AGRICULTURAL IMPACTS AND ADAPTATIONS TO CLIMATE CHANGE IN EUROPE

JE OLESEN[1], M BINDI[2]

[1]Dept. of Agrometeorology, Danish Institute of Agricultural Sciences, 8830 Tjele,
Denmark, e-mail: JorgenE.Olesen@agrsci.dk
[2]DISAT-UNIFI, P.le delle Cascine 18, 50144 Firenze, Italy

ABSTRACT

Global warming resulting from antropogenic greenhouse gas emissions is projected to lead to substantial temperature increases in Northern Europe during winter and in Southern Europe during summer. It also expected to cause increasing water shortages in Southern Europe. Warming will lead to a northward expansion of suitable cropping areas. Changes in atmospheric CO_2 concentrations, temperature and rainfall will affect productivity of crops differently in different regions. In Northern Europe increases in productivity and expansion of suitable cropping 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 in the Mediterranean and southeastern parts of Europe. Agricultural policy will have to deal with these issues in particular supporting the adaptation of European farming systems to climate change. In doing so, 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. The concern of climate change should become a part of the ongoing efforts to reform the Common Agricultural Policy of the European Union.

INTRODUCTION

Global agricultural systems vary considerably in their sensitivity to climate and in vulnerability to change in the climatic regime. Intensive farming systems in Western Europe generally have a low sensitivity to climate change, because a given change in temperature or rainfall have modest impact (Chloupek et al. 2004), and because the farmers have resources to adapt and compensate by changing management. On the other hand some of the low input farming systems currently located in marginal areas may be most severely affected by climate change (Reilly & Schimmelpfennig 1999; Darwin & Kennedy 2000).

Climate change is expected to affect agriculture very differently in different parts of the world (Parry et al. 2004). The resulting effects depend on current climatic and soil conditions, the direction of change and the availability of resources and infrastructure to cope with change. There is a large variation across the European continent in climatic conditions, soils, land use, infrastructure, political and economic conditions (Bouma et al. 1998). These differences are expected also to greatly influence the responsiveness to climatic change (Olesen & Bindi 2002).

Most of Europe has experienced increases in surface air temperature during the 20th century, which amounts to 0.8°C in annual mean temperature over the entire continent (Kjellström 2004; Schär et al. 2004). Results of GCM model simulations indicate that large climatic changes may occur over the European continent as a result of the likely increase in atmospheric concentrations of greenhouse gases caused by anthropogenic emissions. The evaluation of climate change is usually based on simulations with global climate models (GCM) for the four

IPCC emissions scenarios (SRES scenarios), which describe very different socio-economic futures (Houghton et al. 2001). These scenarios indicate that annual temperatures over Europe warm at a rate of between 0.1°C decade^{-1} and 0.4°C decade^{-1} (Figure 1). The projected temperature increases are highest in Northern Europe during winter and highest in Southern Europe during summer. The general pattern of future changes in annual precipitation over Europe is for widespread increases in northern Europe (between +1 and +2 per cent decade^{-1}) and rather small decreases over southern Europe (maximum -1 per cent decade^{-1}). Recent results indicate that variability in temperature and rainfall may increase considerably over large parts of central Europe (Christensen & Christensen 2002; Schär et al. 2004).

This paper briefly described the impacts of climate change on European agricultural systems, and further discusses how agriculture in Europe may adapt to climate change and how this may influence European agricultural policy.

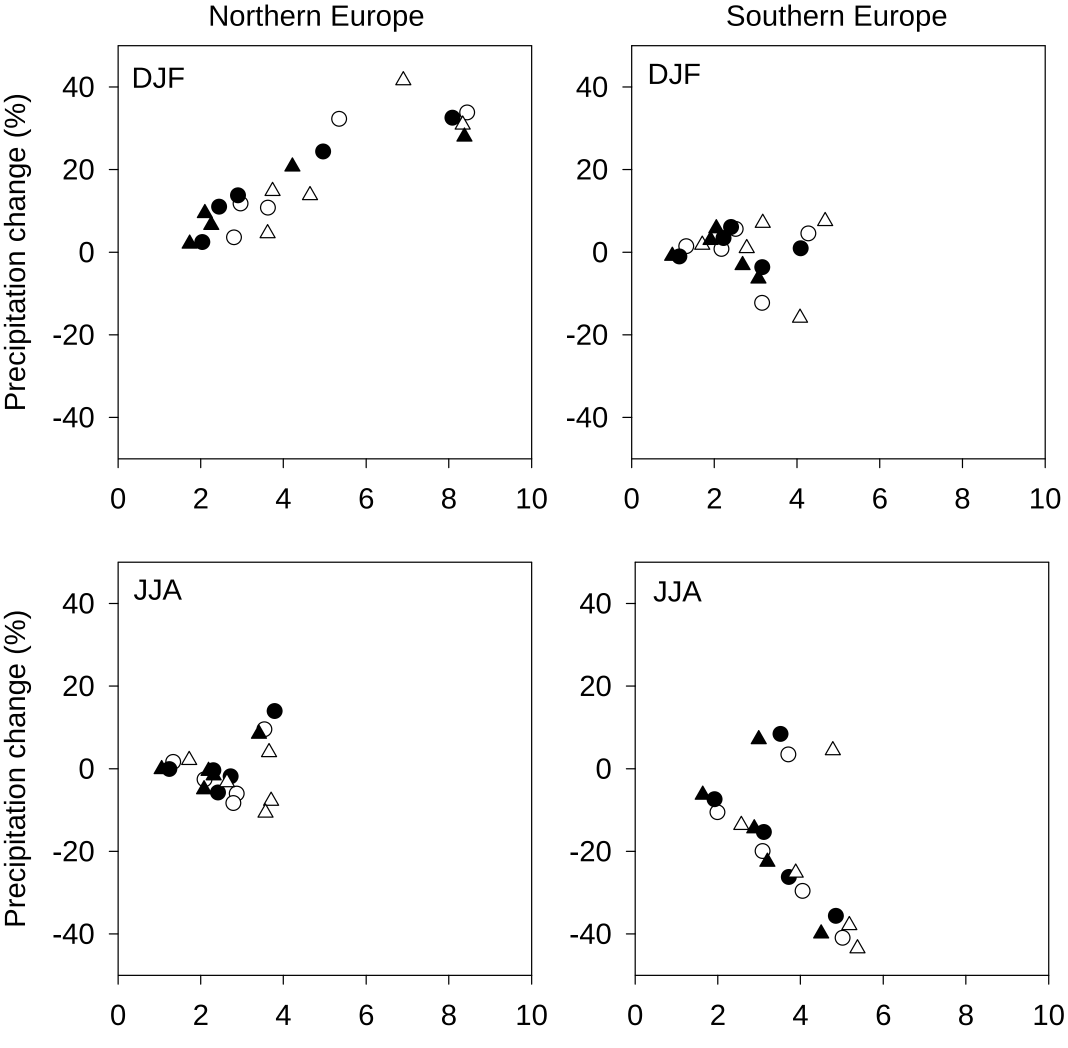

Figure 1: Projected climate change by 2040-2069 relative to the baseline period 1961-1990 depicted as mean relative change in precipitation versus temperature change for the winter (December to February, DJF) and summer (July to August, JJA) periods for Northern and Southern Europe. The points represent simulated results of different coupled atmosphere-ocean models driven by four different IPCC SRES scenarios: A1 (Δ), A2 (○), B1 (▲) and B2 (●) (Ruosteenoja et al. 2003).

EUROPEAN AGRICULTURE

Europe is one of the world's largest and most productive suppliers of food and fibre (Table 1). The 25 countries of the European Union (EU) thus alone accounted for 13% of the global cereal production and 17% of global meat production in 1998. The largest part of this production occurs in the original 15 EU countries, and these countries also have high productivities in the primary agricultural production as can be seen from the fact that the cereal production in these countries have a share of 11% of world production, whereas the cereal area only constitutes 6% of the global cereal area. These countries have 6% of the global population and half of the total population of Europe, but only 3% of global agricultural area.

Table 1: Proportion of world population, area or production for the EU-15 countries, the 10 EU accession countries and for Europe as a whole. The European Union (EU) was enlarged from 15 to 25 countries in 2004. Source: FAOSTAT.

	EU-15 (%)	EU accession (%)	Europe (%)
Population	6	1	12
Agricultural area	3	1	10
Cereal area	6	2	18
Cereal production	11	2	19
Meat production	15	2	22
Milk production	22	4	37

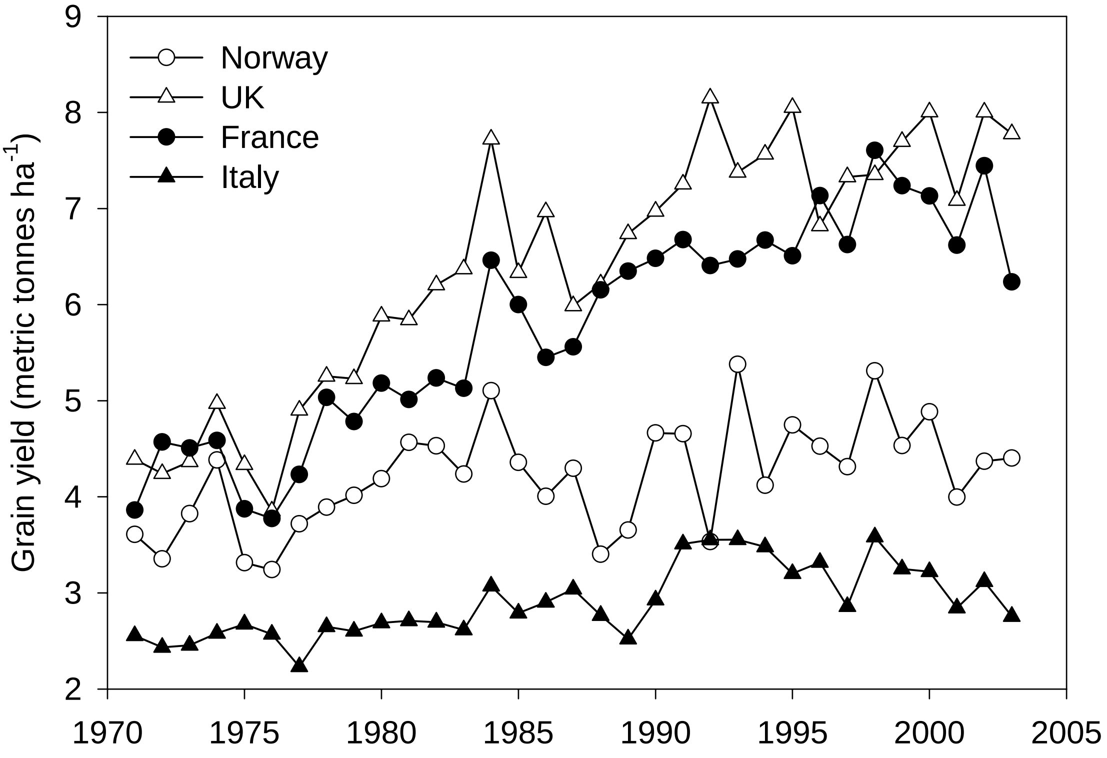

Figure 2: Development in average annual wheat yields in four European countries.

The trends in European agriculture are dominated by the EU Common Agricultural Policy (CAP). The CAP reform of 1992 reduced intervention prices by one third and substituted this by area payments, including set-aside schemes. This process of reducing and transforming subsidies is continued in the Agenda 2000 reform. In 2003 it was thus decided to totally 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 ("cross-compliance"). In addition there will be a strengthened rural development policy with more EU money, new measures to promote the environment, quality and animal welfare and to help farmers meet EU production standards.

The trends in European agriculture can be illustrated by the development of wheat yield over the past three decades (Figure 2). Yields have increased rapidly by about 0.15 Mg ha^{-1} yr^{-1} in the north-western part of Europe (e.g. UK and France). Yields in both the Nordic (e.g. Norway) and the Mediterranean region (e.g. Italy) have increased at a much slower rate, primarily because of climatic restrictions to crop growth in these regions.

IMPACTS OF CLIMATE CHANGE

Biophysical processes of agroecosystems are strongly affected by environmental conditions. The projected increase in greenhouse gases will affect agroecosystems either directly (primarily increasing photosynthesis at higher CO_2) or indirectly via effects on climate (e.g. temperature and rainfall affecting several aspects of ecosystem functioning) (Table 2). The exact responses depend on the sensitivity of the particular ecosystem and on the relative changes in the controlling factors.

Table 2: Influence of CO_2, temperature, rainfall and wind on various components of the agroecosystem.

Component	Influence of factor		
	CO_2	Temperature	Rain/wind
Plants	Dry matter growth Water use	Growth duration	Dry matter growth
Animals	Fodder yield	Growth and reproduction	Health
Water	Soil moisture	Irrigation demand Salinization	Groundwater
Soil	SOM turnover	SOM turnover Nutrient supply	Wind- and water erosion
Pests/diseases	Quality of host biomass	Generation time Earliness of attack	Disease transmission
Weeds	Competition	Herbicide efficacy	

Many studies have assessed effects of climate change on agricultural productivity in Europe (e.g. Harrison et al. 2000). However, relatively little work has been done to link these results across sectors to identify vulnerable regions and farming systems (Olesen & Bindi 2002). Such assessments are needed to properly identify needs for change in agricultural policy caused by climate change.

A climatic warming will expand the area of cereals cultivation (e.g. wheat and maize) northwards (Kenny et al. 1993; Carter et al. 1996). For wheat, a rise in temperatures will lead to a small yield reduction, whereas an increase in CO_2 will cause a large yield increase. The combination of both effects will for a moderate climate change lead to large yield increase in comparison with yields simulated for the present situation (Ghaffari et al. 2002; van Ittersum et al. 2003). Drier conditions and increasing temperatures in the Mediterranean region and parts of eastern Europe may lead to lower yields there and the adoption of new varieties and cultivation methods. Such yield reductions has been estimated for eastern Europe, and the yield variability may increase, especially in the steppe regions (Sirotenko et al. 1997).

Potato, as well as other root and tuber crops, has shown a large response to rising atmospheric CO_2 (Kimball et al. 2002). On the other hand warming may reduce the growing season in some species and increase water requirements with consequences for yield. Climate change scenario studies performed using crop models show no consistent changes in mean potato yield (Wolf & van Oijen 2003). For sugar beet yield the increasing occurrence of summer droughts may severely increase yield variability (Jones et al. 2003).

Grasslands will differ in their response to climate change depending on their type (species, soil type, management). In general, intensively managed and nutrient-rich grasslands will respond positively to both the increase in CO_2 concentration and to a temperature increase, given that water supply is sufficient (Thornley & Cannell 1997). Nitrogen-poor and species-rich grasslands may respond differently to climate change and increase in CO_2 concentration, and the short-term and long-term responses may be completely different (Cannnel & Thornley 1998).

Extreme weather events, such as spells of high temperature, heavy storms, or droughts, can severely disrupt crop production. An increase in temperature variability will increase yield variability and also result in a reduction in mean yield (Trnka et al. 2004). Thus the projected increases in temperature variability over Central Europe (Schär et al. 2004) may have severe impacts on the agricultural production in this region.

ADAPTATION TO CLIMATE CHANGE

To avoid or at least reduce negative effects and exploit possible positive effects, several agronomic adaptation strategies for agriculture have been suggested. Studies on the adaptation of farming systems to climate change need to consider all the agronomic decisions made at the farm level (Kaiser et al. 1993). Economic considerations are very important in this context (Antle 1996). Results of farm level analyses on the impact and adaptation to climate change have generally shown a large reduction in adverse impacts when adaptation is fully implemented (Mendelsohn & Dinar 1999). This often implies land use changes (Darwin 2004).

The agronomic strategies available include both short-term adjustments and long-term adaptations. The short-term adjustments have been studied using agroecosystem models, but often not in a systematic way (Easterling 1996). These short-term adjustments include efforts to optimise production without major system changes. They are autonomous in the sense that no other sectors (e.g. policy, research, etc.) are needed in their development and implementation. Examples of short-term adjustments are changes in varieties, sowing dates and fertiliser use.

Long-term adaptations refer to major structural changes to overcome adversity caused by climate change. This involves changes of land use that result from the farmer's response to the differential response of crops to climate change. The changes in land allocation may also be used to stabilise production. This means substitution of crops with high inter-annual yield variability (e.g. wheat) by crops with lower productivity but more stable yields (e.g. pasture). Crop substitution may be useful also for the conservation of soil moisture. Other examples of long-term adaptations include breeding of crop varieties, new land management techniques to conserve water or increase irrigation use efficiencies, and more drastic changes in farming systems (including land abandonment).

Maize in Denmark

The cultivation of maize has increased considerably in Denmark during the past two decades from 11,000 ha in 1980 to 118,000 ha in 2003 (Figure 3a). The maize is harvested for silage and used as feed for dairy cows. During this period, maize has replaced fodder beets and cereals for whole-crop silage as winter feed for the cattle, and maize silage is now also used as an important feed supplement during the summer season. There are several reasons for this change, including the high quality of maize silage as a feed for cows, and a period from the late 1990's where maize was subsidized and fodder beet was not. However, a main driver for the changes has been increasing yields and fewer years with yield failures. Among farmers and agricultural advisors this has mostly been attributed to new cultivars better adapted to the Danish climate.

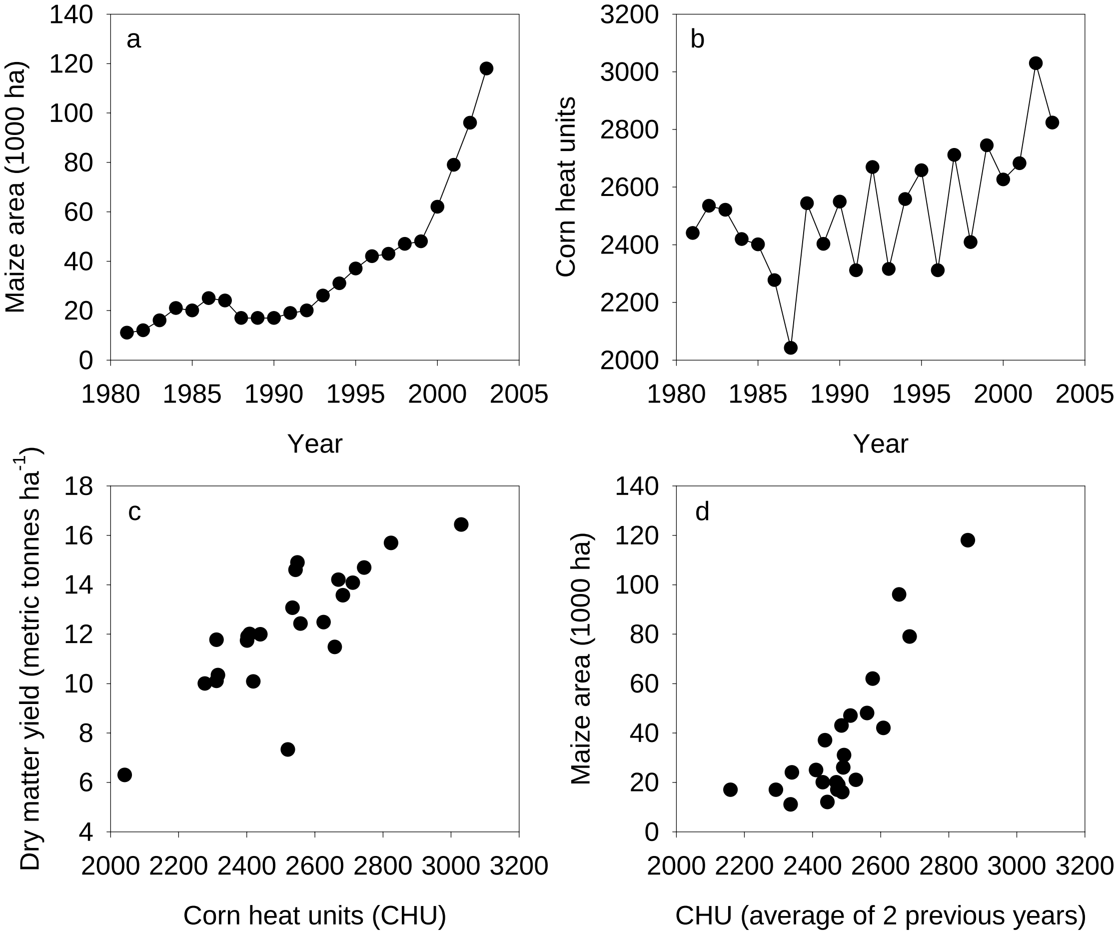

Figure 3: Development in silage maize area (a) and corn heat units (b) in Denmark. Dry matter yield for silage maize from variety trials in Denmark in relation to corn heat units (CHU) (c), and Danish maize area versus corn heat units of the two previous years (d).

The climatic suitability for silage maize in Denmark is usually described by corn heat units (CHU, Begna et al. 1999) accumulated from 15 April to 15 October, and this index has increased over the past ten years (Figure 3b). There is a close relationship between the average dry matter yields obtained in variety trials in Denmark and the corn heat units (Figure 3c). A multiple linear regression of maize yield on CHU and year showed that CHU explained 64% of the variation in yield and year only 1%. The climate therefore seems to be the main factor influencing maize yields, whereas improved technology (including varieties) only plays a small role. The increase in maize area in Denmark can therefore be explained by the warming that has occurred over the past two decades, and Figure 3d illustrates that 67% of the variation in the area cultivated with maize can be explained by the average of the CHU over the past two years. Dairy farmers in Denmark have thus adapted quickly to the gradually warmer climate. This has not been a deliberate adaptation to climate change, and both farmers and advisors attribute the much of the change to other factors, such as improved varieties. Thus even undeliberate adaptation to climate change may be very effective. However, the lack of awareness of the role of climate change may mean that farmers would not be sufficiently prepared for the climatic variability that still exists, and which can result in yield failures in some years.

Drought of 2003

A severe heat wave over large parts of Europe started in June 2003 and continued through July until mid-August, raising summer temperatures by 3 to 5 °C from Northern Spain to the Czech Republic and from Germany to Italy (Schär et al. 2004). Extreme maximum temperatures of 35 to 40 °C were repeatedly recorded in July and to a larger extent in August in most of the Southern and Central European countries from Germany to Turkey. This extreme whether was caused by an anti-cyclone firmly anchored over the western European land mass holding back the rain-bearing depressions that usually enter the continent from the Atlantic ocean. This situation was exceptional in the extended length of time (over 20 days), during which it conveyed very hot dry air up from south of the Mediterranean Sea.

Temperature records were broken in United Kingdom, France and Switzerland, and July was characterised by dry conditions centred on France, Spain, Germany and Italy. This hot and dry spell extended to Central Europe in August. The low precipitation during this period failed to compensate for the accumulated evapotranspiration of almost 400 mm in the Mediterranean area, creating an accumulative water balance deficit of up to 380 mm in South Europe and of 200 mm over most of France, Germany, western Czech Republic, Hungary and southern Romania. The extreme weather conditions decreased the quantity and quality of the harvests, particularly in Central and Southern European agricultural areas; threatening a large proportion of harvests, and increasing production costs (Figure 4).

The winter crops already suffered from the effects of a harsh winter and late spring frost. The heat wave that began in early June accelerated crop development by 10 to 20 days, thus advancing ripening and maturity. The very high air temperature and solar radiation, especially from the second part of July to the beginning of August, resulted in a notable increase in the crops' water consumption. This, together with the summer dry spell, resulted in an acute depletion of soil water and lowered crop yields. Even in Switzerland, the "water tower" of Europe, river withdrawals for agricultural use were banned in some cantons from July to mid October, thus affecting producers of potatoes and tobacco. According to the Union of Swiss Farmers, the agricultural deficit reached more than 300 millions CHF (~US$ 230).

Over all of Europe, the main sectors hit by the extreme climate conditions were the green fodder supply, the arable sector, the livestock sector and forestry. Potato and wine production were also seriously affected. The fodder deficit varied from 30% (Germany, Austria and Spain) to 40% (Italy) and 60% in France. In Switzerland, fodder had to be imported from as far away as Ukraine. The reduction in cereal production in EU reached more than 23 million tonnes (MT) as compared to 2002. This low cereal harvest will have to be topped up by more than 6 MT of imports under the mandatory quotas and more than 10 million tonnes available from carry-over stocks. The livestock farmers suffered the most, and continued to suffer during the winter due to lack of green fodder and the possible increase of compound feed prices.

The summer drought of 2003 has been taken in many parts of the society as an indicator of the climate change that might come, and as such it may be used as an eye-opener for the agricultural community of the adaptations that will need to be taken as a result of climate change.

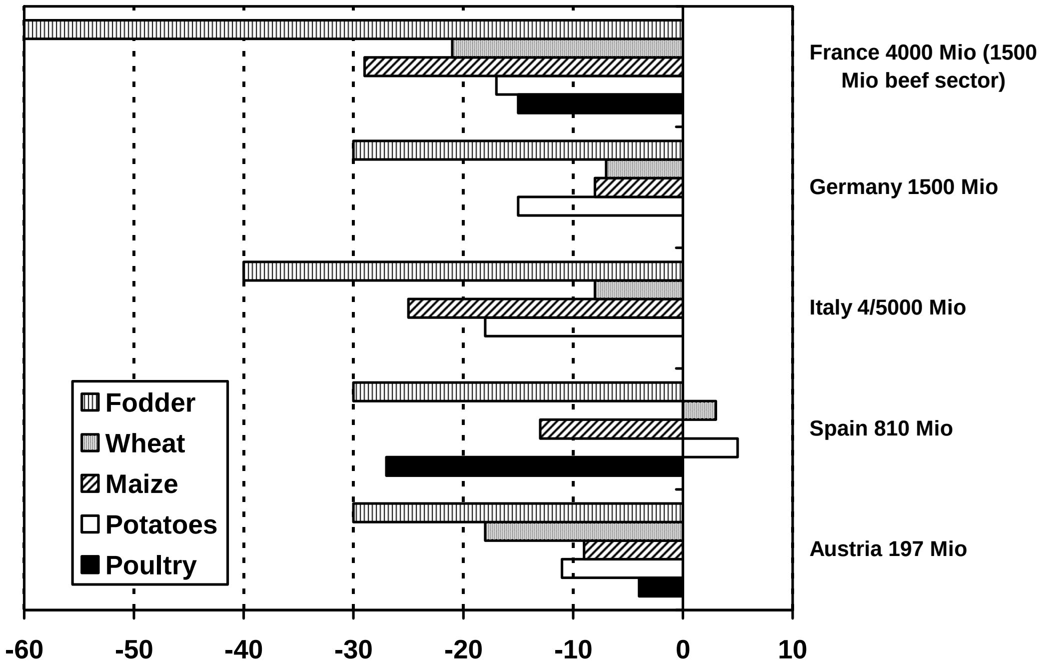

Figure 4: Impact of the summer 2003 heat wave and drought on agriculture (production (% reduction) and financial costs (mio. €) for 2003 relative to 2002) in 5 selected countries (Source: COPA-COGECA 2003).

POLICY IMPLICATIONS

Several current trends are considered to continue to dominate the European agricultural policy in the first part of the 21st century. These are 1) the change to market economy and resulting increasing efficiencies and productivity in the former socialised economies of Eastern Europe, 2) the continued trade liberalisation enforced by institutions like the World Trade Organisation (WTO), and 3) the increasing food safety and environmental protection. In addition to these current trends, European agricultural policy will need to consider support for the adaptation of European agriculture to climate change. This may be done by encouraging as much as possible the flexibility of land use, crop production, farming systems and so on. The current process in EU to decouple subsidies from the primary production is a prerequisite for increasing the adaptive capacity.

Policies to support adaptation and mitigation will need to be linked closely to the development of agri-environmental schemes, which is becoming an increasing component in the EU CAP. There are several reasons for this: 1) Climate change may enhance some of the current negative environmental effects of agriculture (e.g. from fertiliser and pesticide use), and create new ones, 2) climate change may threaten some of the traditional low-intensity farming systems, which are critical to nature conservation and protection of the rural environment (Bignal and McCracken 1996), and 3) many of the measures to protect the agricultural environment will also reduce greenhouse gas emissions, e.g. by changes in cropping systems or adoption of conservation tillage practices (Holland 2004).

The EU CAP aims to maintain a viable rural society including the cultural heritage of many rural areas of Europe. This is partly a concern to maintain a proper management of the farmed countryside to protect biodiversity and prevent desertification and land abandonment. These efforts may be severely affected in regions, where the economic sustainability of traditional farming systems is being threatened by market forces, and which may be susceptible to effects of climate change. Such regions are probably most abundant in southern Europe.

Climate change related policy actions are especially urgent where there are long lead times or large investments at stake. This is the case for some of the large-scale irrigation systems, some of which already deplete available water resources. However, more information on the likely effects of climate change at the detailed regional level is needed before specific actions can be taken.

The impact assessments need to be conducted in close collaboration with the stakeholders, and effort should also be put into increasing the awareness of individual farmers and decision makers on the issues of climate change and the need for adaptation of farming practices. Despite the public debate, the current awareness of climate change in the farming community appears to be low (Robinson, 1999). This is also illustrated by the example with increasing cultivation of silage maize in Denmark (Figure 3), where the role of the current change in climate has not been recognised by farmers or advisors. Thus policies also have a role in promoting the awareness of climate change as a factor in agricultural planning at the farm and regional levels.

REFERENCES

Antle, JM 1996, 'Methodological issues in assessing potential impacts of climate change on agriculture' *Agricultural and Forest Meteorology*, vol. 80, pp. 67-85.

Begna, SH, Hamilton, RI, Dwyer, LM, Stewart, DW & Smith, DL 1999, 'Effects of population density on the vegetative growth of leafy reduced stature maize in short-season areas' *Journal of Agronomy & Crop Science*, vol. 182, pp. 49-55.

Bignal, EM & McCracken, DI 1996, 'Low-intensity farming systems in the conservation of the countryside' *Journal of Applied Ecology*, vol. 33, pp. 413-24.

Cannell, MGR & Thornley, JHM 1998, 'N-poor ecosystems may respond more to elevated [CO_2] than N-rich ones in the long term. A model analysis of grassland', *Global Change Biology*, vol. 4, pp. 431-42.

Carter, TR, Saarikko, RA & Niemi, KJ 1996, Assessing the risks and uncertainties of regional crop potential under a changing climate in Finland. *Agriculture and Food Science Finland*, vol. 3, pp. 329-49.

Chloupek, O, Hrstkova, P & Schweigert, P 2004, 'Yield and its stability, crop diversity, adaptability and response to climate change, weather and fertilisation over 75 years in the Czech Republic in comparison to some European countries', *Field Crops Research*, vol. 85, pp. 167-90.

Christensen, JH & Christensen, OB 2002, 'Severe summertime flooding in Europe', *Nature*, vol. 421, pp. 805-6.

Darwin, R 2004. 'Effects of greenhouse gas emissions on world agriculture, food consumption, and economic welfare', *Climatic Change*, vol. 66, pp. 191-238.

Darwin, R & Kennedy, D 2000, 'Economic effects of CO_2 fertilization of crops: transforming changes in yield into changes in supply', *Environmental Modeling and Assessment*, vol. 5, pp. 157-68.

Easterling, WE 1996, 'Adapting North American agriculture to climate change in review', *Agricultural and Forest Meteorology*, vol. 80, pp.1-53.

Ghaffari, A, Cook, HF & Lee, HC 2002, 'Climate change and winter wheat management: A modelling scenario for South-Eastern England', *Climatic Change*, vol. 55, pp. 509-33.

Harrison, PA, Butterfield, RE & Orr, JL 2000, 'Modelling climate change impacts on wheat, potato and grapevine in Europe' In: Downing, TE, Harrison, PA, Butterfield, RE & Lonsdale, KG (Eds.) *Climate change, climatic variability and agriculture in Europe*. Environmental Change Unit, University of Oxford, UK, pp. 367-90.

Holland, JM 2004, 'The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence', *Agriculture, Ecosystems and Environment*, vol. 103, pp. 1-25.

Houghton, JT, Ding, Y, Griggs, DJ, Noguer, M, van der Linden, PJ, Dai, X, Maskell, K & Johnson, CA 2001, *Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

Jones, PD, Lister, DH, Jaggard, KW & Pidgeon, JD 2003, 'Future climate impact on the productivity of sugar beet (*Beta vulgaris* L.) in Europe', *Climatic Change*, vol. 58, pp. 93-108.

Kaiser, HM, Riha, SJ, Wilks, DS, Rossiter, DG & Sampath, R 1993, 'A farm-level analysis of economic and agronomic impacts of gradual climate warming', *American Journal of Agricultural Economics*, vol. 75, pp. 387-98.

Kenny, GJ, Harrison, PA, Olesen, JE & Parry, ML 1993, 'The effects of climate change on land suitability of grain maize, winter wheat and cauliflower in Europe', *European Journal of Agronomy*, vol. 2, pp. 325-38.

Kimball, BA, Kobayahsi, K & Bindi, M 2002, 'Responses of agricultural crops to free-air CO_2 enrichment', *Advances in Agronomy*, vol. 77, pp. 293-368.

Kjellström E 2004, 'Recent and future signatures of climate change in Europe', *Ambio*, vol. 33, pp. 193-8.

Mendelsohn, R & Dinar, A 1999, 'Climate change, agriculture, and developing countries: Does adaptation matter?' *World Bank Observer*, vol. 14, pp. 277-93.

Olesen, JE & Bindi, M 2002, 'Consequences of climate change for European agricultural productivity, land use and policy', *European Journal of Agronomy*, vol. 16, pp. 239-262.

Parry, ML, Rosenzweig, C, Iglesias, A, Livermore, M & Fischer, G 2004, 'Effects of climate change on global food production under SRES emissions and socio-economic scenarios', *Global Environmental Change*, vol. 14, pp. 53-67.

Reilly, J & Schimmelpfennig, D 1999, 'Agricultural impact assessment, vulnerability, and the scope for adaptation', *Climatic Change*, vol. 43, pp. 745-88.

Robinson, DA 1999, 'Agricultural practice, climate change and the soil erosion hazard in parts of southeast England', *Applied Geography*, vol. 19, pp. 13-27.

Ruosteenoja, K, Carter, TR, Jylhä, K & Tuomenvirta, H 2003, *Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios*, Finnish Environment Institute, Helsinki, Finland.

Schär C, Vidale PL, Lüthi, D, Frei, C, Häberli, C, Liniger, MA & Appenzeller, C 2004, 'The role of increasing temperature variability in European summer heatwaves', *Nature*, vol. 427, pp. 332-6.

Sirotenko, OD, Abashina, HV & Pavlova, VN 1997, 'Sensitivity of the Russian agriculture to changes in climate, CO_2 and tropospheric ozone concentrations and soil fertility' *Climatic Change*, vol. 36, pp. 217-32.

Thornley, JHM & Cannell, MGR 1997, 'Temperate grassland responses to climate change: an analysis using the Hurley pasture model', *Annals of Botany*, vol. 80, pp. 205-21.

Trnka, M, Dubrovski, M, Semerádová, D & Zalud, Zalud, Z 2004, 'Projections of uncertainties in climate change scenarios into expected winter wheat yields', *Theoretical and Applied Meteorology*, vol. 77, pp. 229-49.

van Ittersum, MK, Howden, SM & Asseng, S 2003, 'Sensitivity of productivity and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO_2, temperature and precipitation', *Agriculture, Ecosystems and Environment*, vol. 97, pp. 255-73.

Wolf, J & van Oijen M 2003, 'Model simulation of effects of changes in climate and atmospheric CO_2 and O_3 on tuber yield potential of potato (cv. Bintje) in the European Union', *Agriculture, Ecosystems and Environment*, vol. 94, pp. 141-57.

Author biography

JE Olesen (born 1958) has a M.Sc. in agriculture and currently holds a research professorship at Danish Institute of Agricultural Sciences. He has lead several national interdisciplinary projects on agrometeorology, integrated wheat production, application of remote sensing and GIS, development of simulation models, and evaluation of organic farming systems. He has participated in 9 EU funded projects on climate change and greenhouse gas emissions from agriculture. He is lead author of the IPCC 4th assessment report.

M Bindi (born 1961) has a PhD in crop simulation modelling of forage crops and currently is full professor at the University of Florence. He was involved in several national and international projects dealing with agrometeorology, crop modelling, climate change, environmental physiology and remote sensing. He is author of more than 40 papers on refereed international journals. He is lead author of the IPCC 4th assessment report.