemed to be very high in hot countries although measures are not as easily available as grain crops. Some of these differences could be due to low levels of fertiliser input (assumed to be optimal), which the model could simulate if the level was known, or a soil factor such as pH, which the model could not. It is known that in dry areas, less fertiliser is applied because of the lower expected yield, but since the model simulates soil moisture this should be implicit.

Several prediction errors occurred where grass was the predominant crop rather than arable. The most likely cause is that the profitability of arable was over estimated (relative to grass).

Other than yield, this could be due to quality, input costs or workability. In wetter regions the increased costs of drying and disease control would reduce the crop gross margin. The differences in these factors with region were not modelled. Soil workability was modelled – perhaps or perhaps not successfully – but cereal harvest workability is not a function of soil workability. The method used here included an effect of weather on harvest workability, but may not be sufficient for all regions across Europe.

Farm profitability could also be affected by different labour costs, different distances to the market and whether the region is in surplus or deficit. Labour costs were adjusted for country, but are also likely to reduce with distance from large cities, which would increase the viable agriculture predicted in rural areas. Bulky and perishable products such as milk are also likely to have a higher price near to cities than in remote areas, increasing the attractiveness of grass versus arable.

Clearly history also has an effect as farmers do not make major changes such as dairy to arable immediately, because the profitability and hence difference is very variable. Price is very variable and although attempts were made to use the price averaged over several years, it tends to represent more the current trend in price. Thus a current prediction of arable farming at a location may be a reflection of a trend that is happening or a transient view of the best option. In addition quota and subsidy systems such as the CAP milk quota and arable area payments, restrict change. However such systems are themselves transient in the context of the timescale of a climate change study.

4.2 Future

The major climate trends are quite clearly the northward march of arable farming, but there is also an increase in the same regions in the viability of grassland farming. There is some reduction in profitability in the southern areas. However in between these areas, the largest differences are not due to climate change. In these areas, differences result from the climate models – with the Ardennes being the major example of predominantly arable in one climate scenario and grass in another. Socio-economic scenarios are shown to have an even larger effect on land use.

All scenarios tend to increase the level of European production, through a combination of the fertilising effect of CO_2 and new areas becoming suitable. Setting the price of commodities within scenarios was found to produce unrealistic levels of production of commodities, with levels varying between none at all and treble. Therefore prices were set by an iterative mechanism, which approximately allowed increases in production appropriate for a scenario. Several of the differences may also reflect the inaccuracy of this mechanism. However given the long run times required, a better method was not found. Possible alternative methods could include fitting a meta-model to the linear programme model, which could then be used in a formal optimisation. It is clear that the socio-economic scenarios should define the future level of production and not the price of commodities. The economic scenario cannot know the changes in yields due to climate and soil and the resulting changes in relative gross margins between crops and possible production space, which can generate huge changes in total production. If a given price generates either a huge surplus or virtual absence of a commodity, this is unsustainable in reality and the only realistic alternative is to adjust the scenario price. Thus it is better to fix a target scenario production and allow the price to be adjusted to meet this target.

The main effects of both climate and socio-economics were in the margins of Europe. In central areas, there were relatively few changes. This agrees with experience in the Czech Republic. After 1989, the CEEC´s underwent major changes in their economies and the whole system of financing and profitability collapsed. In the Czech Republic, the present stock of beef and pork is about half of 1989 levels. However, the percentage of arable land has decreased only slightly and the overall structure of crops has not changed much. This suggests that the environmental suitability rather than socio-economics will drive future land use, as is shown in Sweden compared with Finland.

One of the conclusions of the model for Finland is that large areas will become intensive agriculture – in the scenarios that need the land to meet demand, though not in the scenarios where central Europe can meet the demand. Currently these areas of Finland are forests. This model differs from some other models of land use, which start by defining and even expanding the areas of forest in the future (e.g. Nabuurs, et al., 2000), although this assumes that intensive arable agriculture will always be more profitable than forestry. This is an important use of the model as it indicates the situations where forests will come under threat from agricultural expansion.

It is a policy matter as to which land use will be defended. In most countries there are forested (and non-forested) areas that are protected by various environmental designations, often from urban development as much as agriculture. Where land is not suitable for other uses at present, it may or may not be protected. In the future if arable agriculture becomes very profitable, there will be pressure to change. Not changing might be good for the environment (is 10% loss of Finnish forests significant?), whereas changing to a substantial exporter of cereals might be good for the Finnish economy. EU-wide this might represent a surplus of cereals. In fact several of the scenarios indicate that although feasible in Finland, low product prices due to the higher level of production, mean that cereals are not grown in Finland.

Scenario modelling has therefore identified several regions where there is a need to be watchful, such as Finland’s forests and precipitation in the Ardennes. There are, however, few areas where all of the scenario results agree. Scenario modelling has not been able to identify any common (convergent) futures, although in general in central Europe, changes are likely to be relatively small. This implies, however, that no action is required to adapt land use to climate change in these areas, which is useful information for policy. The biggest climate-driven differences are between climate models rather than climate scenarios, which places a worryingly large range to the conclusions from climate impact modelling. In all these areas therefore, the levels of uncertainty suggest that European agricultural policy makers should wait for clearer changes in the climate leading to more agreement among climate modellers.

5. Conclusion

A method for determining agricultural land use over all of Europe was shown to predict many agricultural areas correctly at a NUTS2 regional level, but to fail in other regions, particularly where there were features not associated with conventional arable farming in northern Europe. Trends in farming under climate change were clear. Policy will need to choose between forestry and arable agriculture in the northern regions of Europe. Conversely there is no need for action in the majority of central Europe where the combination of increased production and reduced prices will leave agricultural areas largely unchanged. Of particular note were the differences purely due to differences between climate models, which were particularly apparent in current farming regions. In these cases (e.g. Ardennes) policy actions should await more climate knowledge. Socio-economic scenarios generate larger changes than climate scenarios though there is a need to refine the methods for defining self-consistent scenarios. Policy therefore may need to react more to future socio-economic changes than climate changes.

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Table 1: List of the countries in EU-15 and CEEC groups as used throughout the text.

	List of the countries in each group in alphabetical order
EU – 15 EU member countries prior to the 1st May 2004	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom
CEEC Central and East European countries considered in the study(*)	Bulgaria, *Estonia, Czech Republic, Hungary, Latvia, Lithuania, Poland,* Romania, *Slovakia*, *Slovenia*

(*) countries in italic became EU-members on 1st May 2004

Table 2: Comparison of changes in mean air temperature and precipitation between two emission scenarios of the same model and two climate models of the same emission scenario.

	2041-2050	
	Summer	Winter
Mean air temperature (^{o}C):		
HadCM3 x B1	2.4	2.5
HadCM3 x A2	2.5	2.4
PCM x A2	1.2	1.9
Precipitation (mm/month):		
HadCM3 x B1	-5.1	3.6
HadCM3 x A2	-5.2	4.0
PCM x A2	-0.1	1.9

Table 3: Calculated production increases in each 2050 climate and socio-economic scenario combination

	A1+FP	**A2+FP**	**B1+FP**	**B2+FP**	**A2PCM+FP**	**A1+WM**	**A2+RE**	**B1+GS**	**B2+LS**	**A2PCM+RE**
%inc cereal	84	81	70	74	34	349	97	85	54	23
%inc animal	61	46	34	53	33	-53	171	148	-31	109
%inc pots	252	229	178	203	146	225	204	201	-4	84
%inc sbeet	112	89	70	72	10	617	21	73	13	-81
%inc oil	32	33	40	39	26	113	190	116	181	83
%inc soya	985	948	910	925	525	1821	2572	1712	1191	949

Table 4: Average yield changes (%) between the current climate and the HadCM3 A2 scenario in 2050. For regions with no yield in the current climate, the future yield is given in t/ha. Regions for which the crop is not possible in either the current or future climates are indicated by ‘-‘. Very high percentages imply a crop was marginal in the current climate (low average yield) and is normal in the future climate.

Country	NUTS2	W Wheat	S Wheat	Maize	Soya	W Rape	Potatoes	Sunflower	W Barley	S Barley	Cotton	Grass/silage
Austria	7	-4%	-1%	29%	**6.2 t/ha**	6%	20%	5%	2%	-10%	-	-6%
Belgium	17	17%	25%	**8.8 t/ha**	-	27%	32%	48%	21%	15%	-	16%
Germany (S)	81	5%	12%	53%	**5.9 t/ha**	33%	30%	36%	9%	4%	-	7%
Germany (N)	91	19%	32%	30%	**4.9 t/ha**	50%	34%	42%	20%	21%	-	17%
Denmark	117	24%	25%	**9.8 t/ha**	-	85%	46%	**3.8 t/ha**	30%	27%	-	29%
Spain (NW)	119	-1%	9%	**7.2 t/ha**	**3.5 t/ha**	-3%	16%	**2.0 t/ha**	3%	2%	150%	14%
Spain (Central)	127	13%	22%	0%	56%	13%	42%	29%	19%	8%	33%	10%
Spain (NE)	129	11%	20%	7%	23%	9%	30%	16%	17%	7%	21%	16%
Spain (S)	132	25%	19%	55%	36%	23%	42%	125%	21%	15%	27%	14%
Finland (S)	137	20%	68%	**9.1 t/ha**	-	76%	55%	**4.2 t/ha**	30%	21%	-	26%
Finland (N)	140	**12.3 t/ha**	**6.9 t/ha**	-	-	133%	62%	-	3%	30%	**0.2 t/ha**	43%
France (NW)	155	19%	13%	32%	**4.1 t/ha**	0%	39%	26%	24%	8%	-	20%
France (W)	156	9%	16%	0%	19%	6%	30%	-4%	15%	4%	39%	10%
France (SE)	163	16%	27%	34%	50%	13%	53%	42%	16%	15%	92%	18%
Greece m’nland (N)	166	18%	29%	-7%	33%	16%	54%	27%	22%	17%	33%	10%
Greece mainland (S)	172	28%	43%	-23%	43%	25%	59%	31%	23%	27%	18%	10%
Greece Island	176	29%	26%	**5.6 t/ha**	-	33%	47%	**3.3 t/ha**	27%	30%	33%	35%
Ireland	199	8%	6%	**8.7 t/ha**	-	23%	24%	13%	12%	-11%	-	4%
Italy (E)	211	-1%	6%	-16%	23%	-5%	21%	10%	3%	-4%	67%	12%
Italy (W)	215	19%	26%	14%	67%	9%	53%	70%	19%	15%	27%	13%
Luxembourg	222	10%	19%	**5.6 t/ha**	**5.0 t/ha**	48%	30%	37%	15%	7%	-	8%
Netherlands	250	12%	14%	**7.6 t/ha**	-	63%	21%	**3.2 t/ha**	17%	15%	-	6%
Portugal	310	4%	10%	-9%	150%	9%	32%	**2.9 t/ha**	9%	3%	6%	14%
Sweden (S)	366	20%	21%	**11.2 t/ha**	-	70%	41%	**4.1 t/ha**	30%	17%	-	22%
Sweden (Central)	368	**9.8 t/ha**	**5.0 t/ha**	-	-	**3.6 t/ha**	58%	-	41%	20%	-	34%
UK (NE)	479	22%	32%	-	-	92%	39%	**2.3 t/ha**	27%	26%	-	25%
UK (E)	487	25%	25%	**6.2 t/ha**	-	35%	43%	40%	28%	8%	-	24%
UK (SW)	496	15%	11%	**8.2 t/ha**	-	-11%	38%	50%	21%	-5%	-	19%
UK (N)	509	15%	48%	**8.4 t/ha**	-	50%	27%	**3.6 t/ha**	14%	4%	-	7%

Table 5: Area of intensive agriculture by EU15 country for the different scenarios in 2050, Mha (HADCM unless otherwise stated)

	Current	A1FI +WM	A1FI +FP	A2 +RE	A2 +FP	PCM A2 +RE	PCM A2 +FP	B1 +GS	B1 +FP	B2 +LS	B2 +FP
AU	2.5	0.7	2.1	1.1	1.7	0.9	1.0	1.4	1.5	1.7	1.7
BE	1.4	0.7	1.2	1.1	1.2	0.8	0.9	1.1	1.1	1.2	1.1
DE	17.2	12.1	17.6	15.2	17.2	12.2	14.9	15.3	16.4	15.7	17.1
DK	2.7	2.7	2.7	2.7	2.7	2.6	2.7	2.7	2.7	2.7	2.7
ES	32.2	17.0	33.1	23.6	30.7	21.0	25.8	29.8	29.1	37.2	29.6
FI	2.1	14.5	19.5	17.9	19.4	14.3	18.3	14.4	19.2	1.1	19.3
FR	29.3	18.0	30.8	25.1	30.0	23.1	28.2	29.5	28.3	35.3	29.6
GR	4.5	4.5	4.7	4.6	4.5	4.9	2.8	3.5	4.8	7.8	3.9
IE	3.7	4.3	5.4	5.2	5.4	4.3	4.8	5.4	5.4	5.5	5.4
IT	17.2	10.1	21.6	18.4	20.2	17.8	20.3	18.9	21.3	20.3	21.3
LU	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1
NL	1.8	1.5	1.7	1.6	1.7	1.6	1.7	1.7	1.7	1.7	1.7
PT	5.1	1.8	6.8	7.1	6.8	5.4	5.4	2.8	6.6	0.6	6.7
SE	2.9	3.5	4.3	2.3	3.7	3.5	1.1	2.2	2.6	0.8	3.5
UK	15.0	8.6	15.2	10.8	14.3	9.5	13.4	11.8	13.7	12.9	14.1

Figure 1: Comparison between simulated and measured yields of winter yield (a), maize (b) and winter barley (c) at the selected Bulgarian sites for the period 1980-1993

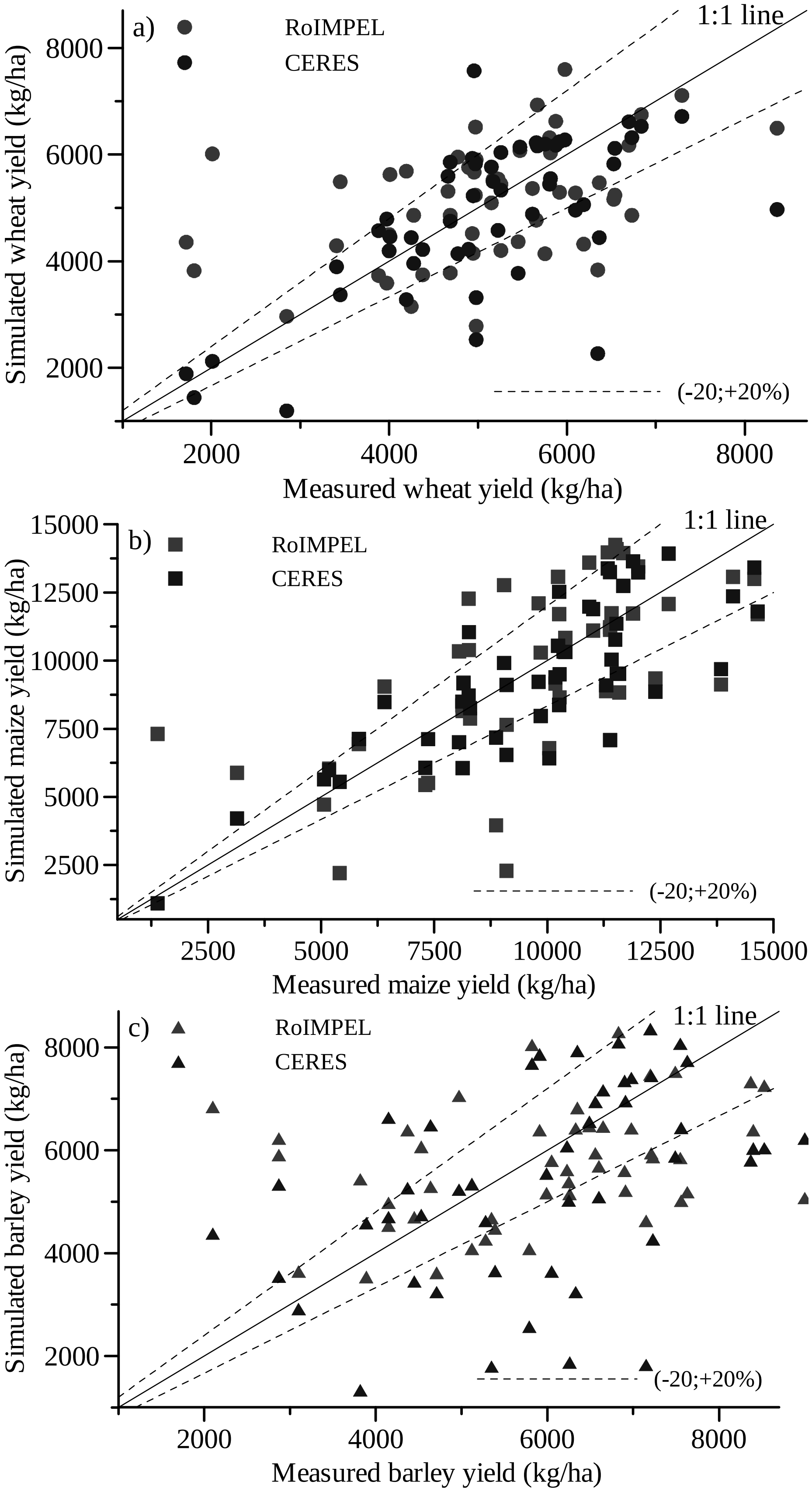


Figure 2: The overview of the mean planting dates of winter wheat in the selected EU countries.

Month	***August***			***September***			***October***			***November***			***December***		
Decade	*I.*	*II.*	*III.*	*I.*	*II.*	*III.*	*I.*	*II.*	*III.*	*I.*	*II.*	*III.*	*I.*	*II.*	*III.*
Bulgaria								■	■						
Czech Rep.						■	■	■	■						
Denmark					■	■	■	■	■	■					
Estonia			■	■											
France							■	■	■						
Greece											■	■	■	■	
Hungary							■	■							
Italy							■	■	■	■					
Latvia			■	■											
Lithuania			■	■											
Poland					■	■	■								
Slovakia					■	■									
Spain										■	■	■	■	■	■
United Kingdom					■	■	■	■	■	■	■	■	■	■	■

Figure 3: Illustration of how areas in a soil polygon are allocated to the four categories of land use based on profit

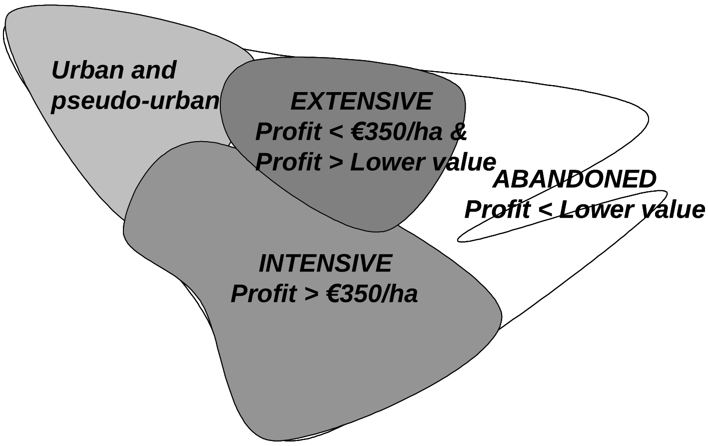


Figure 4. Change in summer mean air temperature (^{o}C) for the HadCM3 and PCM climate models coupled with the A2 SRES emission scenario for 2080.

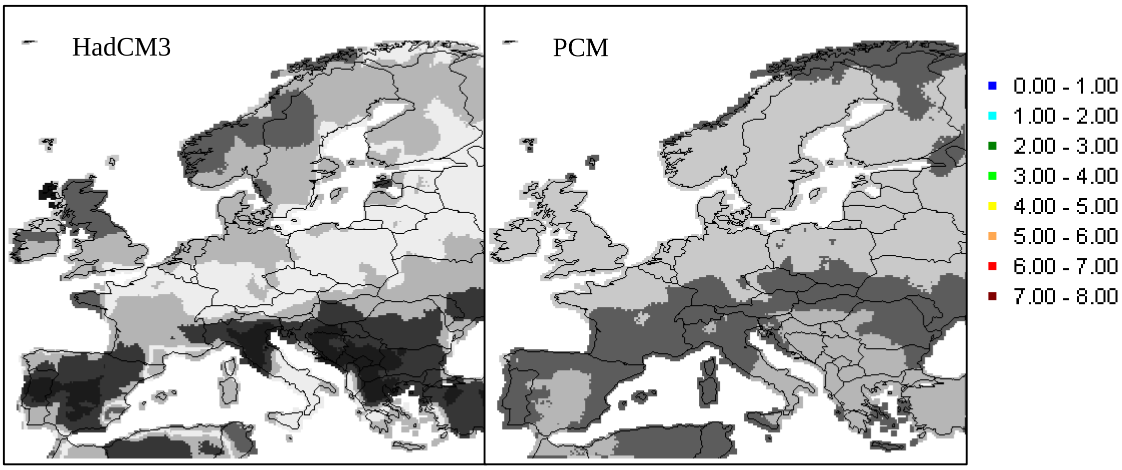


Figure 5. Change in summer precipitation (mm/month) for the HadCM3 and PCM climate models coupled with the A2 SRES emission scenario for 2080.

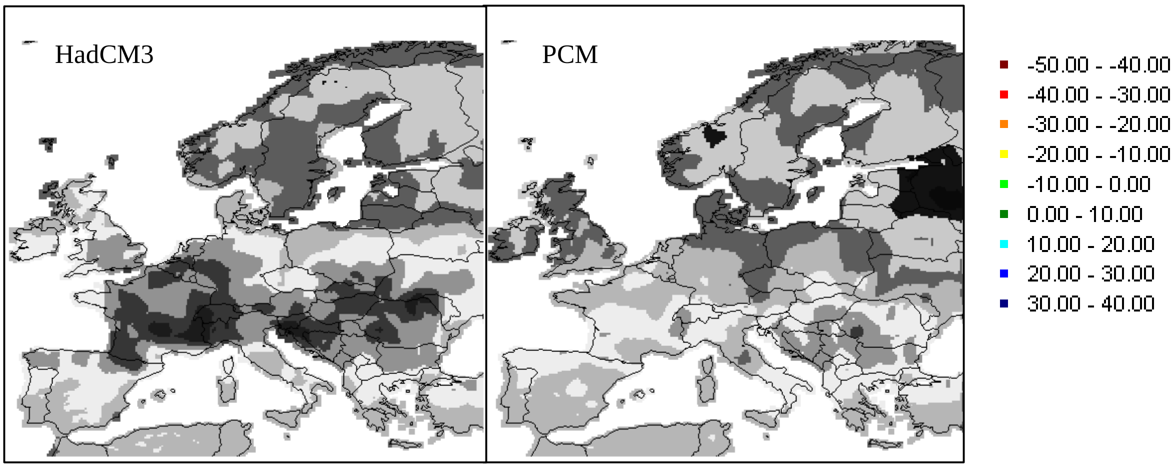


Figure 6. a) REGIO proportion of arable agriculture, b) model baseline proportion of arable agriculture

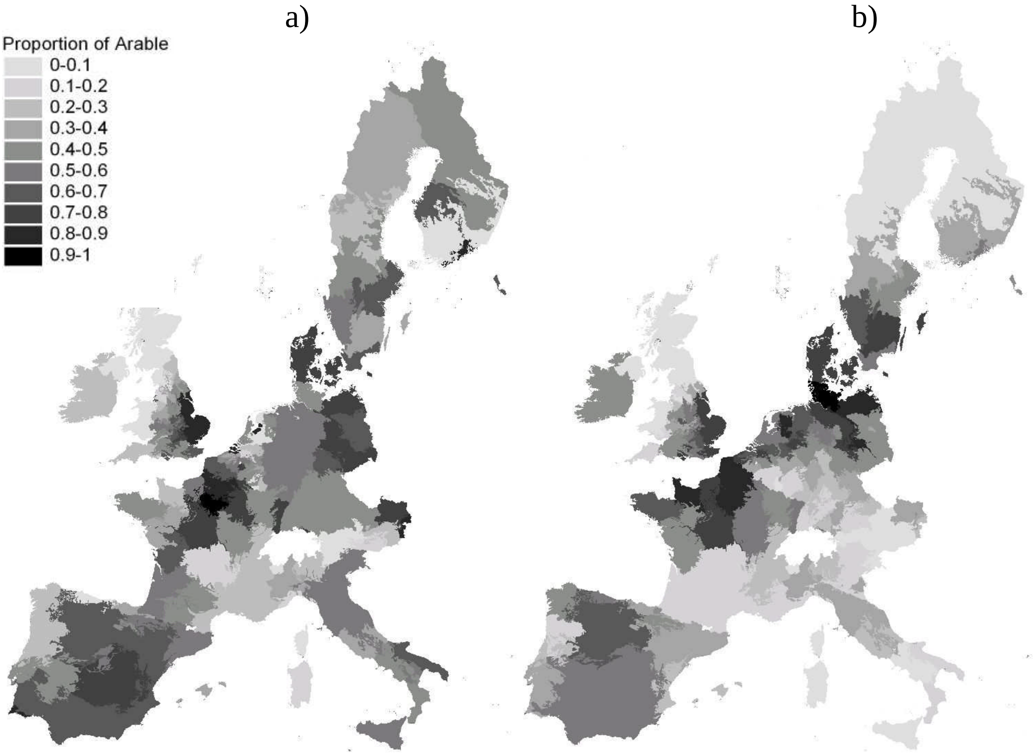
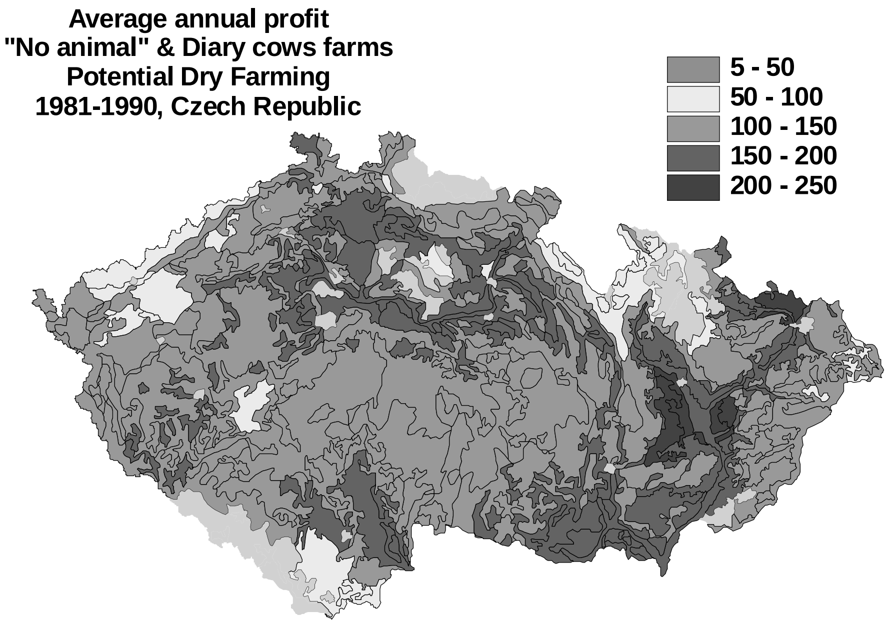


Figure 7a: Profitability of land use in the Czech Republic for 1981-1990 climate and current economics



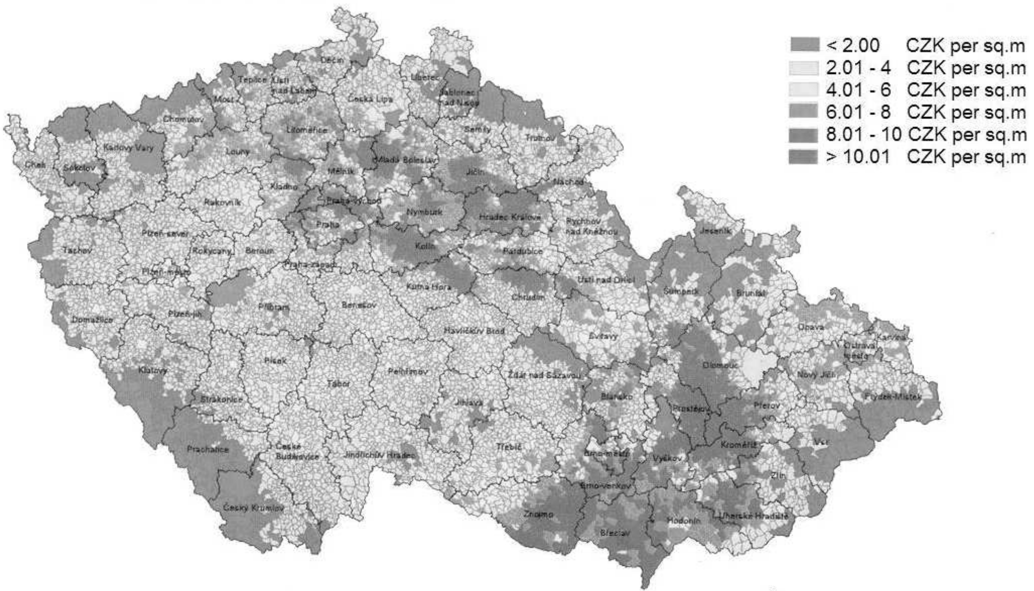


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Figure 7b: Official value of the agricultural land in the Czech Republic (in 1995 prices) in Czech crowns (CZK) per sq. m^2. The mean official price was calculated for each cadastre unit (gray solid lines) as a function of the expected land profitability and is independent of the other market factors (e.g. distance from large urban centres). High official price of agricultural land indicates high profitability of the crop production in the cadastre unit. (*Published with permission of the copyright holder*)

Figure 8: Proportion of arable agriculture in 2050 climates a) HadCM3 A2+FP,and b) PCM A2+FP

a) b)