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ORIGINAL ARTICLE

The responses of agriculture in Europe to climate change

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Abstract Human activities are projected to lead to substantial increases in temperature that will impact northern Europe during winter and southern Europe during summer. Moreover, it is expected that these changes will cause increasing water shortages along the Mediterranean and in the south-west Balkans and in the south of European Russia. The consequences on the European agricultural ecosystems are likely to vary widely depending on the cropping system being investigated (i.e. cereals vs. forage crops vs. perennial horticulture), the region and the likely climate changes. In northern Europe, increases in yield and expansion of climatically suitable areas are expected to dominate, whereas disadvantages from increases in water shortage and extreme weather events (heat, drought, storms) will dominate in southern Europe. These effects may reinforce the current trends of intensification of agriculture in northern and western Europe and extensification and abandonment in the Mediterranean and south-eastern parts of Europe. Among the adaptation options (i.e. autonomous or planned adaptation strategies) that may be explored to minimize the negative impacts of climate changes and to take advantage of positive impacts, changes in crop species, cultivar, sowing date, fertilization, irrigation, drainage, land allocation and farming system seem to be the most appropriate. In adopting these options, however, it is necessary to consider the multifunctional role of agriculture and to strike a variable balance between economic, environmental and economic functions in different European regions.

Keywords Agriculture · Crops · Drought · Yield · Land use

Introduction

Europe is one of the world's largest and most productive suppliers of food and fibre. In 2007, it accounted for 18% of global meat production and 17% of global cereal production. About 67% of this production occurred in the EU countries. The productivity of European agriculture is generally high, in particular in western Europe, and average cereal yields in the EU countries are more than 40% higher than the world average (FAOSTAT 2007).

The trends in European agriculture are dominated by the EU Common Agricultural Policy. In 2003, it was decided to decouple the agricultural subsidies from the production. The future payment to farmers will be linked to the respect of environmental, food safety, animal and plant health and animal welfare standards, as well as the requirement to keep all farmland in good agricultural and environmental condition. This is not expected to greatly affect agricultural production outputs in the short term (OECD 2004). However, the reform is expected to enhance the current process of structural adjustment leading to larger and fewer farms (Marsh 2005).

The hydrological features in Europe are very diverse, and there is also a large diversity in water uses, pressures and management approaches. About 30% of abstracted fresh water in Europe is used for agricultural

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purposes, primarily irrigation (Krinner et al. 1999). The quality of river water is improving in most European countries (Nixon et al. 2003). However, the impact of agriculture on Europe's water resources needs to be reduced, if good status of surface and ground water is to be achieved as required by the EU Water Framework Directive.

Climate change is likely to affect agricultural systems very differently in various parts of Europe (Alcamo et al. 2007). In northern areas, climate change may primarily have positive effects through increases in productivity and in the range of species grown, although there may be negative effects of agricultural on, e.g., the water quality of surface waters. In southern areas, the disadvantages will predominate with lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops. Thus, adaptation strategies will be required to cope with these negative impacts.

At the same time, agricultural activities are among the major contributors to total EU-25 Greenhouse Gas emissions (GHG) (up to 10% in 2004, EEA 2006). Thus, mitigation strategies will also be required within the agricultural sector to comply with the reduction targets of the Kyoto Protocol.

This paper briefly described the responses of European agriculture to climate change, emphasizing in particular the impact, the adaptation and mitigation capacity and the vulnerability of European agricultural systems to climate change.

Future scenarios for Europe

The IPCC AR4 (Christensen et al. 2007) projected that annual temperature over Europe will warm at a rate of between 0.22°C per decade and 0.52°C per decade (under A1B scenarios). The projected temperature increases are slightly higher in northern Europe. The warming in northern Europe is likely to be largest in winter and that in the Mediterranean area largest in summer (Fig. 1). A south–north contrast in precipitation changes across Europe is indicated from A1B scenario projections, with increases in the north (up to 16%) and decreases in the south (from −4 to −24%) (Fig. 1).

The IPCC AR4 (Christensen et al. 2007) also projected that the variability in temperature (on inter-annual and daily time scales) is likely to increase in summer and decrease in winter in most European areas. In contrast, there is still quite a large quantitative uncertainty on changes in extreme precipitation, although indications are for more intense rainfall events (Christensen and Christensen 2003). Also heat waves and droughts are very likely to increase in frequency, intensity and duration. This can be illustrated by the 2003 European heat wave that led to substantial reductions in primary productivity of terrestrial ecosystems and large and widespread reductions in farm income (Fink et al. 2004; Olesen and Bindi 2004; Ciais et al. 2005).

Temporally and spatially explicit future scenarios of European land use, developed for four of the IPCC Special

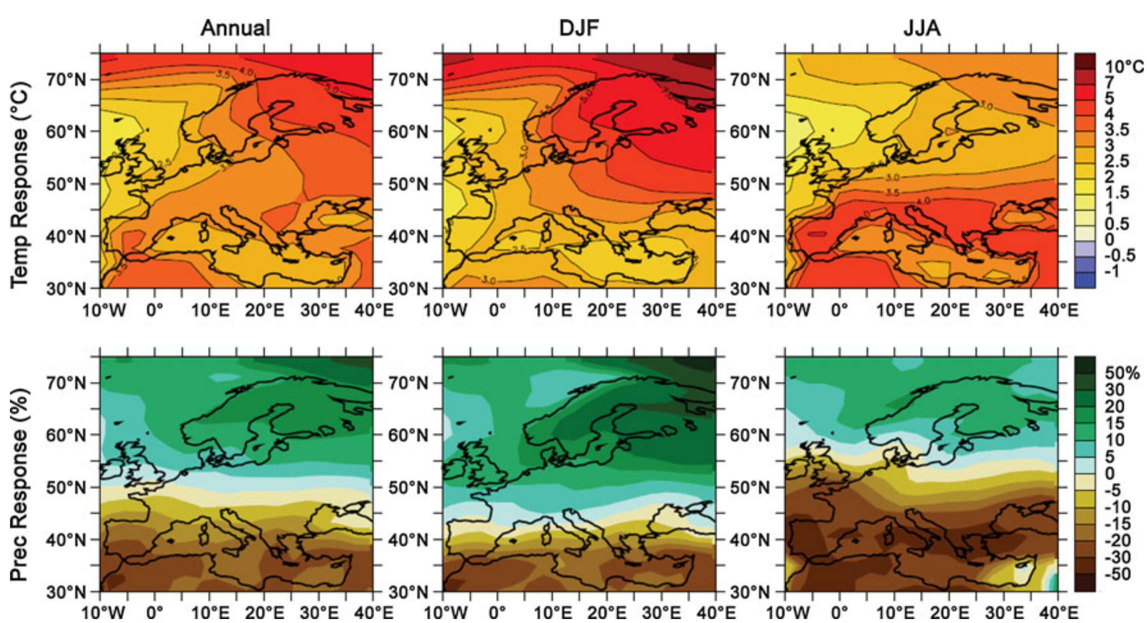

Fig. 1 Temperature and precipitation changes over Europe for the A1B scenario. *Top row* Annual mean, DJF and JJA temperature change between 1980 and 1999 and 2080 to 2099, averaged over 21 models. *Bottom row* same as *top*, but for fractional change in precipitation (from Christensen et al. 2007)

Table 1 Projected changes in wheat yield (%) in EU due to technology and technology plus climate and CO_2 and changes in cropland and grassland area (%) by 2080 (Ewert et al. 2005; Rounsevell et al. 2005)

Factor	Scenario			
	A1FI	A2	B1	B2
Yield, technology only	134	117	87	28
Yield, technology + climate + CO_2	141	142	98	43
Cropland area	−47	−45	−30	−28
Grassland area	−51	−58	−6	−38

Report on Emissions Scenarios (SRES) (Schröter et al. 2005), show large declines in agricultural land uses resulting from the assumptions about future crop yield development with respect to the changes in demand for agricultural commodities (Rounsevell et al. 2005). The scenarios showed decreases in European cropland for 2080 that ranged from 28% (B2) to 47% (A1FI) (Table 1). The reductions in European grassland for 2080 ranged from 6% (B1) to 58% (A2).

The projected decline in agricultural production area provides opportunities for other types of land use. One such possibility is the production of biofuels and biomaterials from biomass to reduce the current reliance on fossil fuels and petrochemicals (Ragauskas et al. 2006). The projected land with bioenergy production is most widespread under the A1FI, A2 and B2 scenarios with increases from 7 to 9% of the land area (Schröter et al. 2005).

Impacts

Crop suitability, yield and productivity

The effects of climate change and increased atmospheric CO_2 are expected to lead to overall small increases in European crop productivity. However, technological development (e.g. new crop varieties and better cropping practices) might far outweigh the effects of climate change (Ewert et al. 2005). Recently, cereal grain yields have shown considerable slowing of growth in yields, indicating that climate change may play a greater role in future than technological progress (Kristensen et al. 2010).

Climate-related increases in crop yields are expected mainly in northern Europe (Alexandrov et al. 2002; Ewert et al. 2005; Audsley et al. 2006; Olesen et al. 2007; Richter and Semenov 2005), while the largest reductions of all crops are expected in the Mediterranean, in the south-west Balkans and in the south of European Russia (Olesen and Bindi 2002; Alcamo et al. 2005; Maracchi et al. 2005). In southern Europe, general decreases in yield and increases in water demand are expected for spring sown crops (Giannakopoulos et al. 2009; Audsley et al. 2006), whereas the impacts on autumn sown crops are more geographically variable (Santos et al. 2002; Giannakopoulos et al. 2009; Audsley et al. 2006; Olesen et al. 2007). However, these results vary between SRES scenarios and climate models (Olesen et al. 2007).

Some crops that currently grow mostly in southern Europe (e.g. maize, sunflower and soybeans) will become more suitable further north or in higher altitude areas in the south (Audsley et al. 2006). The projections for a range of SRES scenarios show a 30 to 50% increase in suitable area for grain maize production in Europe by the end of the 21st century, including Ireland, Scotland, southern Sweden and Finland (Hildén et al. 2005; Olesen et al. 2007) (Fig. 2). Moreover, by 2050, energy crops show a northward expansion in potential cropping area, but a reduction in suitability in southern Europe (Schröter et al. 2005).

Environmental impacts

Environmental impacts of agriculture under a changing climate are considered more and more important. In particular, the role of nitrate leaching on the quality of aquifers, rivers and estuaries is a global problem, now generally recognized (Erisman et al. 2008; Jeppesen et al. 2009). Projections made at European level for winter wheat showed for the 2071–2100 period that decreases in N-leaching predominate over large parts of eastern Europe and some smaller areas in Spain, whereas increases occur in the United Kingdom and in smaller regions over many other parts of Europe (Fig. 3, Olesen et al. 2007).

The climate change scenarios could also lead to increases in greenhouse gas emissions from agriculture. Increasing temperatures will speed soil organic matter decomposition where soil moisture allows, so direct climate impacts on cropland and grassland soils will tend to decrease Soil Organic Carbon (SOC) stocks for Europe as a whole (Smith et al. 2005). This effect is greatly reduced by increasing C inputs to the soil because of enhanced Net Primary Production (NPP), resulting from a combination of technological progress, climate change and increased atmospheric CO_2 concentration. However, decomposition becomes faster in regions where temperature increases greatly and soil moisture remains high enough to allow decomposition (e.g. north and east Europe), but does not become faster where the soil becomes too dry, despite higher temperatures (southern France, Spain and Italy) (Smith et al. 2005).

Extreme weather events

The predicted increases in extreme weather events (e.g. spells of high temperature and droughts) (Meehl and

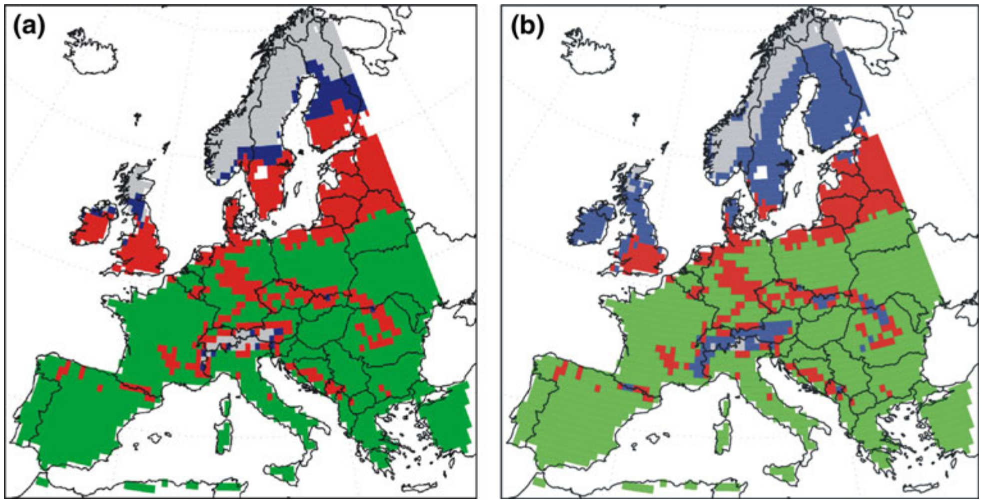

Fig. 2 Modelled bioclimatic suitability for grain maize cultivation during the baseline (1961–1990) and future (2071–2100) periods for: **a** 7 RCM scenarios driven by HadAM3H for the SRES-A2 emissions scenario and **b** 24 scenarios from 6 GCMs (CGCM2, CSIRO-MK2, GFDL-R30, ECHAM4/OPYC3, NCAR-PCM, HadCM3) for the SRES-A1FI, A2, B1 and B2 emissions scenarios. *Green* areas show the suitable area for the baseline, *red* the expansion common under all scenarios and *blue* the uncertainty range of the respective scenario group (Olesen et al. 2007)

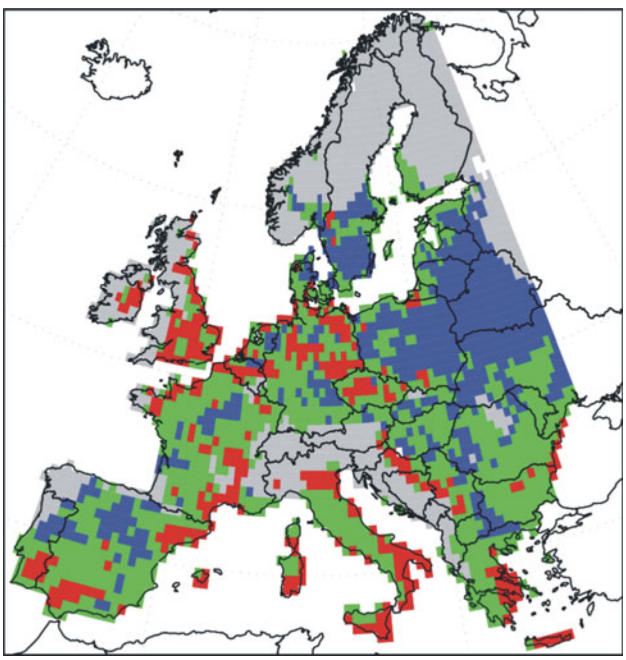

Fig. 3 Estimated change in nitrate leaching from winter wheat cultivation for 9 RCMs with HadAM3H as bounding GCM for the SRES-A2 emissions scenario with decreasing (*blue*), increasing (*red*) and conflicting (*green*) rates of nitrate leaching. *Grey* areas are estimated to be unsuitable for winter wheat (Olesen et al. 2007)

Tebaldi 2004; Schär et al. 2004) are expected to increase yield variability (Jones et al. 2003) and to reduce average yield (Trnka et al. 2004). In particular, in the European Mediterranean region, increases in the frequency of extreme climate events during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of summer crops (e.g. sunflower) (Moriondo et al. 2010).

Crop protection

Conditions are more favourable for the proliferation of insect pests in warmer climates, because many insects can then complete a greater number of reproductive cycles (Bale et al. 2002). Warmer winter temperatures may also allow pests to overwinter in areas where they are now limited by cold, thus causing greater and earlier infestation during the following crop season. A similar situation may be seen for plant diseases leading to an increased demand for pesticide control (Salinari et al. 2006). Changes in climatic suitability will lead to invasion of weed, pest and diseases adapted to warmer climatic conditions (Baker et al. 2000). The speed at which such invasive species will occur depends on the change of climatic change, the dispersal rate of the species and measures taken to combat non-indigenous species (Anderson et al. 2004).

Although not reported very often, the adaptation of crop pathogens to environmental stresses is yet another aspect that adds to the uncertainty of effects under climate change. Recently, wheat yellow rust has adapted to warmer climates in North America by rapid global spread of new aggressive strains of the wheat yellow rust pathogen. This may serve to illustrate the lack of predictability of crop pathogen behaviour more than a few years ahead and the significance of crop pathogen adaptation to new environments (Houmøller et al. 2008).

Livestock production

The expected increases in temperature, heat stresses and droughts seem to be the more relevant climatic impact factors on livestock. The predicted increases in the frequency of severe heat stress in Britain are expected to enhance the risk of mortality of pigs and broiler chickens raised in intensive livestock systems (Turnpenny et al. 2001). Increased frequency of droughts along the Atlantic coast (e.g. Ireland) may reduce the productivity of forage crops such that they are no longer sufficient for livestock at current stocking rates without irrigation (Holden and Brereton 2002, 2003; Holden et al. 2003). Increasing temperatures may also increase the risk of livestock diseases by (1) supporting the dispersal of insects, e.g. *Culicoides imicola*, that are main vectors of several arboviruses, e.g. bluetongue (BT) and African horse sickness (AHS); (2) enhancing the survival of viruses from one year to the next; (3) improving conditions for new insect vectors that are now limited by colder temperatures (Wittmann and Baylis 2000; Mellor and Wittmann 2002; Colebrook and Wall 2004; Gould et al. 2006).

Adaptive capacity and vulnerability

To avoid or at least reduce negative effects and exploit possible positive effects of climate change, adaptation strategies need to be considered. These together with the exposure to climate change exposure and the sensitivity of the agricultural systems will determine the vulnerability of a region. Following the definition provided by IPCC (2001), vulnerability is defined as “the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of the character and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. On the other hand, the adaptive capacity is defined as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences”. The two concepts are thus highly linked, because no change will happen without adaptation, either planned or autonomous, being it in human or natural systems. It is also important to consider the linkages between changes and adaptation in agricultural and natural ecosystems (Berry et al. 2006).

The adaptive capacity of the agricultural systems can be thought of as being applicable at different temporal and spatial scales, e.g. autonomous versus planned adaptations, where autonomous adaptation often occurs at shorter and smaller scales (e.g. farms) than planned adaptation, which requires longer time and often concerns regions or nations. The autonomous adjustments include efforts to optimize production without major system changes. They are autonomous in the sense that no other sectors (e.g. policy, research) are needed in their development and implementation. Examples of such adjustments are changes in varieties, sowing dates and fertilizer and pesticide use (Ghaffari et al. 2002; Alexandrov et al. 2002; Tubiello et al. 2000; Chen and McCarl 2001). In particular, in southern Europe, autonomous adaptations may include changes in crop species (e.g. replacing winter with spring wheat, Minguez et al. 2007), changes in cultivars and sowing dates (e.g. for winter crops, sowing the same cultivar earlier or choosing cultivars with longer crop cycle; for summer irrigated crops, earlier sowing for preventing yield reductions or reducing water demand) (Olesen et al. 2007). In northern Europe, new crops and varieties may be introduced only if improved varieties will be introduced to respond to specific characteristics of the growing seasons (e.g. length of the day) (Hildén et al. 2005).

The planned adaptations refer to major structural changes to overcome adversity caused by climate change. This involves changes in land allocation and farming systems, breeding of crop varieties, new land management techniques, etc.

Recent studies at European level have demonstrated the need to include changes in climate and non-climate factors (technological, socio-economic, etc.) for assessing the changes in crop yield and suitability (Schröter et al. 2005). A different allocation of European agricultural land use seems to represent one of the major planned adaptation strategies available. Rounsevell et al. (2005) estimate a decline of up to 50% in cropland and grassland areas under the A1FI and A2 scenarios. For the A1FI and A2 scenarios, both the quantity and the spatial distribution of crops will change, whilst for the B1 and B2 scenarios, the pressures towards declining agricultural areas should be counterbalanced by policy mechanisms that provide only small yield increases.

This projected land surplus may provide potential opportunities for the substitution of food production by energy production through widespread cultivation of bioenergy crops (Tuck et al. 2006). Several temperate and Mediterranean crop species are suitable for various types of biofuels, including oilseed crops, starch crops, cereals and woody biofuel crops. All climate change scenarios show a northward expansion of these species with northern Europe becoming more favourable for most species. However, the choice of energy crops in southern Europe may be severely reduced in future, both due to increased temperatures and due to reduced rainfall.

Finally, farming systems may play a fundamental role in the adaptation of European agriculture to climate change. The interpretation of four IPCC-SRES scenarios suggests that different types of adaptation of farming systems (intensification, extensification and abandonment) may be appropriate for particular scenarios and areas (high latitude and altitude, marginal areas, etc.) (Berry et al. 2006).

Taking into account both potential impacts and adaptive capacity, agriculture vulnerability, based on "Farmer livelihood" (profit), has been analysed for EU15 (Metzger et al. 2006). The results depict the agricultural sector in the Mediterranean region as vulnerable under most scenarios starting at different time slices, depending on the scenario. The A1FI and A2 scenarios anticipate greater vulnerability throughout, whilst the B2 scenario seems to be the least harmful for farmer livelihood (Metzger et al. 2006).

Enhancing resilience

Two major current trends are expected to continue to influence the development of agricultural systems in Europe. These are (1) the continued trade liberalizations and globalization of markets for agricultural products and (2) increased focus on goods and services provided by agricultural systems, including environmental and social functions.

The first trend is likely to lead to increased intensification and rationalization of agricultural production systems with larger farms, simplified cropping systems and less use of labour. Such systems may be particularly vulnerable to climate change, since they function on market conditions and any changes in productivity, product quality or production costs will have immediate consequences for the viability of those systems. The projected climate changes are likely to reinforce the current trend of intensification in northern Europe. The possible negative effects concern adverse environmental effects, including increased nitrate leaching (Olesen et al. 2004) and increased need for crop protection measures (Boland et al. 2004).

The second trend is currently supported by the rural development pillar of the EU Common Agricultural Policy (CAP), where focus is on maintaining livelihoods in rural areas across Europe. In principle, it should be possible to maintain agricultural activities throughout Europe, and some of the lower input systems, such as organic farming, may have a higher resilience to climate change, because these systems often are more diversified than conventional farming systems and thus offer more options for change. The price for this is higher costs for running such systems, which are therefore reliant on premium prices or subsidies.

The EU CAP is continuously being reformed to comply with both the trade liberalization and the needs to preserve environment and maintain rural structures. This involves transferring production subsidies to area-based subsidies and rural development measures. It appears that many parts of Europe would need in future to be protected from world markets in order to maintain agricultural production and rural communities (Rounsevell et al. 2005). Future CAP changes should therefore be able to facilitate autonomous adaptation to climate change. In particular, since the impacts of climate change will vary between the regions, the CAP should be designed to deal with these regional differences (e.g. in southern Europe, major concerns will be abandonment of cultivated areas and water supply for irrigation, whereas in northern Europe intensified production and the adverse environmental effects of farming are the major concerns) (Olesen and Bindi 2002).

The design of future agricultural production systems and agricultural policies also need to consider the need for reductions in greenhouse gas emissions. It may be particularly difficult to obtain increases in soil carbon storage or even maintain current stocks, since the global warming will inevitably lead to higher turnover rates of soil organic matter, which will only partly be compensated by increased inputs (Bellamy et al. 2005; Smith et al. 2005). However, there are a number of possibilities for reducing emissions of methane and nitrous oxide emissions through improving management practices and introducing new technologies (Schils et al. 2006; Weiske et al. 2006).

Conclusions

The results of studies performed in recent years over Europe indicated consistent increases in temperature and different patterns of precipitation with widespread increases in northern Europe and rather small decreases over southern Europe. These changes in climate patterns are expected to affect all components of the European agricultural ecosystems (e.g. crop suitability, yields, environmental impacts, crop protection, livestock). Thus, adaptation strategies should be introduced to reduce negative effects and exploit possible positive effects of climate change. Among these, it seems that both autonomous adjustments (e.g. changes in crop species, cultivars and sowing dates) and planned adaptations (e.g. land allocation and farming system) should be considered. However, the differences in climate exposure, sensitivity and adaptive capacity will affect in a different way the agricultural ecosystems across Europe. In particular, agriculture in the Mediterranean and south-east European regions seems to be more vulnerable than other European regions.

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