Socio-economic Impacts—Agricultural Systems

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Abstract

Europe is one of the world's largest and most productive suppliers of food and fibre. In the North Sea region, agroecosystems vary from highly productive farming systems such as the arable cropping systems of western Europe to low-input and low-output farming systems with or without livestock. Climate change impacts on agricultural production will vary across the North Sea region, both in terms of crops grown and yields obtained. Given adequate water and nutrient supply, a doubling of atmospheric CO_2 concentration could lead to yield increases of 20–40 % for most crops grown in the North Sea region. The high-input farming systems could also respond favourably to modest warming. Extreme weather events may severely disrupt crop production. Increased temperature and more frequent extreme weather events could affect animal production through changes in feed production, changes in the availability of grazing, direct heat stress, and increased risk of disease. Overall, there seems to be potential for agriculture in the North Sea region to adapt to the changing climate in such a way that productivity and profitability may both increase, particularly over the long term. The challenge will be to ensure sustainable growth in agricultural production without compromising environmental quality and natural resources.

13.1 Introduction

Agriculture is situated at the interface between ecosystems and society with the main aim of ensuring food supply. Located at this interface, agriculture is both affected by and helps drive changes in global environmental conditions, for the latter by contributing to emissions of greenhouse gases, notably methane and nitrous oxide. Management of agricultural ecosystems varies from highly productive farming systems such as the arable cropping systems of western Europe to low-input and low-output farming systems with or without livestock, some of which are also located in Europe.

Europe is one of the world's largest and most productive suppliers of food and fibre (Olesen and Bindi 2002). In 2012, it accounted for 19 % of global meat production and 17 % of global cereal production. About 78 % of the European meat production and 63 % of cereal production occurred within EU countries, with the remaining production primarily in Russia, Belarus and Ukraine. The productivity of European agriculture is generally high, especially in western Europe, and average hectare cereal yields in EU countries are about 40 % higher than the world average (Olesen et al. 2011).

The overall driving force in agriculture is the globally increasing demand for food and fibre. This is primarily caused by a growing world population with a high demand for food production and a wealthier world population with a higher proportion of meat in the diet (Godfray et al. 2010). The result is that agriculture globally exerts increasing pressure on the land and water resources of the earth, which often results in land degradation (such as soil erosion and salinization), and eutrophication. Agriculture is also associated with greenhouse gas emissions (Kirchmann and Thorvaldsson 2000).

Agricultural land use along the Atlantic coast in Europe is dominated by grassland and forage crops, because the wet conditions limit soil trafficability (i.e. capability of supporting

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agricultural traffic/machinery without degrading the soil) required for cultivating annual crops. In regions with less rainfall such as continental parts of Europe, arable cropping systems often dominate the agricultural landscape. In northwest Europe the arable cropping systems are dominated by cereals, in particular winter wheat and spring barley, and break crops (secondary crops grown to interrupt the repeated sowing of cereals as part of crop rotation) like oilseed rape, grain legumes, and root and tuber crops like sugar beet and potato. Over recent decades the area cultivated with high yielding crops such as winter wheat and silage and grain maize has increased. This increase in area of winter wheat has largely happened at the expense of less productive spring cereal crops.

Increases in winter wheat yield are mostly due to crop breeding and improved crop protection coupled with increased fertilisation; however, wheat yields in Europe have been stagnating over the past 10 to 20 years (Olesen et al. 2011). There also seems to have been greater variability in grain yields for wheat over the past two decades. Stagnating wheat yields in France have been attributed to lower yields under the rising temperature (Brisson et al. 2010), but changes in management may also have played a role in some countries (Finger 2010). In contrast to wheat, yields of grain maize show a continued increase in both France and Germany, such that grain maize yields now exceed those of winter wheat. The area of silage and grain maize is therefore growing in northern Europe (Elsgaard et al. 2012), and this appears to be linked to the warmer climate (Odgaard et al. 2011).

High-input farming systems in western and central Europe generally have a low sensitivity to climate change, because a given change in temperature or rainfall has a modest impact (Chloupek et al. 2004) and because farmers have resources to adapt management. However, there may be considerable difference in adaptive capacity between cropping systems and farms depending on their specialisation (Reidsma et al. 2007). These systems may therefore respond favourably to modest climate warming (Olesen and Bindi 2002). Across the North Sea region there is a large variation in climatic conditions, soils, land use and infrastructure, which greatly influences responsiveness to climatic change.

13.2 Impacts

13.2.1 Crop Responses to Climate Change

Rising greenhouse gas emissions affect agroecosystems directly (primarily by increasing photosynthesis and water use efficiency at higher CO_2 levels) and indirectly via climate change (temperature and rainfall affect several aspects of the functioning of cropping systems). Effects may also be both direct through changes in crop physiology and indirect through impacts on soil fertility, crop protection (weeds, pests or diseases) and the ability to perform field operations in a timely manner. The exact responses depend on the sensitivity of the particular agricultural system to environmental change and on the relative changes in controlling factors.

Increasing atmospheric CO_2 concentration stimulates yield of crops that have the so-called C3-photosynthesis pathway, which constitute almost all crops grown in the North Sea region, with the exception of maize and *Miscanthus* (cultivated for biofuel). A doubling of atmospheric CO_2 concentration is projected to lead to yield increases of 20–40 % in most crops (Ainsworth and Long 2005), provided adequate water and nutrient supply. The response is considerably less for C4-plants, which include tropical grasses such as maize. Higher CO_2 concentration not only increases photosynthesis, but also reduces plant water consumption. This may result in improved tolerance of plants to drought and generally drier conditions.

Higher CO_2 concentrations also affect the quality of plant biomass, because plants accumulate more sugar leading to higher carbon contents of leaves, stems and reproductive organs. This has consequences for the quality of the food and feed, which in some cases are negative. It will thus reduce the protein content of cereal grains and diminish the baking quality of wheat (Högy et al. 2013). The attraction of plants for pests and diseases will also change, which could make the plants more resistant to attack. However, weed growth will also benefit from increased CO_2, which may necessitate intensified or different control measures, for example, due to reduced efficacy of herbicides (Ziska 2001).

Temperature affects crops in different ways, partly through affecting the timing of crop phenological phases (crop development); partly through the efficiency of energy capture, conversion and storage (crop growth); and partly through crop water demands (temperature affects evapotranspiration). With warming, active growth starts earlier, plants develop faster, and the potential growing season is extended. This may have the greatest effect in colder regions (Trnka et al. 2011), and may be most beneficial for perennial crops or crops which remain in their vegetative phase, such as sugar beet and grasslands.

Higher temperature reduces crop duration of determinate species (plants that flower and mature). This concerns all cereals and seed plants such as pulses and oilseed crops. For wheat, a temperature increase of 1 °C during grain fill is estimated to reduce the length of this phase by 5 %, and yield to decline by a similar amount (Olesen et al. 2000). However, in the North Sea region such reductions can often be more than offset by changing to cultivars with longer growth duration (Olesen et al. 2012) and this may even lead

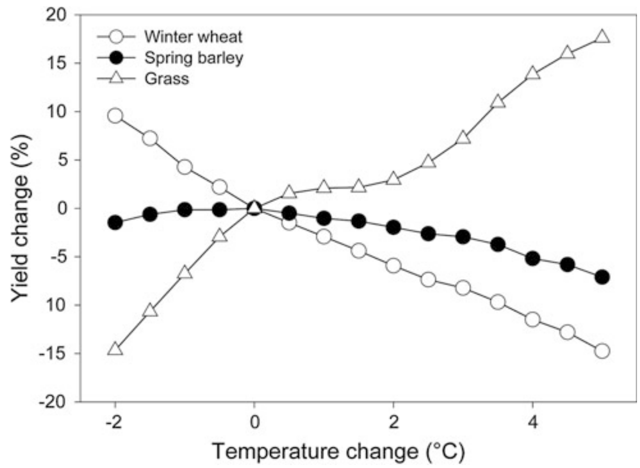

Fig. 13.1 Mean simulated change in yield of winter wheat, spring barley and ryegrass with increasing temperature for a site in Denmark. The simulations were performed with the CLIMCROP model assuming that water is not growth-limiting (Olesen et al. 2000; Olesen 2005)

to improved yields with potential for longer growing seasons at high latitudes (Montesino-San Martin et al. 2014).

These differential responses of crop yield to rising temperature in plants with different responses of crop development are illustrated in Fig. 13.1. The results were produced with a crop simulation model that integrates the biophysical interactions between soil, climate and plants on crop growth and yield over the growing season. Such models are commonly used to assess the effects of climate change on crop yield and quality (Ewert et al. 2015).

The greatest reductions in grain yield in Fig. 13.1 were simulated for winter wheat, where growth duration is reduced, because any changes in sowing date in autumn would have little effect on duration of the vegetative and reproductive phases in the following spring and summer. This response concurs well with observed response of winter wheat yields in Denmark, where the largest reductions were found to be related to high temperatures during the grain filling phase (Kristensen et al. 2011). Figure 13.1 shows a smaller response of spring barley to higher temperatures, because this crop can be sown earlier in spring thus maintaining a productive growing season. In contrast, yields were simulated to increase for a grass crop, which represents crops with a non-determinate growth pattern, where yields depend on the total duration of the growing season with suitable temperatures and rainfall.

Peltonen-Sainio et al. (2010) characterised the coincidence of yield variations with weather variables for major field crops using long-term datasets to reveal whether there are commonalities across the European agricultural regions. Long-term national and/or regional yield datasets were used from 14 European countries for spring and winter barley and wheat, winter oilseed rape, potato and sugar beet. Harmful effects of high precipitation during grain-filling in grain and seed crops and at flowering in oilseed rape were recorded. In potato, reduced precipitation at tuber formation was associated with yield penalties. Elevated temperature had harmful effects for cereals and rapeseed yields. Similar harmful effects of rainfall and high temperature on grain yield of winter wheat were found by Kristensen et al. (2011) in a study using observed winter wheat yields from Denmark.

13.2.2 Impacts of Climatic Variability and Weather Extremes

Extreme weather events, such as periods of high temperature, heavy storms, or droughts, can severely disrupt crop production. Individual extreme events do not usually have lasting effects on the agricultural system. However, if the frequency of such events increases, agriculture will need to respond, either by adapting or by ceasing its activity.

Crops often respond nonlinearly to changes in their growing conditions and have threshold responses, which greatly increases the importance of climatic variability and the frequency of extreme weather events in terms of absolute yield, yield stability and quality (Trnka et al. 2014). This may lead to drastic reductions in yield from short episodes of high temperature during sensitive crop growth phases such as the reproductive period. Temperatures above 35 °C during the flowering period can in most crops severely affect seed and fruit set and thus greatly reduce yield (Porter and Semenov 2005). High temperatures will also greatly increase evapotranspiration leading to higher risk of drought, if rainfall is insufficient to compensate for the water losses (Lobell et al. 2013). Such high temperature stresses may severely impact crop yields, even in the North Sea region (Semenov and Shewry 2011).

An increase in temperature variability will increase yield variability and also result in a reduction in mean yield. Even in the North Sea region there may be a sufficient increase in climatic variability to significantly affect crop yield (Kristensen et al. 2011), although this effect is expected to be more severe in other parts of the world. This risk is likely to be particularly large for high-input production systems (Trnka et al. 2012), where the demand for continued high soil water supply is greater than for low-input systems (having lower rates of evapotranspiration). Also, a given proportional reduction in crop yield will have a greater absolute yield effect on high- rather than low-yielding crops. Therefore increases in climatic extremes will also have greater effects in high-input rainfed systems than in less intensive and diverse systems (Schaap et al. 2011). The high-input rainfed cropping systems may thus be particularly vulnerable to climate change, although some will also benefit in terms of higher average yields from the warming and higher CO_2 concentrations.

13.2.3 Changes in Crop Productivity and Suitability

Climatic warming will in temperate regions result in earlier onset of the growing season in spring and a longer duration in autumn. A longer growing season allows the proliferation of species that have suitable conditions for growth and development and can thus increase their productivity (e.g. crop yield, number of crops per year). This may also allow for the introduction of new species previously unfavourable due to low temperatures or short growing seasons. This is relevant for the introduction of new crops, such as for grain maize or winter wheat in northern Europe (Elsgaard et al. 2012), but will also affect the spread of weeds, pests and diseases that often follow the crops grown (Roos et al. 2011).

Warming has already caused a northward expansion of the area of silage maize in northern Europe into southern parts of Scandinavia, where the system of grass and silage maize for intensive dairy production has largely replaced the traditional fodder production systems (Odgaard et al. 2011; Eckersten et al. 2014; Nkurunziza et al. 2014). Very recently grain maize has started to be grown in southern parts of Denmark, reflecting the warming trends (Elsgaard et al. 2012). Analyses of the effects of observed climate change on yield potential in Europe have shown positive effects for maize and sugar beet, which have benefited from the longer growing season for these crops (Supit et al. 2010). Yield benefits have been greatest in northern Europe. The warming may also have contributed to higher potato yields in northern regions of Europe. In contrast, warmer and more variable climatic conditions with increased occurrence of drought have reduced crop yields in parts of central Europe (Eitzinger et al. 2013).

A further lengthening of the growing season as well as a northward shift for some species are projected to result from further increases in temperature across Europe (Olesen et al. 2011). The date of last frost in spring is projected to reduce by 5–10 days by 2030 and 10–15 days by 2050 throughout most of Europe compared with the period 1961–1990 (Trnka et al. 2011). Since a longer growing season will increase productivity of many crops in northern Europe, this could lead to further intensification of cropping systems.

Projected climate change is expected to result in more favourable conditions for crop production at high latitudes than at low northern European latitudes (Table 13.1). The agroclimatic indices show a substantial lengthening (one month) of the growing season by 2050 in northern regions, but much less in southern parts of the North Sea region. Although the duration of the growing season is projected to increase throughout the North Sea region, in southern and continental parts this increase may be counteracted by drier conditions during summer resulting in reduced crop growth.

Projected impacts of climate change on crop yields depend on crop type, emission scenario and the sensitivity of the underlying climate model used to project climate changes (Olesen et al. 2007). Projections for most crops in the North Sea region show an increase in projected yield during the first half of the 21st century (Supit et al. 2012). However, later in the century yield is projected to decrease due to the effects of temperature rise and reduced summer rainfall that together exceed the benefits achieved from higher atmospheric CO_2 concentration, in particular for cereal crops. For root and tuber crops in Europe (such as sugar beet and potato) yields are projected to continue increasing (Angulo et al. 2013). However, even for potato some regions may become less suitable for production due to drier summer conditions and constraints imposed on the use of irrigation (Daccache et al. 2012).

At high latitudes or at high elevations with wet and cool climates, cropping systems with grasslands and forage production for ruminant livestock currently tend to dominate. Timothy *Phleum pratense* L. and perennial ryegrass *Lolium perenne* L. are the most important forage grasses at high latitudes, and in cold and snow-rich regions, timothy outcompetes perennial ryegrass due to better winter survival (Höglind et al. 2013). Due to the higher productivity and better feed quality of ryegrass compared to timothy, warming leading to less risk of winter kill is expected to shift the patterns in the cultivation of grassland species in Norway and Sweden northwards. Similar shifts may be expected in grazing season duration (Uleberg et al. 2014). In some cases these shifts will be constrained by rainfall, either with conditions too dry during summer or too wet during spring or autumn.

13.2.4 Environmental Impacts

Soils have many functions, of which water and nutrient supply to growing crops are essential for sustained crop production. However, soils are also important in regulating water and nutrient cycles, for carbon storage and greenhouse gas emissions. Soils are habitats for many of the organisms that contribute to the functioning of soils and agroecosystems, having both positive and negative effects on crop yield. Where soil moisture allows, increasing temperatures will enhance decomposition of soil organic matter, which tends to decrease soil organic stocks unless counterbalanced by larger inputs of organic matter in crop residues (Falloon and Betts 2010). A reduction in soil carbon enhances the

Table 13.1 Effects of projected climate change on changes in key agroclimatic indices in northern European agroecological zones by 2050 compared to the period 1961–1990 (Trnka et al. 2011)

Zone	Change in effective solar radiation (%)	Change in effective growing days (days)	Change in date of last frost (days)	Change in dry days in spring (%)	Change in dry days in summer (%)
Alpine North (Norway and north Sweden)	+8	+29	−10	+1	−2
Boreal (Finland, central Sweden, parts of Norway)	+8	+16	−11	−1	+2
Nemoral (south-central Sweden)	+8	+12	−10	+1	+11
Atlantic North (Ireland, British Isles, western Denmark, Netherlands)	−1	+5	−11	−4	+21
Continental (east Denmark, south Sweden, Germany)	−6	−6	−12	−2	+20

contribution of agriculture to global warming through higher net CO_2 emissions. In contrast, the effects of warming on nitrous oxide emissions from agricultural soils are less clear, since effects depend on the balance between the separate effects of temperature, rainfall and CO_2 as well as their seasonal changes, relative to effects of changes in crop growth patterns (Dijkstra et al. 2012).

Any reduction in soil organic matter stocks implies a decrease in fertility and biodiversity, a loss of soil structure, reduced soil water infiltration and retention capacity, and increased risk of erosion and compaction. If these changes are significant, this leads to lower productivity of crops growing on the soils. Changes in rainfall and wind patterns, in particular more intense rainfall, can lead to increased erosion from soils with poor crop cover or with little surface cover of plant residues to protect the soil. Also, increasing frequencies of freeze/thaw cycles during winter, due to reduced snow cover, in combination with stronger rainfall may greatly enhance soil erosion (Ulén et al. 2014). In addition to depleting soil fertility this erosion may also enhance nutrient runoff to sensitive aquatic ecosystems (Jeppesen et al. 2009).

Faster decomposition of soil organic matter at higher temperatures increases mineralisation of soil organic nitrogen. This in turn may increase the risk of nitrate leaching during periods of little or no crop cover with sufficient nitrogen uptake to prevent nitrate being leached in periods of precipitation surplus (Jabloun et al. 2015). This may increase the risk of nitrate leaching to surface and groundwater systems (Stuart et al. 2011; Patil et al. 2012). Current measures to reduce nitrate leaching may not be sufficient to maintain low leaching rates under projected climate change (Doltra et al. 2014) and this could increase the risk of algal blooms and the occurrence of toxic cyanobacteria in lakes (Jeppesen et al. 2011).

13.2.5 Crop Protection

Most pest and disease problems are closely linked with their host crops. Introducing new crops will therefore mean new pest and disease problems. In cool regions, higher temperatures favour the proliferation of insect pests, because many insects can then complete a greater number of reproductive cycles. Higher winter temperatures will also allow pests to overwinter in areas where they are currently limited by cold periods, causing greater and earlier infestation during the following crop season (Roos et al. 2011). Earlier insect spring activity and proliferation of some pest species will favour some of the virus diseases that spread with insects. A similar situation may occur for plant fungal diseases leading to increased need for pesticides.

Unlike pests and diseases, weeds are directly influenced by changes in atmospheric CO_2 concentration. Differential effects of CO_2 and climate change on crops and weeds will alter the weed-crop competitive interactions, sometimes to the benefit of the crop and sometimes to the weeds. Interaction with other biotic factors and with changing temperature and rainfall may also influence weed seed survival and thus weed population development.

Improved climatic suitability will lead to invasion of weeds, pests and diseases adapted to warmer climatic conditions. The speed at which such species invade depends on the rate of climatic change in terms of suitability ranges (e.g. in km per year), the dispersal rate of the species (e.g. in terms of km per year) and on measures taken to combat non-indigenous species. The dispersal rates of pests and diseases are often so high that their geographical extent is determined by the range of climatic suitability. The Colorado beetle *Leptinotarsa decemlineata* L. and the European cornborer *Ostrinia nubilalis* Hubner are examples of pests and diseases that are expected to show a considerable northward expansion in Europe under climatic warming (Olesen et al. 2011).

Studies show projected increases in the occurrence of several crop diseases with projected warming in the currently cooler parts of high-input cropping regions, such as UK (Butterworth et al. 2010; Evans et al. 2010) and Germany (Siebold and von Tiedemann 2012), whereas the risk of some diseases may reduce with warming in regions further south, such as France (Gouache et al. 2013). As well as affecting crop yield, such changes will also affect the quality of the yield, for example through the occurrence of mycotoxins which may increase in northern Europe under the projected climate change (Madgwick et al. 2011; van der Fels-Klerx et al. 2012). This would increase the need for fungicides or alternative strategies such as breeding for resistance.

13.2.6 Livestock Production

Increased temperature and more frequent extreme weather events could affect animal production through changes in feed production, changes in availability of grazing, direct heat effects on animals, and increased risk of disease.

More variable weather and more extreme weather events are projected under climate change (Jacob et al. 2014). This is likely to result in more variable quantities and quality of crops such as cereals, forage crops and protein crops, causing unstable feed prices both globally and locally. This has already occurred in recent years, with large fluctuations in grain price due to heat waves and droughts in wheat-producing regions. This has mostly affected production of monogastric livestock such as pigs and poultry. However, ruminant animals have also been affected through the production of grass and forage, either because conditions are too wet or too dry, which affects grazing. For example, in 2003 a long drought across western and central Europe severely affected not only arable crop production, but also fodder production for ruminants, to the extent that livestock production costs greatly increased (Fink et al. 2004).

Climate change will exacerbate problems with existing animal diseases, which negatively affect animal welfare and livestock production. Global warming and more frequent extreme weather events (droughts and increased rainfall) will provide more favourable climates for some viruses, their vector species, and for fungal or bacterial pathogens. New viral vector-borne diseases may not necessarily originate from nearby regions but may arrive from outside Europe. An example is bluetongue disease, where climate change has allowed the midge *Culicoides imicola* Kiefer that acts as a vector for the disease to spread—causing the virus to expand its distribution northwards in Europe (Purse et al. 2005). The risk of bluetongue and other emerging pathogens and vectors becoming established in the North Sea region will greatly increase under higher temperatures. Blood-sucking midges *Culicoides* spp. are one of the major threats to animal welfare, because they spread viruses that cause serious diseases in animals. Ticks, mosquitoes and lymnaeid snails can also transmit extremely harmful diseases to livestock. Increased annual temperature, milder winters and higher rainfall will favour the propagation of helminth parasites, resulting in disease and pronounced negative effects on the welfare of grazing cattle and sheep (Skuce et al. 2013).

13.3 Adaptation, Vulnerabilities and Opportunities

13.3.1 Adaptation at Farm and Regional Scale

Farmers are already adapting to climate change since farming is very weather dependent. Farmers constantly experiment with new cropping techniques, and the most successful ones spread quickly among the farming community where agricultural advisors and researchers are ready to take up and disseminate new results. This is evident, for example, in the northward spread of silage maize into Denmark and southern Sweden (Odgaard et al. 2011). Such adaptations are autonomous in the sense that they require no external action or planning. In a European context they are also fairly effective due to the high capacity among farmers to incorporate new technologies and management practices.

Adaptation only works when the basic resources for crop growth are still maintained and when the climate allows proper soil and crop management to take place (Table 13.2). In northern areas climate change may have positive effects on agriculture through introducing new crop species and varieties, higher crop production and expansion of areas suitable for cultivation. Negative effects may be an increase in the need for plant protection, risk of increased nutrient leaching and the degradation of soil organic matter. Further south in Europe issues around managing drier summer conditions will dominate adaptation needs.

The responsiveness of agricultural systems to climate change depends on many factors, both how current crops are being affected by climate change, but also on the options available for modifying the systems to reduce negative impacts and take advantage of new opportunities. The capacity for agriculture in the North Sea region to adapt to future changes is expected to be good, since the changes could be largely favourable for production, and because research, educational and advisory capacities are high (Table 13.2). However, there may be barriers to adaptation, not least within the current agricultural and environmental policies that may have to be adjusted to ensure effective adaptation.

Table 13.2 Resource-based policies to support adaptation of agricultural systems to climate change (adapted from Olesen and Bindi 2002)

Resource	Policy
Land	*Reforming agricultural policy to encourage flexible land use.* The great extent of cropland in northern Europe across diverse climates will provide diversity for adaptation
Water	*Reforming water management to ensure balance between maintaining the amount and quality of water resources and the ecosystems that these support, with the needs of agricultural production.* Climate change will affect the demand for irrigation and drainage, which depending on location have consequences for water resources and their ecological quality and may affect needs for revising management and governance schemes
Nutrients	*Improving nutrient use efficiencies through changes in cropping systems and development and adoption of new nutrient management technologies.* Nutrient management needs to be tailored to the changes in crop production as affected by climate change, and utilisation efficiencies must be increased, especially for nitrogen, in order to reduce climate change induced emissions to water and air
Agrochemicals	*Support for integrated pest management systems (IPMS) should be increased through a combination of education, regulation and taxation.* There will be a need to adapt existing IPMS to changing climatic regimes
Energy	*Improving the efficiency of food production and exploring new biofuels and ways to store more carbon in trees and soils.* Reliable and sustainable energy supply is essential for many adaptations to new climate and for mitigation policies
Genetic diversity	*Assembling, preserving and characterising plant and animal genes and conducting research on alternative crops and animals.* Genetic diversity and new genetic material will provide important basic material for adapting crop species to changing climatic conditions, such as by improving tolerance to adverse conditions
Research capacity	*Encouraging research on adaptation, developing new farming systems and developing alternative foods.* Greater investment in agricultural research may provide new sources of knowledge and technology for adaptation to climate change
Information systems	*Enhancing national systems that disseminate information on agricultural research and technology, and encouraging information exchange among farmers.* Fast and efficient information dissemination and exchange to and between farmers using the new technologies (e.g. internet) will increase the rate of adaptation to climatic and market changes
Culture	*Integrating environmental, agricultural and cultural policies to preserve the heritage of rural environments in a new environment.* Integration of policies will be required to maintain and preserve the heritage of rural environments which are dominated by agricultural practices influenced by climate

Some of the adaptation is beyond farm scale, and requires collective action. This is the case for breeding new cultivars and for infrastructure projects that provide water for irrigation or for improving drainage at the catchment scale. Such efforts may have long time perspectives and involve many actors and so require planning and in some cases approval from authorities. Actions for managing water at the catchment scale require a consideration not only of the needs of farmers, but also of the needs of human settlements and nature conservation, including consideration of surface and groundwater quality (Refsgaard et al. 2013).

Plant and livestock breeding is one of the most effective options for adapting to climate change, as well as switching livestock and crop species used. Among the measures required for both plant and livestock breeds is to increase tolerance to heat stress events (Semenov et al. 2014). For plants, there is also a need to enhance tolerance to a wider range of stresses, including drought, extreme heat and flooding. Soil management will need to accommodate the projected increase in frequency and intensity of erosion events associated with more intense rainfall. This may involve trade-offs between various factors that all contribute to crop yield. Therefore there is a risk that higher yield stability may come at the cost of reduced yield in favourable years. Plant breeders will need to deliver cultivars that are more resilient to weather extremes and resistant to new diseases. Plant breeding is a long-term activity, and timely delivery of such cultivars will require good and early predictions of future environmental conditions to allow the development and use of suitable germplasm.

13.3.2 Role of Vulnerability and Uncertainty in Adaptation

Projecting the effects of climate change on agricultural systems involves many uncertainties, some concern the climate change projections themselves while others concern biophysical understanding of how crops and livestock will respond to climate change. However, an even larger uncertainty concerns how well farmers and agricultural systems can and will adapt to climate change in the longer term in order to minimise losses and take advantage of new opportunities (Moore and Lobell 2014). Part of the uncertainty lies in how quickly some of the longer-term adaptations needed to overcome major changes in climate (expanding irrigation or drainage systems, new crops etc.) can be implemented, since short-term adaptations (e.g. changes in varieties or sowing time) are likely to be much less effective (Fig. 13.2). In southern Europe, farming profits are expected to decline

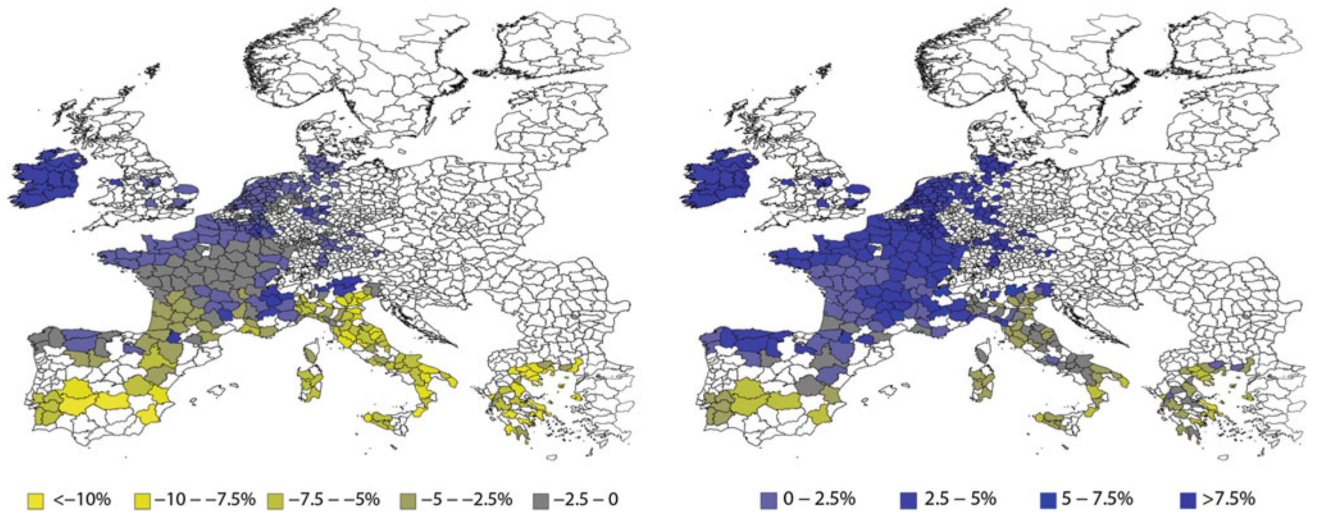

Fig. 13.2 Projected change in farm profit by 2040 under the IPCC A1B scenario for selected growing regions in Europe. Data concern wheat, maize, barley, sugar beet and oilseed. Projections made with short-run response function of crop yield to temperature and precipitation (*left*) and projections made using a long-run response function that includes farm-level adaptations (*right*) (Moore and Lobell 2014). White areas reflect regions with insufficient data

under climate change, while the North Sea region may see a rise in farming profits, particularly over the long term.

Temperature and rainfall regimes in combination with soil properties dictate the potential for agricultural production. Thus climate change, particularly in terms of dryness or wetness will affect agricultural land use, and even moderate changes may have marked effects on land use, especially for soils that are borderline with respect to which crops can be grown (Brown et al. 2011). Such areas are therefore more sensitive to environmental change than areas that are clearly favourable or unfavourable for specific agricultural land uses under both current and future climatic conditions.

Adapting to increased frequency of extreme weather events may be a significant challenge, since extreme events are by nature difficult to predict and so are also difficult to prepare for. Even with statistical evidence that shows extremes are changing in frequency such information may be interpreted differently among decision makers, resulting in over- as well as under-adaptation (Refsgaard et al. 2013).

The European agricultural sector is regulated and financially supported in several ways. Therefore, a major consideration must be how the adaptation responses will interact with regulations on environmental and nature protection, as well as on issues such as food safety and local employment. The vast amount of EU support for farming may be used strategically to support adaptations that maintain the balance between the need for high-production output of healthy and safe foods on the one hand and the need to protect the environment as well as the agricultural resource base on the other.

13.4 Ecosystem Functions and Services

Climate change impacts on agricultural production will vary across the North Sea region, both in terms of crops grown and yields obtained. Overall, there seems to be potential for adapting to the changing climate in such a way that productivity and profitability may both increase. In some parts of the region, a longer growing season would enable a switch to longer season crops such as highly productive grasses or *Miscanthus*, which with the use of biorefinery technologies could increase the output not only of food and feed for livestock, but also of the production of biofuels as a fossil fuel substitute (Smith and Olesen 2010). Because similar increases are not projected for most annual crops, this may facilitate changes in cropping systems, provided the technologies become profitable.

In grasslands, a longer growing season would allow more cuts and higher production, particularly in areas less affected by summer drought. This may facilitate greatly increased production of protein-rich crops by cultivating highly productive grass-clover pastures with little fertiliser and pesticide use. These pastures may be harvested for feed or grazed by ruminant livestock such as dairy and beef cattle and sheep. The pastures may also be a new source of sustainable protein production for monogastric farm animals (pigs and poultry) as well as for farmed fish. This would require the development and implementation of new biorefinery technologies, for which Europe with its ability to combine advanced technologies may be particularly well suited (Parajuli et al. 2015). This would strengthen the role of northwest Europe as a continued supplier of food, but also as a supplier of the technologies for sustainable intensification of production systems that target both adaptation and mitigation to climate change.

Changes in climatic suitability may lead to major changes in land use, which would affect not only the production of goods in agriculture, but also the landscape and ecosystem services (such as the quality of nature, the environment, groundwater and freshwater systems) (Harrison et al. 2013). This would challenge current land use planning, and would call for a strategic, long-term perspective on land-use policy under climate change (van Meijl et al. 2006).

In arable farming systems, higher temperatures will enhance turnover of soil organic matter and this, in combination with increased and more intense rainfall, would enhance the risk of nitrogen and phosphorus losses to the aquatic environment, thereby threatening the quality of these waters for recreational use and fish production. New and revised policy may be needed to manage the environmental impacts of agricultural production. Likewise, an increased need for pesticide use in agricultural production would be problematic in relation to current EU pesticide policies.

Policies will need to promote active resource management and the utilisation of renewable raw materials as substitutes for metal and oil-based products and fossil fuels. This is essential for sustainable resource management, as well as for mitigating climate change. Resource management of this type would need to take multiple needs into consideration, including: provision of biomass for food, feed, bioenergy and biomaterials within the bioeconomy; recycling of nutrients and resilient organic matter to the agricultural systems; maintenance of soil carbon stocks; and provision of other ecosystem goods and services, such as clean water and air and a diverse natural environment.

Cultivation of agricultural crops requires suitable and well-drained soils. The anticipated increase in winter rainfall across large parts of the North Sea region would place additional stresses on current drainage systems. This issue is expected to become increasingly important in areas where agricultural production may expand due to increased suitability. Enhancing drainage of agricultural soils cannot be implemented without ensuring that water can be effectively transported in streams and rivers. Aligning drainage needs with the need to protect parts of the landscape from flooding may cause conflict among actors, and will require new planning at the landscape and catchment level. Similar considerations must be taken into account when preparing for increased risk of summer drought.

13.5 Conclusions

Agricultural systems in northwest Europe are generally characterised by high inputs of fertilisers and pesticides and resulting high crop yields and livestock productivity. Observations over recent decades show consistent changes in crop phenology and geographical shifts towards higher latitudes of intensive crop cultivation in accordance with observed climate change. The observed effects on crop yield range from negative (dominating for cereal and seed crops) to positive (dominating for non-determinate crops such as many forage and grass crops). The combined effects of enhanced CO_2 and changes in temperature and precipitation are expected in many cases to increase productivity. Model-based and empirical studies show an increased risk of higher interannual yield variability with the projected climate change, resulting from changes in interannual temperature variability as well as from nonlinearities in the response of crops to changes in temperature and rainfall, increasing the risk of low yields. Negative effects on crop yield may be further exacerbated by extreme temperature and rainfall events. Climate change will further increase needs to reconsider measures for dealing with soil fertility, crop protection and nutrient retention in intensive cropping systems.

To contribute to global food security and help mitigate agricultural greenhouse gas emissions, there is a need to focus on sustainable intensification of agricultural production (Tilman et al. 2011). The challenges in the North Sea region will be to ensure sustainable growth in agricultural production without compromising environment and natural resources. This is likely to require the development of new production systems with a greater use of perennial crops such as grasses or increased use of cover crops in the rotations to make use of a longer growing season and to protect the soil and wider environment from erosion and nutrient leaching.

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