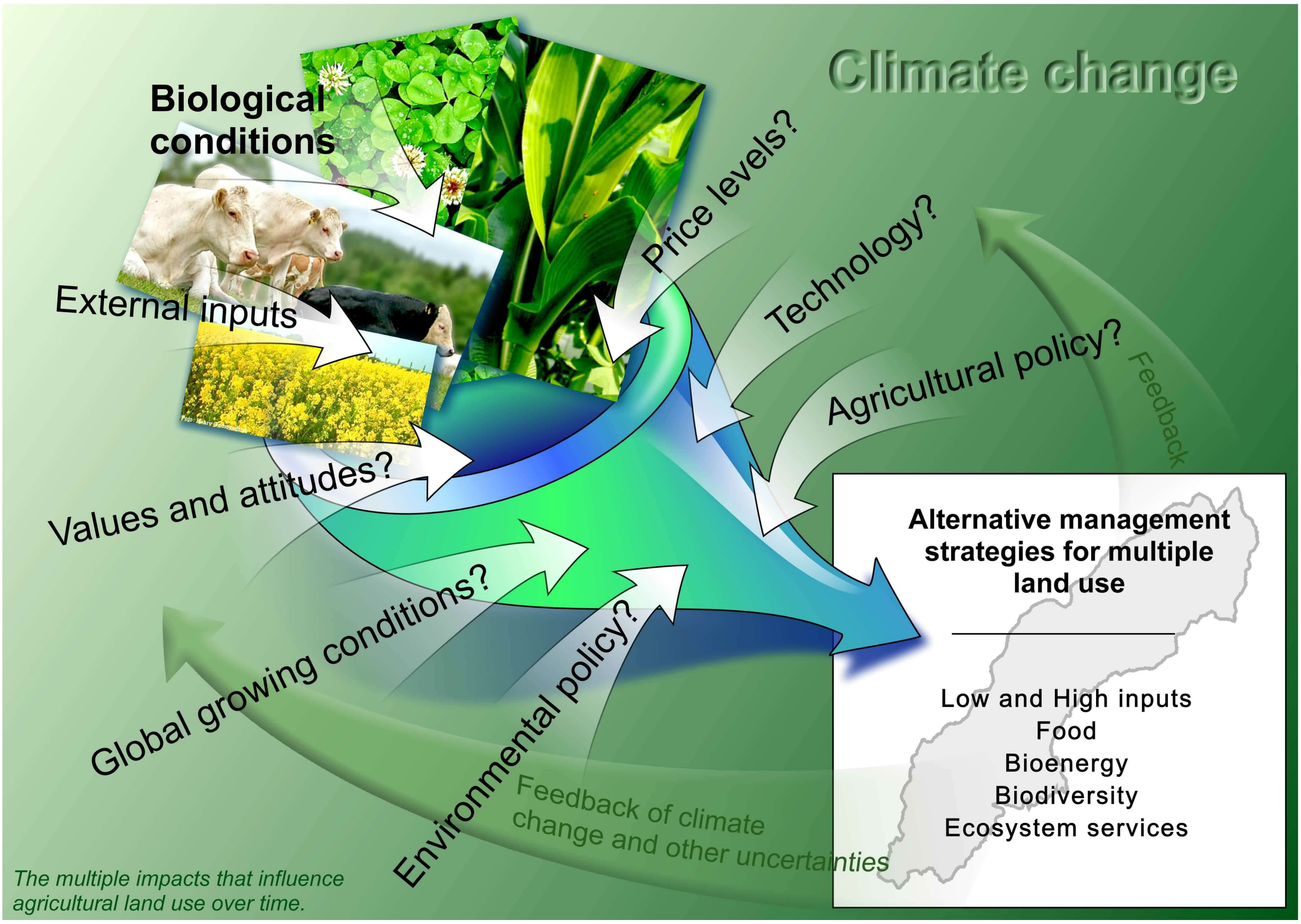
Strategic Analysis of Swedish Agriculture

Production systems and agricultural landscapes in a time of change

Håkan Fogelfors, Maria Wivstad, Henrik Eckersten, Fredrik Holstein, Susanne Johansson and Theo Verwijst



Swedish University of Agricultural Sciences (SLU)
Department of Crop Production Ecology (VPE)
Uppsala 2009

Strategic Analysis of Swedish Agriculture. Production systems and agricultural landscapes in a time of change.
Fogelfors, H., Wivstad, M., Eckersten, H., Holstein, F., Johansson, S. & Verwijst, T.
Report from the Department of Crop Production Ecology (VPE) • No. 10
Swedish University of Agricultural Sciences (SLU)
Uppsala 2009
ISSN 1653-5375
ISBN 978-91-86197-55-1

Strategic Analysis of Swedish Agriculture

Production systems and agricultural landscapes in a time of change

Swedish title of parent project:

Framtidsanalys av svenskt jordbruk

Odlingssystem och jordbrukslandskap i förändring (FANAN)

Håkan Fogelfors[1], Maria Wivstad[1], Henrik Eckersten[1], Fredrik Holstein[2], Susanne Johansson[3]and Theo Verwijst[1]

[1] Department of Crop Production Ecology (VPE)
[2] Department of Economy
[3] Centre for Sustainable Agriculture (CUL)

As requested by

The Faculty of Natural Resources and Agriculture
Swedish University of Agricultural Sciences

Diagrams and illustrations on pages 1, 17, 19, 35, 37, 38, 41, 44, 47, 48, 49, 50 and 51: production by
Fredrik M Stendahl
www.ritaren.se

Preface

The project Strategic Analysis of Swedish Agriculture (FANAN) was initiated through a dialogue between the Faculty of Natural Resources and Agriculture and the Department of Crop Production Ecology at the Swedish University of Agricultural Sciences, SLU, at the end of 2005.

The objectives were to:

- Identify possible future changes affecting agriculture in terms of climate change, resource availability and economic globalisation.
- Identify research areas necessary for sustainable, multifunctional and competitive land use in Sweden in the future.

Climate change, globalisation and higher levels of consumption of natural resources have increased the pressure on agriculture resources. The challenge for mankind is to resolve the issue of how to use the limited resource of agricultural land to meet this growing demand, not least in the very charged issue of food and biofuels. The task of intensifying agricultural production while at the same time conserving ecosystem services is complex and fundamental. At the present time there is insufficient knowledge upon which to base an action plan. Uncertainties are considerable: this applies to trading patterns, resource availability and effects on plant and animal production. Our responsibility to future generations demands new strategies for land use.

FANANs conclusions are based on the three reviews of the literature carried out within the fields of climate change, resource availability and economic globalisation.

The goal of SLU is to develop **land use strategies** that are both adaptable and sustainable in a future of change. This requires a network of researchers from different disciplines and representatives from diverse sectors in society in which the results of empirical investigations, computer simulations, scenario analyses and synthesis work are weighed.

We within the FANAN group would like to thank all the experts from various disciplines who contributed to this work in different ways through holding seminars, participating in the organised workshops and/or reading and commenting on manuscripts during the course of the work.

Uppsala 2008-05-11

Håkan Fogelfors

Project leader, FANAN

Contents

Summary

This strategic analysis of Swedish agriculture – production systems and agricultural landscapes in a time of change – focuses on climate change, future availability of natural resources and economic regulation in a global food market. The background to the project was that the Faculty of Natural Resources and Agriculture of the Swedish University of Agricultural Sciences identified an urgent need to explore the implications and opportunities of coming changes for agricultural production systems, arable land use and farm landscape functions in Sweden. Another objective was to determine the research needed to ensure that we are equipped to adapt to the coming changes.

The analysis was carried out in the form of three literature reviews (*Climate Change and Agricultural Land Use in Sweden: A Literature Review*, (Eckersten *et al.,* 2008a); *Changes in the Global Natural Resource Base Relevant for Future Agriculture in Sweden – A Literature Review*, (Johansson, 2008); and *Economic Globalisation and Swedish Agriculture – Future Changes Affecting Swedish Agriculture from an Economic Perspective with Special Emphasis on Globalisation*, (Holstein, 2008). It also comprised workshops and seminars and finally production of this synthesis report, which summarises the work done and suggests six research themes.

Different IPCC emission scenarios describe pathways for those factors that are regarded as important for emissions of greenhouse gases (GHG), such as demography and social, economic and technological development. The projected global temperature increase varies from a little less than 2 °C up to 3.5-4.0 °C by the end of this century. Shrinking glaciers and rising sea levels are some of the consequences of the temperature increase. This climate change will have considerable consequences for agriculture, ecosystem function and human health on a global scale.

The conditions for food production in Sweden are projected to become more favourable in terms of potential productivity as a result of future climate change. However, despite more favourable average cropping conditions, there could be drawbacks in the form of more frequent extreme weather events and, for example, more severe crop pathogen attacks and increased risks of nutrient leaching. The temperature increase is predicted to be greater during winter than during summer. Furthermore, precipitation will probably increase and the precipitation pattern will change. The temperature increase may lead to an extension of the growing season by several months in southern Sweden.

Swedish agriculture is currently dependent on high inputs of external resources. The situation at present is that agricultural demands are increasing with regard to the natural resource base, e.g. ecosystem services and fossil fuels. The use of fossil fuels to sustain food production cannot continue indefinitely; agriculture world-wide must adopt mitigation strategies. One way is to search for self-sustaining, diversified, low-input, energy-efficient agricultural systems, using local renewable resources and ecosystem services. Another way to meet the challenges of future food supply and at the same time sustain life-support systems might be through intensive high-input agriculture on the 'best' land in order to save other areas for nature conservation.

Swedish agriculture and food production are closely linked to the global food and feed market. Increased globalisation means that the profitability of Swedish farms is

influenced to an increasing extent by actors on the global market. Conditions for Swedish agriculture in the past have been largely determined by political regulations, national and subsequently by CAP (Common Agricultural Policy in EU), but are gradually becoming more dependent on world market forces. Sweden has a comparative disadvantage in primary production compared with many other countries but the competitiveness of the Swedish food sector as a whole has increased during recent years due to increased exports of processed products. Another opportunity is to increase production of products with added value, e.g. organic products. However, the effects of globalisation on Swedish agriculture are hard to predict. Increased liberalisation will lead to increased competition, which will most probably lead to decreased production in Sweden. However, future changes in land productivity could potentially affect land use more than does the degree of liberalisation in trade. The conclusion that Swedish agriculture will decrease, at least in terms of land use, may very well turn out to be incorrect. This should be clear, not only from scenarios where climate change makes Swedish production more competitive but also from the latest developments on the world market where large increases in demand for agricultural products have been noted. This increase may have the consequence that land in less competitive countries will become sufficiently productive.

Twelve climate scenarios for different regions in Sweden were developed within the FANAN project, from south-west Skåne in the south to Övertorneå in the north. Projections of future cropping systems under the new climatic conditions are described for three regions, south-west Skåne, Mälardalen district and the coast region of Västerbotten.

There are diametrically opposed scenarios for future land use and appropriate design of agricultural production systems in the literature, which implies a need for a great variety of research. Research in adaptation as well as mitigation strategies will be important. Problems are interlinked and interdisciplinary research will probably be necessary to solve the complex problems concerning agriculture and the food supply of future populations.

Six different strategic research themes are presented as a result of the FANAN project:

1. Future analyses of long-term sustainable land use, p.54.
2. Sustainable production systems — crop and animal sciences, p. 55.
    - Cooling crops — crop-soil interactions
    - Crop breeding — perennial cereals
    - Domestic animal production
    - Cultivation techniques
3. Ecosystem services in production systems of the agricultural landscape, p. 59.
4. From words to action, p. 60.
5. Monitoring of agricultural production, p. 62.
6. Multidisciplinary research network, p. 62.

Large research programmes rather than small disciplinary projects will promote the solution of future complex problems. It will be necessary to combine empirical research with modelling and synthesis work in order to generate good science that is relevant to the challenges in sustainable agricultural management. FANAN concludes that SLU has a central role to play in developing these sustainable strategies.

Introduction

Major changes in the world are predicted for the relatively near future. This strategic analysis (FANAN) focuses on changes in the following three areas: *Climate change*, *availability of natural resources* and *economic regulation in a global market for food* all of which will be of central importance for Swedish agriculture in the future.

Major future changes

The global climate has undoubtedly become warmer. The Intergovernmental Panel on Climate Change (IPCC) has revealed that the mean global temperature has increased by an average of ≈ 0.7 °C in the past 100 years (IPCC 2007a). The majority of this global warming effect has occurred since 1950 and has most probably been caused by emissions of greenhouse gases (GHG) (mainly carbon dioxide, methane and dinitrogen oxide) generated by human activities. The effects of the global warming are already discernible in terms of less extensive snow cover, shrinking glaciers and rising sea levels. The IPCC reports that rainfall has increased in certain parts of the world, while drought is becoming more common and more intensive in other parts. If far-reaching actions are not taken, the global mean temperature will rise considerably, and this rise could by end of this century be 3.5-4 °C according to an IPCC high emissions scenario (IPCC 2007b). The geographical pattern shows that the warming will be greatest at northern latitudes (Fig. 1). This will be of considerable consequence for agriculture, ecosystem function and human health on a global scale.

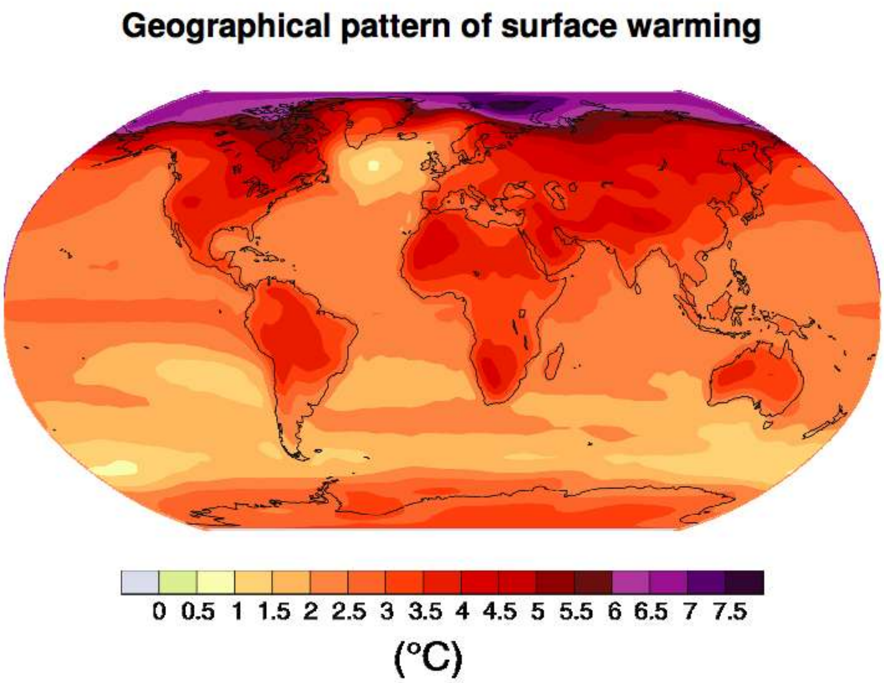


Figure 1. Global temperature changes for the late 21st century according to the IPCC high emission scenario A1B (IPCC 2007b).

Conditions for food production in Sweden, on average and initially, are predicted to become more favourable due to an extended growing season (SOU, 2007). However, there could be drawbacks in the form of increased extreme weather events such as summer heat-waves and for example more severe crop pathogen attacks, increasing number of animal diseases and greater plant nutrient leaching losses. Furthermore, the indirect effects of global warming caused by the severe effects on global food production world-wide could be greater for Swedish agriculture than the direct effects on production potential in Sweden.

Many experts are concerned about the ability of the planet to feed a growing population with fewer available resources and degrading ecosystems (MA 2005; IAASTD 2008). While the increasing demands for agricultural products and non-renewable resources may be difficult to quantify, there is no doubt that they will be large in the future. Conventional Swedish agriculture at present can be described as a high external input system, since mainstream agricultural production systems in Sweden are highly dependent on the use of external resources such as fertilisers, pesticides and fossil fuels for draught and transportation. It will most probably be an unprecedented challenge to adapt these Swedish agricultural production systems to a future with natural resources less available and/or available at a higher cost, and at the same time reduce our impacts on natural ecosystems. Sweden has ample land area, forests, fertile soils and fresh water per capita compared with the average global citizen, but no major sources of other crucial resources such as phosphate rock and fossil fuels. At present our consumption patterns are increasingly resource demanding, and we are dependent on agricultural land abroad for about 30% of the food we consume (Johansson, 2005).

Swedish agriculture and food production are closely linked to the global food and feed market. Increased globalisation means that the prices for produce and production investments, which greatly influence the profitability of farms, are influenced to an increasing extent by actors on the global market. There are great uncertainties involved in predicting future changes in economic regulations on the global food market since many different kinds of interacting driving forces are involved. Such driving forces are development of international trade, resource availability and prices of agricultural inputs, climate change and changes in income levels, world population and productivity. It can also be anticipated that the magnitude of changes will increase in the future. The conditions for Swedish agriculture in the past have been to a relatively large extent determined by political regulations, nationally and subsequently by CAP, but are gradually becoming more dependent on world market forces.

Background to the project

All these changes are likely to result in a new context for the agricultural sector in Sweden. We predict that the key issues for future land use will be sustainability and multi-functionality. In addition to food production this will involve disposal of organic wastes from urban areas, management of biological diversity, care of the cultivated landscape and ideas concerning production of raw materials for industrial purpose and bio-energy.

There is an urgent need to explore the implications and opportunities of these coming changes for agricultural production systems and arable land use as well as for farm landscape function in Sweden. It is also important to identify the research that needs to be done to ensure that we are equipped to adapt appropriately.

The future of Swedish agriculture is complex and there is a need to evaluate the roles of land use in food production and in the delivery of other services. Research is required in order to ensure long-term sustainable production of goods while at the same time conserving other ecosystem functions.

The Strategic Analysis of Swedish Agriculture (FANAN) was initiated through a dialogue between the Faculty of Natural Resources and Agriculture (NRA) and the Department of Crop Production Ecology (VPE) at the Swedish University of Agricultural Sciences at the end of 2005. The Faculty of NRA funded the project.

Objectives

The objectives of the project were to:

- Identify possible future changes affecting agriculture concerning:

  - climate change
  - resource availability
  - economic globalisation

- Identify research necessary for sustainable, multifunctional and competitive land use in Sweden in the future

Approach and methods

The work began with literature reviews of previous work on scenarios for food production, land use and environmental impacts, taking account of the substantial changes that are predicted in the following areas:

- Implications of climate change
- Supply of natural resources, particularly the consequences of energy shortages/major increases in cost
- Global economic regulations

In cross-disciplinary scientific seminars and workshops, the future changes and results from food production and land use scenarios were discussed and analysed. From these analyses, conclusions were drawn regarding the further research that needs to be carried out.

A group of six scientists from different research disciplines, crop production, economics and agroecology, at SLU worked continuously in the project; Håkan Fogelfors, project leader and together with Maria Wivstad, editor of the current synthesis project report, Henrik Eckersten, climate change review, Fredrik Holstein, globalisation review, Susanne Johansson, resource availability review, and Theo Verwijst, member of the project group. Experts from other disciplines (e.g. animal production, soil science, plant biology and forest genetics, nature conservation biology, human nutrition) were also frequently invited for discussions.

Literature reviews

The literature reviews within FANAN are published by the Department of Crop Production Ecology (VPE Report Series).

- Climate Change and Agricultural Land Use in Sweden: A literature review, (Eckersten *et al*. 2008a).
- Changes in the Global Natural Resource Base relevant for Future Agriculture in Sweden – A literature Review, (Johansson 2008).

- Economic Globalisation and Swedish Agriculture – Future Changes affecting Swedish Agriculture from an Economic Perspective with Special Emphasis on Globalisation – A literature review, (Holstein 2008).

Seminars and workshops

A series of wide-ranging seminars and workshops were arranged, and a network of contacts created with researchers in other regions/countries with similar constraints on future predicted conditions for agriculture, e.g. the Netherlands, Denmark, Finland and Scotland.

Furthermore, there has been considerable interest within organisations and authorities in the agricultural sector in the results from FANAN. Project staff members have been invited to more than 20 workshops, seminars and conferences (see below) to present and discuss the implications of future changes on agriculture.

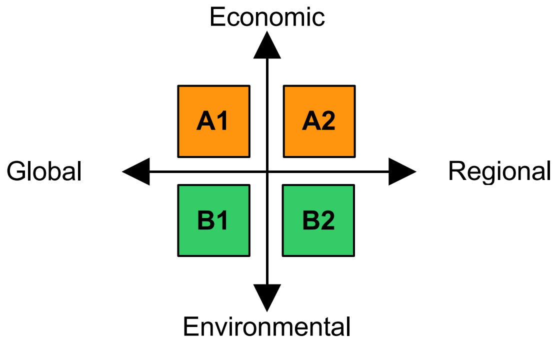
- *Climate change and agriculture.* Gunn Persson, SMHI.
- *Climate change – ecosystem services – globalisation.* Rik Lemans, Environmental Systems Analysis Group, Wageningen University.
- *Climate change effects and adaptation.* Jørgen E. Olesen, Ministry of Food, Agriculture and Fisheries, Danish Institute of Agricultural Sciences.
- *Possibilities to substitute non-renewable resources with local ecosystem services*. Workshop about ecosystem services with invited speakers, Jan Bengtsson, EKOL, Lennart Salomonsson, SOL, Gunnela Gustavsson, HUV, Marie Byström, CBM.
- *Possibilities and restrictions for substitution of the use of fossil energy sources with bioenergy*. Workshop on bioenergy with invited speakers from SLU, JTI and LU.
- *FINADAPT — An investigation of climate change adaptation in Finland.* Timothy Carter, Environmental Administration in Finland.
- *Natural resources - effects of changed availability of natural resources on sustainable, multifunctional and competitive land use in Sweden in the future.* Susanne Johansson, Centre for Sustainable Agriculture, presentation of a literature review in FANAN.
- *Climate change and agricultural land use in Sweden*. Henrik Eckersten, Department of Crop Production Ecology, presentation of a literature review in FANAN.
- *Economic globalisation and Swedish agriculture – future changes affecting Swedish agriculture*. Fredrik Holstein, Department of Economics, presentation of a literature review in FANAN
- *Agricultural future analyses and research needs*. Synthesis workshop with SLU researchers.
- *Effects of climate change on Swedish agriculture - presentations of climate scenarios for three regions in Sweden*. Open synthesis seminar at SLU.
- *New conditions for Swedish agriculture when the climate change* – presentation at a conference about ecological farming ‘Food in a new climate’

Final seminars

- The FANAN project was presented at a seminar in September 2007: *Research needs for agriculture in a time of change*. Invited speakers presented views on research needs. Seminar programme and presentations are presented on the project website (see p. 13)
- Faculty seminar in February 2008.

Climate change and effects on Swedish agriculture

IPCC emission scenarios



Figur 2. SRES storylines with the transects Economic-Environmental, A-B, Global-Regional, 1-2 (IPCC 2000).

The IPCC emission scenarios are presented in a Special Report on Emission Scenarios, SRES (IPCC 2000) and are built on different socio-economic future developments. They describe pathways for those factors that are regarded as important for emissions of GHG, such as demography and social, economic and technological development. The SRES include four main storylines, A1, A2, B1 and B2 (Fig. 2). The scenarios involve large differences in GHG emissions (Fig. 3, IPCC 2007a).

In the A scenarios the focus is on economic growth and in B scenarios it is on sustainable development. The suffix 1 represents a globalisation focus and 2 more regionalised developments (Fig. 2). The use of energy is higher in A2 than in B2 and these two scenarios represent a great span in emissions. According to B2, atmospheric CO_2 concentrations will be about 550 ppm at the end of this century (compared with the current level of 380 ppm) and the corresponding level for A2 will be 850 ppm.

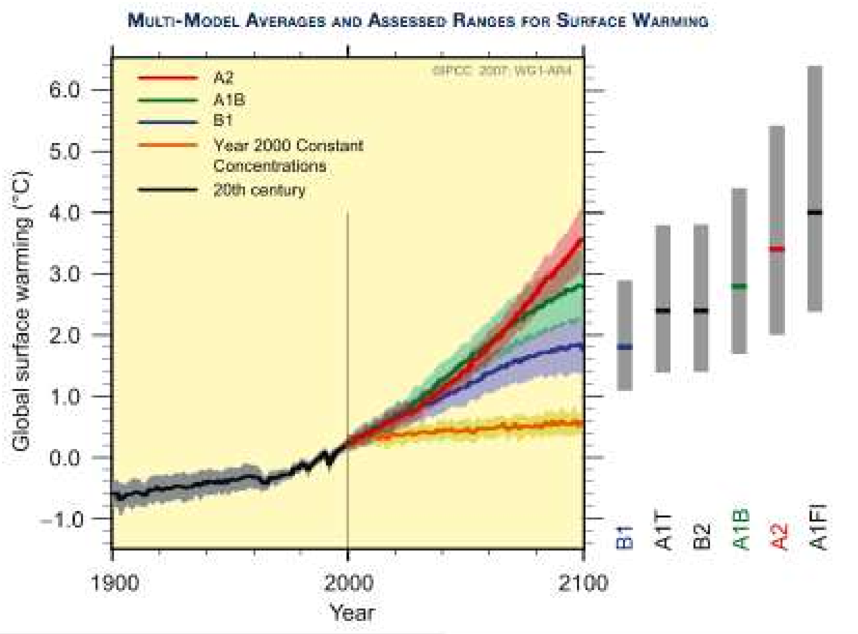


Figure 3. Global surface warming according to different IPCC emission scenarios (IPCC, 2007a). A = economic growth, B= sustainable development, 1 = globalisation focus, 2 = regionalised development. Difference between A1 scenarios: A1F1 = fossil fuel-based energy sources, A1T = non fossil fuel energy sources, A1B = mix of all available energy sources. The orange line shows the warming projection with constant year 2000 GHG concentration levels.

Climate change in Sweden

Projected general changes

The conditions for food production in Sweden are projected to become more favourable in terms of productivity due to future climate change (SOU, 2007). If the IPCC high emission scenario A2 comes true, the temperature in southern Sweden might correspond to the current conditions somewhere in France or northern Spain by the end of this century, while at the same time, the summer could be 20-30% drier than at present in southern Sweden. The regions of northern Götaland and southern Svealand (Fig. 4) could have climatic conditions similar to those in the present day's southern England or northern Germany. The region of southern Norrland could acquire average temperatures similar to those of southern Sweden at present. An estimated temperature increase in Sweden of 4 ºC during this century would mean the temperature climate moving northwards by between 500 and 800 kilometres, which is equivalent to half a metre per hour. For every one degree increase in mean temperature, the temperature climate would also move up along mountain slopes by between 100 and 150 metres. Despite more favourable cropping conditions on average, there could be drawbacks in the form of more frequent extreme weather events and, for example, more severe crop pathogen attacks.

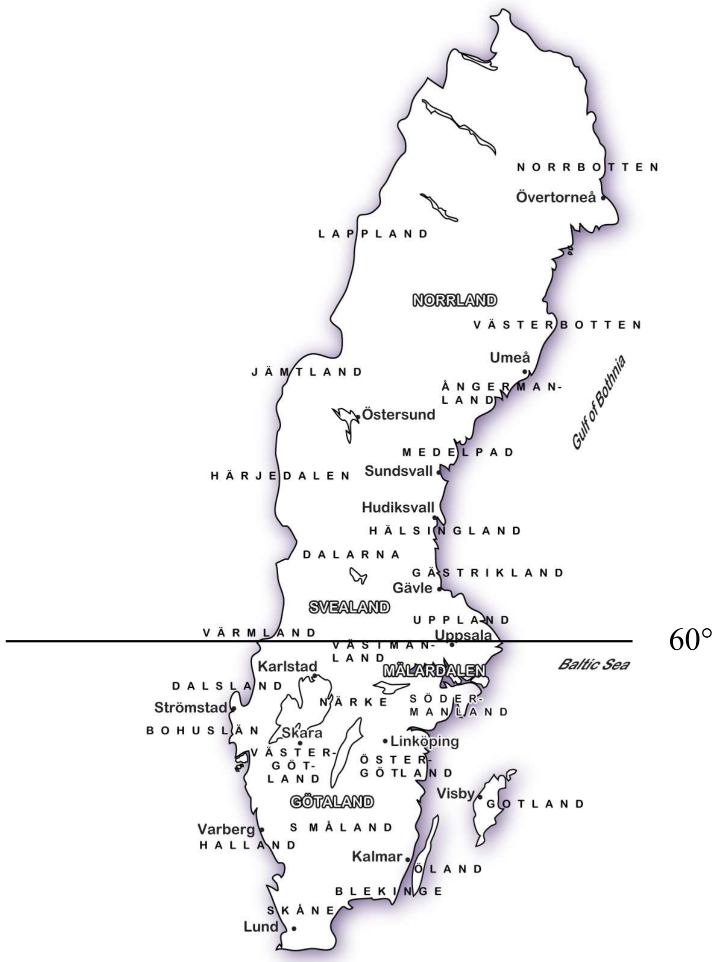


Figure 4. Map of Sweden showing different regions, counties and locations.

Climate changes will require the adaptation of cropping methods to changes in, among other things, rainfall and temperature conditions. The link with the environmental impact of agriculture will also become increasingly more apparent. This may include issues such as land drainage and irrigation, soil tillage, fertilisation as well as control of crop pests and weeds. Many projections are hampered by complicated interactive effects. The outcome will also be controlled to a high degree by technological developments and political decisions.

Increasing temperatures

According to the SMHI regional climate scenarios (SOU 2007) the mean temperature in Sweden might rise by more than the global average, during this century (A2 IPCC high emission scenario). The greatest changes are expected in the north during winter and in the south during summer (Fig. 5). There might be an increase in extreme high temperatures in the summer, especially in the south-east. The snow cover period will probably gradually decrease throughout the country, by most in northern Svealand and central Norrland. In northern and central Sweden the number of oscillations around zero might increase and decrease in the south. Summer heat waves and more long hot spells could become more frequent. Since around 1970 the long term mean temperature in Sweden has gradually increased, and the average temperature for the period 1991-2005 was 1-2 ºC higher during the winter and 0.5-0.8 ºC higher during the summer compared to the average for the period 1961-1990 (SMHI 2006).

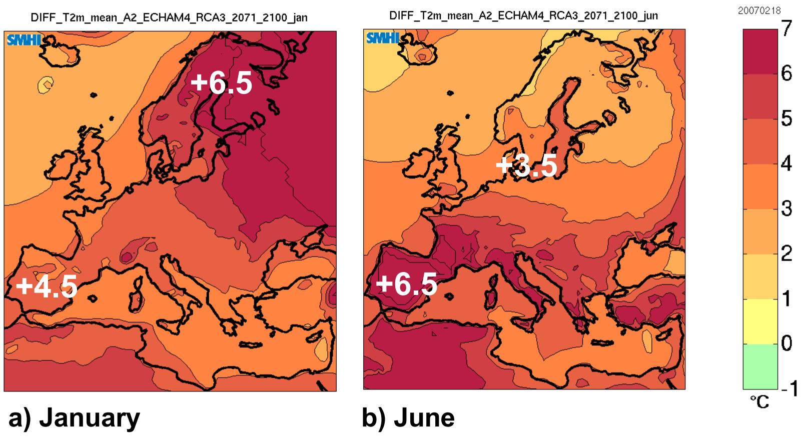


Figure 5. Changes in mean temperature according to SRES scenario A2 for ~2085 (a) in January and (b) in June (Rossby Center, SMHI).

Increased precipitation and changes in precipitation pattern

The regional scenarios for Sweden show that winter precipitation might increase by 30-50%. There could also be an increased risk of heavier daily precipitation. Mean summer rainfall might decrease, by up to 30 mm/month in the south, but there will probably be only minor changes in the north. However there may be an increased risk of heavy rainfall events in summer. On an annual basis, precipitation may increase in all parts of the country. As a consequence of increased precipitation and temperature, the number of warm days (>10ºC) with a relative humidity greater than 90% might increase over the year throughout the country, except for summer in the south where it might decrease. As a consequence of increased temperature and reduced rainfall, there would be a reduction in soil moisture in the summer months in the south by 25-45 mm per three-month period (rainfall - evapotranspiration). The corresponding figures for the winter months show an increase of 30-70 mm/three-month period (rainfall - evapotranspiration) above current levels.

Rising atmospheric CO_2 concentrations

Concentrations of CO_2 have increased from 290 ppm before the industrial revolution to the current ~380 ppm. The rate of increase is now (~2006) over 2 ppm/year (global mean). Up to around 2050, the expected increases in atmospheric CO_2 are about the same for all emission scenarios. After that, the increase will be higher for an emission rate corresponding to scenario A2, compared with scenario B2.

Extended growing season

The growing season is projected to increase in all parts of the country, in the south by up to 4 months, primarily through the early arrival of spring (Fig. 6). However, it should be noted that there are large uncertainties (1-2 months) in these estimates, due to the fact that small changes in temperature result in large changes in length of the vegetation period. In the extreme north the increase is expected to be limited to 1-2 months. These projections suggest that the extension of spring will be greater than the prolongation of autumn in southern and central Sweden. In Götaland the changes are expected to be realised as soon as by ~2025. In Svealand and Norrland, however, approximately only half of the projected changes for ~2085 are expected to have occurred by ~2025.

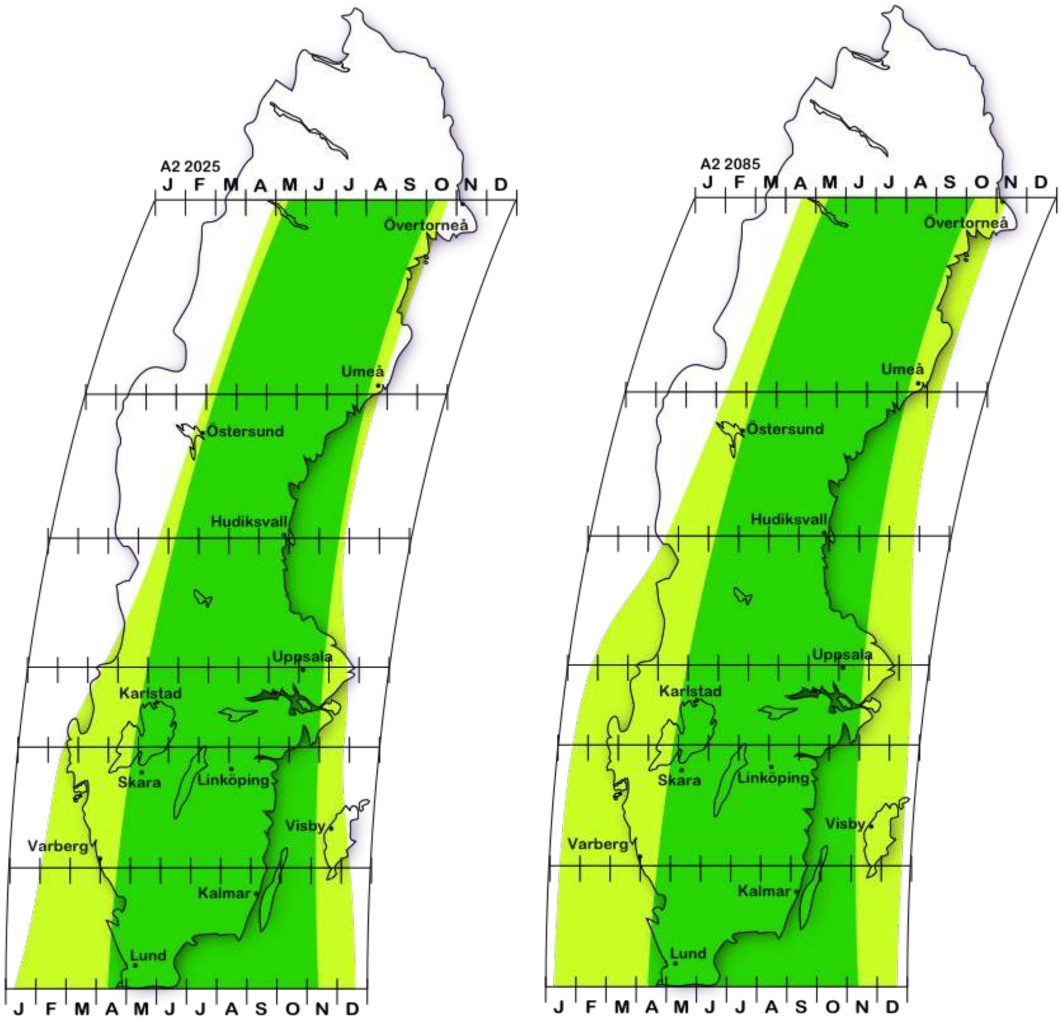


Figure 6. Length of vegetation period (average daily temperature > +5 °C) according to IPPC scenario A2 (a) for the year ~2025 and (b) for ~2085. Dark green = average vegetation period 1961-1990. Light green = projections for ~2025 and ~2085 respectively.

Possible effects on agriculture

A number of potential effects of projected climate change in Sweden on biological, physical, chemical and ecological processes of relevance for agricultural systems are listed below. The assessments are qualitative and constitute further evaluation of results presented in the literature review by Eckersten *et al.* (2008a), in appendices in the Vulnerability Official Report (SOU 2007), in climate change assessment for Swedish crop production by Eckersten *et al.* (2008b) and on human and animal health effects by Lindgren *et al.* (2007). We present the effects separately, but are aware of interactions between the different factors.

Effects due to increased temperature

- Decomposition of organic material in the topsoil will increase if water conditions allow. Also an increased maize acreage on the expense of ley will tend to decrease the humus content.

- Decreased frequency of freezing can leave clay soils more difficult to till, which can be weighed against an increased frequency of cracking due to drought, which will benefit soil structure.

- Increased mean temperature will cause a faster rate of development in annual crops (e.g. cereals and oilseed crops), resulting in these crops maturing earlier. Yields will decrease due e.g. to shorter grain/seed filling period. This will also affect quality. Yields of perennial crops such as leys will be promoted.

- Increasing mean temperature will increase problems with pests in particular and thus the need for crop protection/pest control measures, while the persistence of crop protection chemicals in the soil will decrease. Several species of insects will have an increased number of generations per year and new species will be able to establish.

- Changes in weed flora composition will occur. New species will migrate in from the south and some existing species may produce several generations in one season, which can pave the way for herbicide resistance problems. Increasing temperatures might also allow some native ‘sleeping’ weeds to become invasive and to move into agricultural habitats where they have not previously been found in modern agriculture. This is strongly linked to the design of future cultivation practices and cropping systems.

- Changes regarding fungal diseases are difficult to project as these depend on temperature and water conditions in a complex way, but milder winters will mean greater spread of infection by e.g. Fusarium (potential increased risk of mycotoxins), brown leaf rust and potato leaf blight, leading to an increased need for preventive measures, e.g. fungicide spraying.

- As regards pests, aphid attacks in cereal will increase sharply, which will lead to an increase in aphid-borne virus diseases (e.g. yellow dwarf virus in oats). There will probably be even greater problems with yellow dwarf virus in winter cereals because the higher temperature during autumn will favour aphids (the vector). We can also expect increased pest attacks in oilseed plants (flea beetle, pollen beetle, virus diseases). This leads to increased pesticide use and increasing resistance problems. Colorado beetle in potato and corn borer in maize are other possible new pests. Seed potato production can be affected to a greater extent by virus diseases in the future due to an increased number of vectors. Aphids will be found even in northern Sweden

- Increased frequency of frost burn in the north due to an increase in temperature fluctuations around zero, causing poorer winter survival. This also applies to the protective snow cover on frozen ground, which will become increasingly infrequent, while snow/slush on unfrozen ground will be more common, also creating winter die-off problems.
- Increased heat stress in farm animals and thus an increased need for ventilation/air conditioning.
- Increased parasite pressure in farm animals.
- Increased disease pressure and new diseases in farm animals. Infectious diseases may increase due to extended geographical distribution of disease vectors, e.g. the diseases Blue Tongue and West Nile fever.
- Risk of mycotoxin contamination of feed due to high air humidity during feed storage.

Effects due to changes in precipitation

- Increased rainfall during spring, autumn and winter will increase leaching of nutrients, mainly nitrogen. Increasing temperatures and production levels with higher nitrogen fertiliser rates will increase the risk of leaching. Larger maize acreage and less area of ley will also promote leaching losses. The losses of phosphorus through erosion may also increase as a consequence of high-intensity rainfall. Reduced snow cover and ground frost may, on the other hand, reduce the risk of surface runoff in conjunction with snowmelt. At the same time the crop uptake of nitrogen in particular will probably increase due to the possibility of climate-induced increases in productivity.
- Increased precipitation during the period October to March will also affect the opportunities for soil tillage and harvest. The question is whether the longer growing season can be utilised optimally with regard to spring tillage, choice of crop and autumn tillage. Increased winter rainfall can delay opportunities to exploit the extended growing season during the spring, so the acreage of winter-sown crops might increase at the expense of spring-sown crops. This will benefit soil structure. Spring tillage may be delayed by rain, giving weeds a longer period for undisturbed growth and favouring certain pests.
- Decreasing soil moisture during the summer can create good soil tillage opportunities, especially on clay soil, which would favour autumn sowing.
- Greater risks of flooding during autumn and winter.
- Autumn sowing is favourable when summer drought conditions ensue. Spring-sown crops are more affected by drought during the summer months which prevents them from establishing as successfully as autumn-sown crops.
- An extended grazing season might be expected, due to warmer springs and autumns, for free-range animals in particular. However on the minus side,

summer drought and rainy autumns may bring a risk of trampling damage. Wet and warm autumns may also pose a threat to animal health.

- Increased humidity may affect attacks by fungal diseases, species and scope.

Effects due to rising atmospheric CO_2 concentration

- Increasing CO_2 concentrations will increase plant production, especially of C_3 plants, which includes most agricultural crops (although maize is a C_4-plant). Warmer climate and drier conditions during the summer, especially in the south, could still result in an outcome that favours C_4 crops/weeds, due to greater tolerance to high temperatures.

- Legumes will be particularly favoured, resulting in increased N_2 fixation. Root growth will be favoured more than leaf growth in perennial weeds, which can make them more pernicious and also render control measures more difficult.

Effects due to extended growing season

- The seasonal changes in temperatures and the earlier start to the vegetation period will be particularly important during the spring, as current low temperatures limit growth despite good light availability.

- Later autumn tillage will provide a longer sowing window for autumn-sown crops. However, during autumn low light intensity increasingly limits photosynthesis, while high temperatures increase respiration losses, and the light compensation point for photosynthesis might be passed. This can significantly affect winter crop survival.

- New species and varieties will be introduced. However, it can be noted that several agricultural crops have a high introduction threshold. National plant breeding programs may be required as the longer growing season in combination with long-day conditions at high latitudes will create unique situations.

- In many cases, pests will be favoured more than crops by changes in the growing season, e.g. certain insects, virus diseases and fungal diseases in winter cereals. Earlier attack by fritfly and aphids in spring cereals can be expected. Pests can adapt faster than weeds under changed environmental conditions.

- Increased grassland production potential is expected, which would give a longer grazing season.

- Simpler buildings may be introduced for farm animals.

Availability of resources and effects on Swedish agriculture

This review summarises the effects that changes in the availability of natural resources (NR) may have on future agricultural land use in Sweden. The NR in focus are agricultural land use, fossil fuels and its derivates (external inputs) and ecosystem services. Human consumption patterns and possibilities to produce bioenergy also have an impact on NR use and vice versa and are therefore included in the review. The current situation is that human activities, including agriculture, place increasing demands on the natural resource base, e.g. ecosystem services and fossil fuels, and sink abilities, e.g. sequestration of greenhouse gases.

Several factors will have an impact on availability of NR and agricultural land use in Sweden in the future. The most critical may be climate change (see Eckersten *et al.* 2008a), globalisation (see Holstein 2008), the health of ecosystems and their ability to generate resources and buffer against disturbances, changes in consumption patterns nationally and globally, possibilities to recycle material, technological development and development of new, sustainable production systems and population changes. At present trends show an increased impact of climate change, degradation of ecosystems, more resource-demanding consumption patterns (higher meat consumption) and global population increase. However, one resource that is increasing is availability of human labour.

Agricultural land

Bioproductive land is one of the most significant natural resources for food production. Land use has generally been considered a local environmental issue, but the issue is of global importance induced by increasing needs to provide food, bioenergy, fibre, water and shelter to more than six billion people. Lack of domestic agricultural land or production is compensated for by trade. The global available arable land area per capita has decreased since the middle of the 20th century (Table 1) (FAOSTAT 2003; UNDP 2005). Average yields, at least in the EU countries, have also dramatically increased (Ewert *et al.* 2005), with a doubling of cereal yields since the 1960s.

Table 1. Historical and projected future change in available arable land area in the world (FAOSTAT 2003; UNDP 2005).

Year	
1960	0.48 ha/capita
2000	0.23 ha/capita
2025	0.18 ha/capita

Global cropland, pastures, plantations and urban areas have expanded in recent decades. Together with yield increases, these changes are accompanied by large increases in consumption of energy, water and fertiliser, along with considerable use of ecosystem services and impacts on biodiversity.

Predictions for world agricultural land use in the first half of the 21st century vary widely, largely depending on assumptions on yield growth (Ewert *et al.* 2005; Nonhebel 2005). Ewert *et al.* (2005) estimate for the EU countries that the increase in crop productivity will range between 25 and 163% depending on the scenario explored[1]. Land use scenarios for the EU15, Norway and Switzerland based on IPCC global storylines involve large declines in agricultural area resulting from assumptions about future crop yield development (Rounsevell *et al*. 2006). The scenarios also assume increases in the area of bioenergy crops. However, several technical and conceptual difficulties in developing future land use change scenarios are also discussed. These include for example, the problems of the subjective nature of qualitative interpretations, and the problem of validating future change scenarios. Another study shows that only 55% of the current agricultural land area at the global scale will be needed for food production in the future (i.e. year 2050), if a high external input system of agriculture is applied (Wolf *et al.* 2003). On the other hand all current agricultural land will be needed if a low external input system is applied at the global scale for food production, implying no surplus land area will be available for bioenergy production.

Other scenarios on a global scale show a more pessimistic view of the future, with risks of higher soil erosion and lower water availability that could slow down an increase in food production. Simulations show an intensification of present trade-offs between ecosystem services, e.g. expansion of agricultural land may be one of the main causes of a 10-20% loss of total current grassland and forest land and the ecosystem services associated with this land (Alcamo *et al.* 2005). Projections for supply and demand of food in the 21st century based on a logistic model of yield growth consistent with ecological limits on soil fertility, water availability and nutrient uptake imply that the world is indeed close to carrying capacity in agriculture, and that specific resource and ecological constraints are of particular importance (Harris & Kennedy 1999).

Fossil fuels

Fossil fuels have developed from ancient deposits of organic material, from which society today meets >80% of its energy needs. The use of fossil fuels to sustain food production cannot continue indefinitely, meaning that agriculture world-wide must adopt mitigation strategies (Hirsch *et al.* 2006). The Swedish food system today is responsible for about 15% of total fossil fuel consumption in Sweden (Uhlin 1997; Johansson *et al.* 2000). As peak oil is approached, liquid fuel prices will probably increase dramatically at next trade boom, and the economic, social, and political costs may be unique. The population of the world, which grew six-fold in parallel with oil, faces a decline, probably accompanied by rising migration pressures, according to Cambell (2002), and radical new political structures may be needed.

Current Swedish agriculture can be described as a high external input system, since the mainstream agricultural production systems in Sweden are highly dependent on use of external resources such as fossil fuels for traction and transportation, mineral fertilisers, chemical pest control and equipment. Less than 15% of resource use in Swedish agriculture is local and renewable (Johansson *et al.* 2000).

To decrease dependence on fossil fuels in the agricultural food system, the search for self-sustaining, diversified, low-input, energy-efficient agricultural systems, using local renewable resources and ecosystem services, is now a major concern of many researchers, farmers and policymakers worldwide.

[1] These are the same scenarios (SRES) that are explored in the climate change chapter.

Agricultural production of biofuels

Negative environmental consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. To be a viable alternative, a biofuel should provide a net energy gain, have environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies. However, studies vary widely regarding how much net energy can be delivered from agriculturally-based fuels, as well as the environmental load they generate (e.g. Bastianoni & Marchettini 1996; Ulgiati 2001; Nonhebel 2005).

In future there will be increased competition for land between production of biomass for food and biomass for energy. Dukes (2003) estimates that replacing the energy humans derive from fossil fuels with energy from modern biomass would require 22% of global terrestrial net primary production. Several authors conclude that availability of land for production of bioenergy is related to the level of intensity in food production, i.e. extent of external inputs, determining whether there will be surplus land for bioenergy crops (Wolf *et al*. 2003; Nonhebel 2005). If low external input agriculture is applied, using less non-renewable resources such as fossil fuels, no land will be available for biomass production for energy (Wolf *et al.* 2003). Ewert *et al.* (2005) and Rounsvell (2005) believe that substantial future increases in productivity will open the way for future production of bioenergy on surplus agricultural land in Europe, but do not discuss the impacts of changes in availability of these external inputs.

Ulgiati (2001) states that since production strategies for bioenergy are strongly linked to the existence of special conditions, such as large amounts of available land, highly productive crops and high water availability, biofuels are unlikely to become a general solution to the foreseen energy shortages. The conclusion is that at the moment, it is not possible to replace the actual performance of an energy sector based on fossil energy with an energy sector running on biofuel. When crop production and conversion to fuel are supported by commercial energies and external inputs, the fraction of the fuel energy that is actually renewable, i.e. the net energy available, is negligible. However, there are differences in potential between biomass sources. Production of biodiesel from soybean has proved to be more preferable in respect of net energy gain and greenhouse gas emissions compared with ethanol from maize grain. The advantages come from lower agricultural inputs and more efficient conversion to fuel (Hill *et al.* 2006). However, neither type of biofuel can replace much petroleum without impacting food supplies. It is concluded that biofuels produced from low-input biomass grown on agriculturally marginal land or from waste biomass could provide greater supplies and environmental benefits than food-based biofuels.

Ecosystem services and resilience

The ability of ecosystems to supply us with services and goods is frequently taken for granted, often because many of them are free of charge and are hard to see. Our lack of recognising the work of nature, and its limits to restock, has therefore led us to overuse and degrade many of these ecosystems, thus decreasing their ability to do work (Daily 1997). The growing demand for ecosystem services has been met by consuming an increasing fraction of the available supply (e.g. fresh water) and by increasing the production of some services, such as crops and livestock. However, actions to increase one ecosystem service often cause the degradation of other services (MA 2005). Balancing the inherent trade-offs between satisfying immediate human needs and maintaining other ecosystem functions requires quantitative knowledge about ecosystem responses to land use (De Fries, Foley & Asner 2004). Several promising approaches are considered by The Millennium Ecosystem Assessment (MA) scenarios, including uses of biodiversity to build resilience of ecosystem services, actively adaptive management, and green technology (Carpenter *et al*., 2006).

A doubling in global food demand projected for the next 50 years poses huge challenges for the sustainability of food production and of terrestrial and aquatic ecosystems and the services they provide to society. Agriculturalists are the principal managers of global useable lands and will shape, perhaps irreversibly, the surface of the Earth in the coming decades. New incentives and policies for ensuring the sustainability of agriculture and ecosystem services will be crucial if we are to meet the demands of improving yields without compromising environmental integrity or public health (Tilman *et al.* 2002).

Biodiversity and agriculture

A key strategy in sustainable agriculture is to restore functional biodiversity of the agricultural landscape. Increasingly, research suggests that the level of internal regulation of function in agroecosystems is largely dependent on the level of plant and animal biodiversity present. In agroecosystems, biodiversity performs a variety of ecological services beyond the production of food, including recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Altieri 1999).

Biodiversity conservation in agricultural landscapes is important because reserves alone will not protect biodiversity and biodiversity is vital since it enhances resilience, or the capacity of a system to recover from external pressures such as drought or management mistakes (Bengtsson *et al. 2003;* Fischer *et al.* 2006). The major opportunity for maintaining ecosystem services and biodiversity outside conservation areas lies in promoting diversity of land use at the landscape and farm scale and requires an economic and policy climate that favours diversification in land uses and diversity among land users (Swift *et al.* 2004). Diversity can be enhanced in time through crop rotations and in space in the form of cover crops, intercropping, agroforestry, crop/livestock mixtures, etc. Correct biodiversification can contribute to pest regulation through restoration of natural control of insect pests, diseases and nematodes. It can also lead to optimal nutrient recycling and soil conservation by activating soil biota, all of these factors lead to sustainable yields, energy conservation and less dependence on external inputs (Altieri 1999).

Adequate biodiversity for maintaining key ecosystem services will differ depending on whether the aim is e.g. to increase yield stability or deal with salinity, groundwater levels, soil erosion, leaching of nutrients or weed control (Main 1999). The point is that ecosystems and their composition are contingent in nature so the history of events, their frequency and intensity all need to be considered when interpreting the natural biodiversity present and thus determining what is adequate in particular circumstances.

Consumption patterns

Throughout the world there appears to be a direct link between dietary preferences, agricultural production and environmental degradation (Carlsson-Kanyama *et al.* 2003). It is argued that in the near future changes in consumption patterns rather than population growth will form the most important variable for total land requirements for food (Gerbens-Leenes & Nonhebel 2002). World-wide, an estimated 2 billion people live primarily on a meat-based diet, while an estimated 4 billion live primarily on a plant-based diet. The meat-based food system requires more energy, land and water resources than the plant-based diet (Pimentel & Pimentel 2003).

Trends towards the consumption of foods associated with affluent lifestyles will bring with them a need for more arable land, energy and water. A difference of a factor of two has been found in relation to the requirements for existing European food patterns, while the land requirement for a hypothetical diet based on wheat is six times less than that for an existing affluent diet with meat (Gerbens-Leenes & Nonhebel 2002). However, differences in resource use and environmental influence could be obtained by different livestock production systems, mainly caused by feeding strategy. Nonhebel (2004) reports lower land requirements for livestock fed with residues from the food industry compared with growing of special feed crops.

Concluding remarks

Within the last few years, three major global assessments have stressed that agriculture has a major role to play in climate change (IPCC 2007a), ecosystem health (MA 2005) and global development (IAASTD 2008). None of these assessments identifies simple solutions to decrease impacts from agricultural activities or to mitigate the impacts on agricultural production. The two most recent reports stress that business as usual is not an option and modern agriculture will have to change radically to better serve the poor and hungry if the world is to cope with a growing population and climate change, while avoiding social breakdown and environmental collapse. The reports also call for a more holistic view of agriculture and urge governments, NGOs and the private sector to work together.

There is a wide spectrum of views on possible futures for agriculture and our prospects of living within our means while providing better from more. Intensification leading to increased yields per hectare provided most of the last doubling of agricultural production, and much of the debate over world agricultural futures centres on the issue of the potential for another doubling in yield growth. Furthermore, the research community is not in agreement on whether the solution is to further intensify and develop modern high external input agriculture to increase yields, or whether we must develop low external agriculture with better appropriation of local and renewable resources to decrease pressure on natural ecosystems and adapt to lower availability external inputs. In order to build preparedness when there are such divergent views on the future and what the solutions are, future research will have to allow for a rich diversity of approaches.

Economic globalisation and effects on Swedish agriculture

In this chapter, the effects that the globalised food market may have on Swedish agriculture in the future are summarised. Globalisation is a combination of world-wide economic, cultural and political processes leading e.g. to increased global trade. By globalisation we have increased our dependence on agricultural raw materials and food products from other nations to support our food supply system at the same time as we have decreased our dependence on domestic production and increased the variability in products available for Swedish consumers. Contributing factors to increased international trade are possible deregulation of current (EU) policy in the agricultural area and liberalisation of international trade policies. The general effect of increased trade possibilities and increased trade is that prices are, to some extent, levelled out. However, since there are e.g. transportation costs, prices will generally not totally equalise. In the short run, increased trade will benefit producers in countries where prices used to be lower and consumers in countries where prices used to be higher. At the same time, the producers in countries where prices are decreasing will be losers, as will the consumers in countries where prices are increasing. A central conclusion in economics is however that the general standard of living will increase in each country since the winners will gain more than enough to compensate the losers. However, this redistribution will not be an immediate effect of increased trade but will require political measures, which are in reality seldom introduced. Increased trade will generally benefit farmers in developing countries, while the non-farming poor will be losers in the short run.

In the long run, theory presumes that trade liberalisation will also benefit poorer consumers, since more trade will increase the possibilities for even the poor to increase their standard of living through increased demand for their work (Winters *et al.* 2004). Increased trade will lead to increased competition and thereby to strengthened incentives for technological improvements that increase productivity and thereby standard of living. Liberalisation will also mean that new technology will be spread and adopted faster, promoting an increasing standard of living.

The empirical evidence in general supports this view, while there is weak support for the opposite view that trade will make poor people worse off. Hence, in the long run, there is a higher potential for all to become winners even without any political redistribution. However, this requires that the initial losers have (economic) possibilities to adapt to the new circumstances (Winters *et al.* 2004).

The competitiveness of Swedish agriculture

For many products, Swedish consumers have the option of choosing between Swedish and imported food, as the Swedish market over the years has become more open for international, especially European, agricultural products. Even if imported foods of all kinds are not available to all consumers, the possibility of imports is a factor that increases the competition for Swedish farmers. The question of the competitiveness of Swedish agriculture has been analysed e.g. by SLI (Hammarlund 2004; Ekman & Gullstrand 2006).

It can be noted that even though Swedish imports and exports of agricultural products have doubled since EU membership in 1995, the volumes of cereals, milk, meat and pork produced have not altered significantly. However, since the productivity has increased, the land use and the number of animals have decreased over the same period, with the exception of broiler chickens, where production has doubled since 1990. Even though domestic production has not decreased, its market share on the Swedish food market has decreased, especially for meat, where consumption has increased. At the same time as production volumes are being maintained with less land and fewer animals, the number of farmers has also decreased, while farm size has increased.

The competitiveness of Swedish agriculture depends on the relative production costs and it can be noted that Swedish agriculture has some conditions that increase the costs compared with other countries generally. Historically, agricultural policy has helped farmers with higher production costs to survive, which means that the average production costs have become higher. However, average productivity will increase, and costs decrease, either if these farmers are forced to close down or if they improve their productivity as an effect of increased competition. Compared with many countries in the world, Sweden has higher costs for production factors such as labour, which means that it is important to utilise the economies of scale if the competitiveness of Swedish agriculture is to be preserved or improved. Finally, the costs for Swedish farmers are also affected by the climate (e.g. higher costs for buildings in animal production) and by more stringent regulations concerning the environment and animal health. However, it should be noted that the relatively high costs for buildings in Sweden are only partly explained by climate and regulations. Hence, the conclusion by Ekman & Gullstrand (2006) is that Swedish agriculture will face increased international competition but that a combination of well-educated farmers and labour and utilisation of economies of scale will possibly lead to production volumes being maintained. On the other hand, if Swedish agriculture fails to reduce costs sufficiently, the production volumes will decrease in the future. It should be noted that this conclusion is a result of assumptions concerning total demand on the world market. If increased demand on the world market leads to increased world market prices, as currently projected by OECD/FAO (2007), this will of course lead to more production, and greater land use, in Sweden and elsewhere compared with the case of decreasing production prices assumed by Ekman & Gullstrand (2006).

Even if Sweden has comparative disadvantages in *primary* production, the competitiveness of the food sector as a whole has increased since EU membership (Hammarlund 2004). This is due to increased exports of processed products, which receive a higher price than the imported products of the same kind. This highlights the fact that the competitiveness of the Swedish food sector is dependent on the Swedish food industry and its development of highly valued products, where vodka and chocolate can be mentioned as examples. The later example also indicates that the Swedish food industry may be competitive, even without any primary agricultural production in Sweden.

Although the costs of primary production are generally higher in Sweden, the competitiveness may be maintained if consumers (domestically and/or internationally) of agricultural products are prepared to pay more for products produced in Sweden. As reported by Gullstrand & Hammarlund (2007), there has been an argument that Swedish production is characterised by more environmentally- and animal-friendly methods and a higher level of food security. Consumers should therefore be prepared to pay more for Swedish agricultural products. However, their analysis showed that Swedish products in general do not receive higher prices on the

European market. In the cases where there is a difference in price, the Swedish products are more often valued lower than other products. However, there are some cases where Swedish products receive a higher price, namely on some markets close to Sweden and for highly processed products. Hence, it seems as if the qualities referred to in the debate do not strengthen the competitiveness of Swedish agriculture but that, as concluded in the study referred to above, it is in highly processed products that Sweden has the main advantage on the European market.

It can be discussed whether it is possible to increase consumer willingness to pay for Swedish products by better information about e.g. environmentally- and animal-friendly production methods. However, there are good reasons to question such expectations (Gullstrand & Hammarlund 2007). These qualities are so-called public goods, which means that the benefit, e.g. of a cleaner environment, is shared among all consumers irrespective of who paid the higher price for the environmentally-friendly product. If others pay, one can enjoy the values for free, and if no one else pays the effect of one person's expense is very small. Hence, the incentive for actually paying for public goods is low. This general theoretical result is supported by the findings of Gullstrand & Hammarlund (2007). General economic knowledge suggests that the production of public goods, in economically efficient quantities, has to be supported by some kind of political regulation. Since such regulations may affect the competitiveness of Swedish agriculture in a more globalised world and/or be illegal in relation to international trade agreements (e.g. WTO), it is a challenge for the future to create good incentives.

It should be noted that some consumers actually *are* paying a higher price for e.g. organically produced foods. The market share for these products is currently about 3% and consumption is growing by 10-20% per year (van der Krogt 2007). Does this contradict what was stated about public goods above? It might of course be that some consumers do not free ride even if there are incentives to do so. But, a probable explanation is that they pay the higher price for a quality (e.g. more healthy food) that is not a public good. However, even if some consumers are prepared to pay more for what they perceive as a higher quality, the results referred to above show that this kind of production will probably not increase the competitiveness of Swedish agriculture in general.

Global market changes

How then will changes in the world market and in European agricultural policy affect Swedish agriculture? To answer this question, assumptions must be made concerning how the important driving forces will change in the future.

The effects of changes in CAP 2003 have been investigated by SLI (Ekman 2005), where the CAPRI-model (an economic model of the European agricultural sector) has been used to predict the situation for the agricultural sector in 2009 with the changes in CAP compared with a situation without those changes. One of the results was that the amount of set-aside land would increase and that less acreage would be used for cereals. It was also concluded that prices in the EU would increase to the benefit of farmers at the detriment of consumers and tax-payers. It should be noted that it was only the policy changes that were analysed and how the agricultural sector would be affected by the change in CAP if everything else remained unaffected. The report notes that land not used for agricultural production will probably not be used for forest production, since subsidies will be received for land that is kept as agricultural land. This means that improved conditions for agricultural production may lead to increased production. Even though this is not explicitly mentioned in the report, increased prices on the world market may represent such a change in conditions. It can therefore be concluded that the analysis in one way failed to predict the current situation with drastically improved conditions for the Swedish agricultural sector. However, since the changes on the world market are the kind of changes that were not explicitly analysed, this is not to be regarded as a shortcoming of the analysis.

The Swedish National Chamber of Commerce investigated the potential outcome of three levels of liberalisation of trade and the conclusion was that regardless of the scenario, the Swedish agricultural sector will decrease, with the exception of production of pigs and poultry (Kommerskollegium, 2006). Even if the exports of pigs and poultry are expected to increase quite significantly in percentage terms, the increase in production will be very modest. The main effect seemed to be for the production of grain, which will decrease by about 23%, independently of scenario.

Developments in the world market for agricultural products for the coming 10-year period are projected annually by OECD-FAO. In the latest Agricultural Outlook 2007-2016 (OECD-FAO, 2007), the coming ten years are projected in the light of the increased prices in the latest year. It is concluded that the drastically increased prices are mainly explained by temporary factors but that a continued high demand for biofuel will probably lead to prices at a higher level than those in the last ten years. In summary, OECD-FAO concludes:

- The current high prices are partly due to temporary factors, but the price levels will be higher than the historic levels for the ten-year period.
- The higher prices will negatively affect net importing countries, poor urban populations and producers that use animal feed (since they are competing with e.g. biofuel feedstock).
- A higher price level may lead to policy reforms and less price support.
- The rapidly growing biofuel industry is expected to be one of the main drivers for the coming ten-year period. This will lead to higher crop prices and, indirectly, higher prices for livestock products.
- The prognoses are based on assumptions regarding economic support for biofuel production. If production technologies, biofuel policies and/or crude oil prices develop in a different way, then assumed prices for agricultural products may be lower than projected.
- Demand will grow strongly in many developing countries, which will lead to increased imports but also to increased domestic production. Taken together, OECD countries will lose production and export share.
- World trade will grow, especially the south-south trade. Hence, OECD countries will face increased competition.

It can be noted that the price of crude oil is projected to vary between 55 and 65 USD/barrel as yearly mean price, which can be compared with the average price for 2001-2005 of 34 USD/barrel and the current price of about 115 USD/barrel. The main effect of a relatively high crude oil price is its influence on the demand for biofuel crops. This increased demand will affect the prices of other agricultural products as well (1 barrel = 159 litres).

The results are based on predictions concerning macroeconomic development, changes in agricultural and trade policies, trends in technology development and consumer preferences. On the other hand, the predictions do not consider occasional weather events and their corresponding agro-ecological effects, such as crop yield effects.

Global agricultural production is predicted to continue to grow in the coming decade (OECD/FAO 2006; 2007). One of main determinants of future agricultural production and consumption is economic development and it is assumed that economic growth will remain strong. The growth potential of large developing countries such as China and India make them key drivers on global agricultural markets. The shift towards developing countries will probably accelerate, with increased investments in infrastructure. The increased wealth will also increase demands for livestock products, which will have large effects on agricultural land use, i.e. increased agricultural area for production of feed. Population growth rate is assumed to decline and will lose its relative importance with regard to increased food demand. There will be strong competition from developing and former transition countries, which reflects their comparative advantage in agricultural commodities. Production increases are presumed to become lower in OECD countries compared with countries outside the OECD, especially for red meat, pork, dairy products and sugar. However, increased trade in processed products may give an advantage for developed countries such as Sweden, with a high-technology based food industry.

In comparison with earlier reports from the OECD, the 2007 report has a stronger focus on effects of the developing market for biofuels, as well as the development of the animal production sector. So far, the rising food prices only partly depend on the increased demand for biofuel, with the exception of US maize grain prices. Further increases in demand will lead to important changes on the agricultural market. However, the OECD concludes that there are still great uncertainties about the future development of the agricultural biofuels market, i.e. effects of changed agricultural policies, technological development and fossil fuel prices.

There are several factors where there are especially great uncertainties, which may strongly affect the predictions for the global food market:

- Production shocks related to climate change, e.g. drought in important food production regions, heat-waves etc., which can lead to drastic changes in trade patterns and/or to greater migration
- Animal disease outbreaks, e.g. BSE (Bovine Spongiform Encephalopathy, or the “Mad-Cow Disease”), can lead to immediate and severe trade restrictions
- The extent of economic growth, especially in China, India and Brazil, will have great impacts on global demand for agricultural products
- Future structure of the EU agricultural policy
- Outcome of multilateral trade negotiations such as the World Trade Organization (WTO)

Long-term scenarios for land use

Previous sections illustrate some of the problems concerning prognoses or scenarios; uncertainties regarding the development of driving forces increase as the time horizon increases and every model has to use some assumptions. In the short run, the effects of known changes in policy may be analysed without taking e.g. climate change into account. On the other hand, if the effects of climate change are to be analysed, the time horizon has to be much longer in order to evaluate different scenarios for climate change. Then, if analysing agricultural production in 2050 or 2080, the uncertainties about agricultural policy, for example, become huge. Through models, possible future ways of development could be described and some analyses have been made of combined environmental and socio-economic scenarios using the IPCC scenarios and different land use models for future land use changes in Europe (Ewert *et al.* 2005; Rounsevell *et al.* 2005, 2006; Abildrup *et al.* 2006). Here, the uncertainties are partly handled by the analyses of different scenarios. They show divergent results in future land use in the EU countries including Sweden, caused by different kinds of simplifications concerning food demand. For most scenarios the results indicate a surplus of agricultural land on EU level as well as in Sweden, due to substantial increases in productivity, opening the way for alternative land use, such as bioenergy crops, in the future. However several difficulties in developing future land use change scenarios exist, see Rounsevell *et al.* (2006) for a discussion. These include problems with the subjective nature of qualitative interpretations and the problem of validating future change scenarios. One important conclusion from a comparison between the models is that it is not just the assumptions about the development of the driving forces that affect the result, but also the model itself. Nevertheless, the results of the models are highly dependent on assumptions regarding climate change and, especially, regarding future changes in productivity due to technological improvements.

One problem with the long-term models is that they fail to take the dynamics of the economic system into consideration. For example, there are factors in a market-based system that will mitigate the effects of changes in another factor. If decreased production in one part of the world due to climate change tends to increase prices, this will stimulate increased production in other places and also affect the consumption patterns and decrease the demand.

Final remarks

The effects of globalisation on Swedish agriculture are difficult to project. Increased liberalisation will lead to increased competition, which will most probably lead to decreased production in Sweden. However, future changes in land productivity seem to affect land use more than the degree of liberalisation in trade. It is also clear that the projections are sensitive to assumptions regarding the development of drivers, but that there are mitigating factors that make the most extreme outcomes less probable. The conclusion that Swedish agriculture will decrease, at least in land use, may very well turn out to be incorrect. This should be clear both from scenarios where climate change makes Swedish production more competitive and from the recent increases in demand on the world market. This increase may have the consequence that land in less competitive countries will be sufficiently productive.

Effects of climate change on crop production systems – regional scenarios

Regional scenarios

Within FANAN, future conditions for crop production were predicted for three regions in Sweden according to the A2 climate scenario; South-west Skåne in the far south of the country, Mälardalen district in central Sweden, and the coast of Västerbotten in the far north.

Furthermore, projections based on scenarios A2 and B2 were made regarding changes in the length of the growing season and precipitation patterns for nine additional regions. These scenarios were chosen in accordance with available regional climate change scenarios from SMHI (Swedish Meteorological and Hydrological Institute), used in the study on vulnerability and climate change in Sweden (SOU 2007; Eckersten *et al.* 2008b). The locations selected represent different regions. From south-west to north these locations were: Varberg, Kalmar, Visby, Skara, Linköping, Karlstad, Hudiksvall, Östersund and Övertorneå (Fig. 4, p. 17).

Historical introduction to crop rotation development in Sweden

Like all other activities, agricultural development is a continually ongoing process formed by our needs and values in various environments at the national and global levels. The first stage in this chain of development has millennia-old natural traditions, including clearing and burning a piece of land (slash and burn farming). Some crops, commonly a cereal, were grown mostly for household use on this land as long as the soil reserves of plant nutrients and the fertiliser effect of the ash and plant residues persisted. When yields began to decrease, a new piece of land was tilled. Over time, it was recognised that slash and burn land could again be used for cropping after some years of fallow. This led to more regular crop rotations. Animal feed was at that time primarily obtained from pasture. In Sweden with its humid leaching-prone climate, the search for plant nutrients has dominated the design of cropping systems through history.

The upheaval that occurred in conjunction with the land reforms during the first half of the 1800s contributed strongly to continuous cereal growing being replaced by more varied cropping. Pastures were no longer used for production of animal feed and were instead ploughed to become arable land. Leys (artificial meadows) now became part of the crop rotation system (Fig. 7), promoted by influences from Germany, where a system with 3-4 years of cereal followed by long-term leys was common.

The introduction of other crops, such as legumes, root crops and potatoes, made crop rotations more variable. Strict rotational farming was mainly applied in the intensive agricultural regions of Sweden. An example of such a mixed rotation system is the well-known Norfolk rotation, comprising winter cereal, root crops, spring cereals and ley. In large parts of Sweden, mixed rotations dominated for over 100 years under the name of *crop rotation farming*. For example, in Central Sweden an eight-course crop rotation with fallow, winter cereal, three-year ley, spring cereal, spring cereal was often used. In large parts of Norrland, rotations with one or a few years of cereal followed by many years of leys were common. Crop rotation farming is thus based on a cropping system where pure cash crops are alternated with perennial crops for feed (e.g. perennial leys). This system is very suitable where ruminants are reared, as an important part of their feed is roughage from leys.

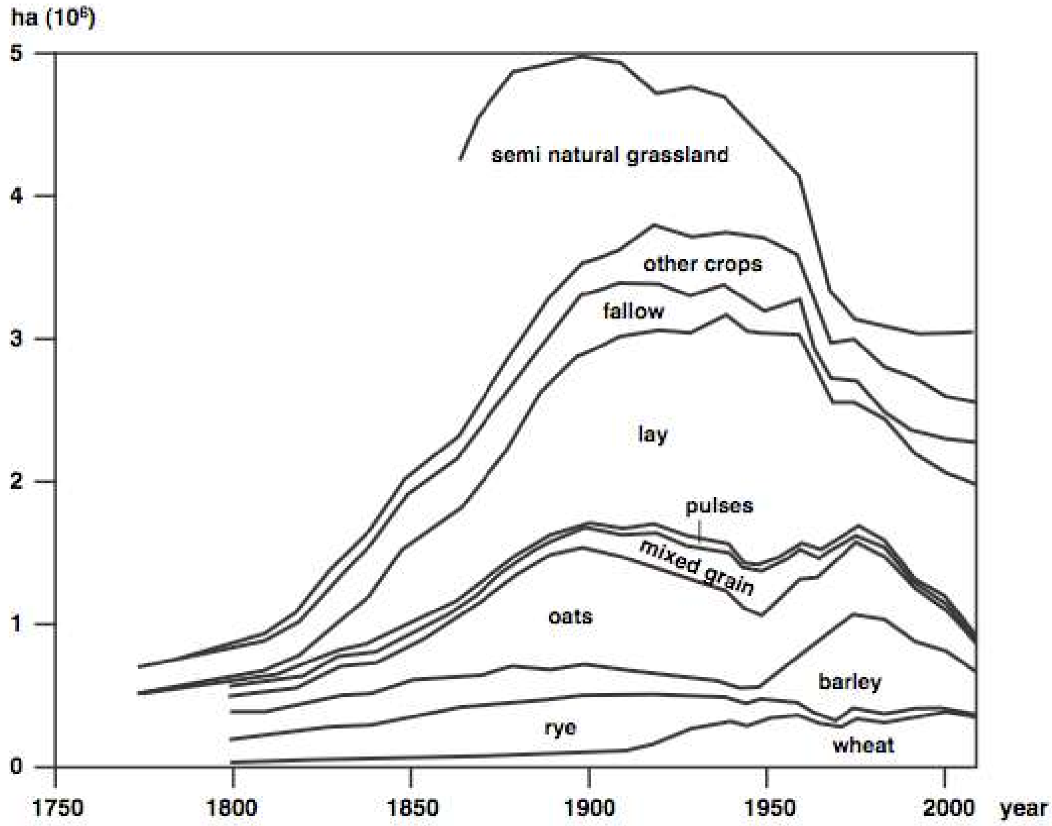


Figure 7. Agricultural land use in Sweden from about 1800 to the present time (Mattson 1978, modified 2005).

The demands for rationalisation and specialisation together with access of external inputs, e.g. industrial fertilisers and pesticides, have brought about a change towards more *free crop rotations*. Free crop rotations are mainly practised on farms with few or no animals, and have resulted in monotonous crop rotations, often cereal. The link developed in ancient times between cropping and animal rearing has been broken. Crop rotation agriculture is consequently less pronounced today. However, the benefits of crop rotational farming systems are again being investigated and frequently discussed, even for high-input systems. We are now on the threshold of advances in the technical development of agriculture, e.g. computerisation and precision farming. At the same time, biological and ecological knowledge of the functioning of agricultural systems has increased. We are able to manage large amounts of information and thus also better understand the biological processes involved. This can help us to develop future sustainable agricultural systems and cropping methods.

Future climate scenario for south-west Skåne

The A2 regional scenario for Skåne shows an average temperature increase of about 4 °C at the end of this century (Fig. 9 a-c). The growing season may increase dramatically, from around 215 days to 340 days, i.e. almost all year round. A major part of these changes may occur within the next few decades (~year 2025) as relatively small increases in temperature result in large changes in vegetation period length. Already today, the growing season in Skåne is on average about three weeks longer compared with the period 1961-1990. The future precipitation pattern also shows major changes, with less rainfall than today mainly during July and August and with large amounts in late autumn and winter. The regional B2 scenario for Skåne shows minor differences from the A2 scenario.

Consequences for cropping systems in south-west Skåne

Figure 8 shows the crop distribution at present (as of 2006) (SCB 2007). The area of ley is large, but is mostly grown outside the great arable plains. On the plains of western Skåne, cereals together with sugar beets and winter rape seed are the dominant crops. During recent years the area of sugar beet has markedly decreased and the growing of rape seed increased. For example, between 2005 and 2006 the area of rapeseed increased by 30%.

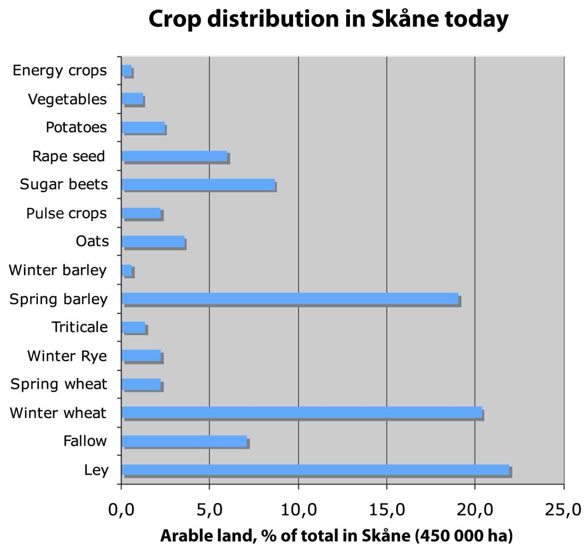
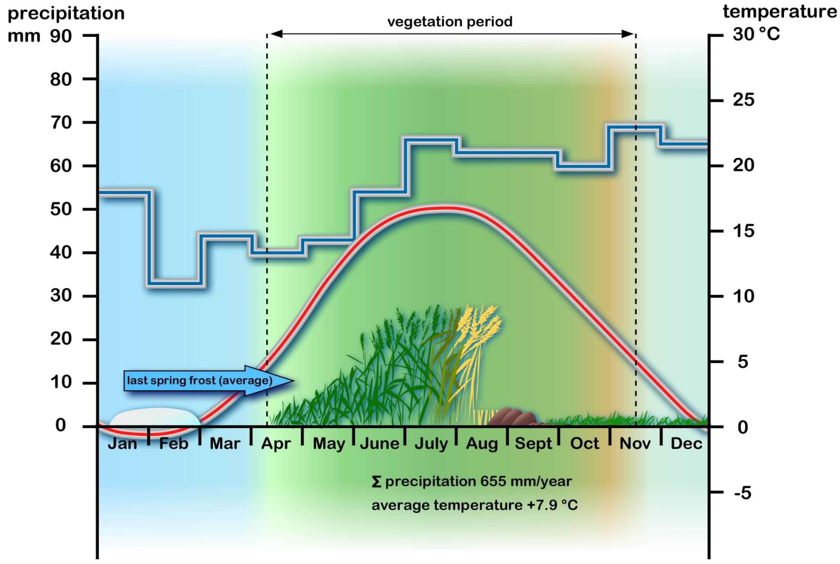


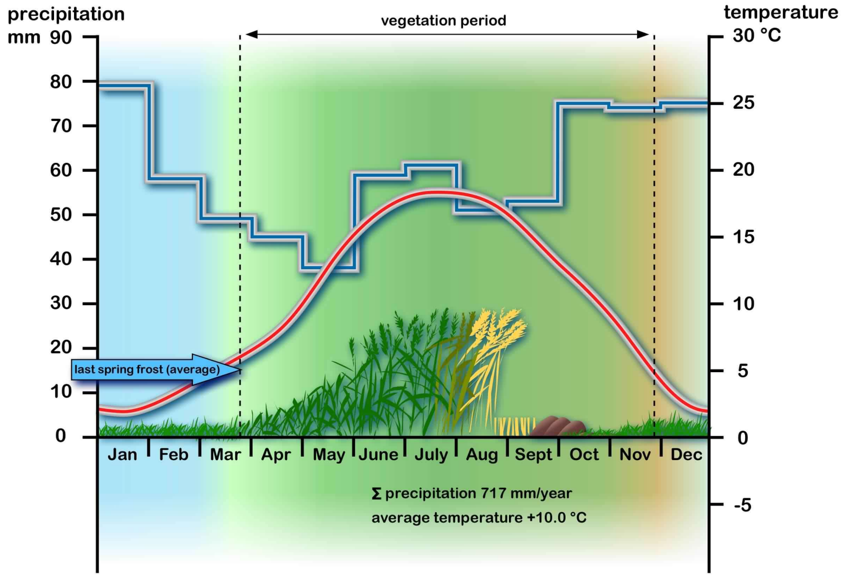
Figure 8. Percentage of arable land in Skåne used for different crops in 2006 (SCB 2007).

Due to the expected increased precipitation during autumn and winter, Skåne might have wetter soil conditions in spring. This would favour autumn-sown crops, which could dominate future crop rotations, and spring-sown crops may decrease. Also plant protection aspects might strengthen this trend as autumn and spring sown crops of the same species may cause increased problems with pests. Autumn-sown crops are also able to use the longer growing season to a greater extent than spring crops. The warmer winter period will allow the growing of new varieties and crops, for example winter barley and autumn-sown spring wheat (see figure p.39). However, there might be problems with over-wintering of autumn-sown crops due to high precipitation and limited light intensity during warmer autumns.

a)
Average 1961-1990



b)
A2 ≈ 2025



c)
A2 ≈ 2085

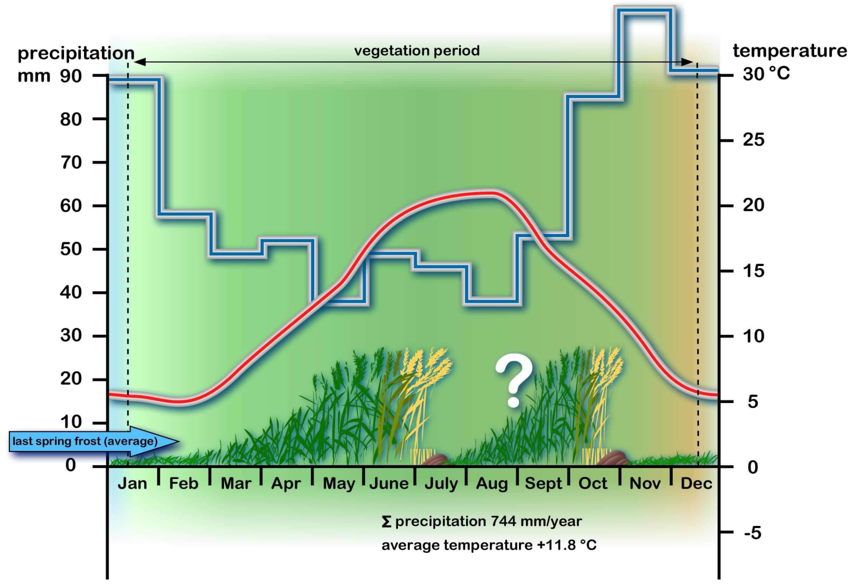
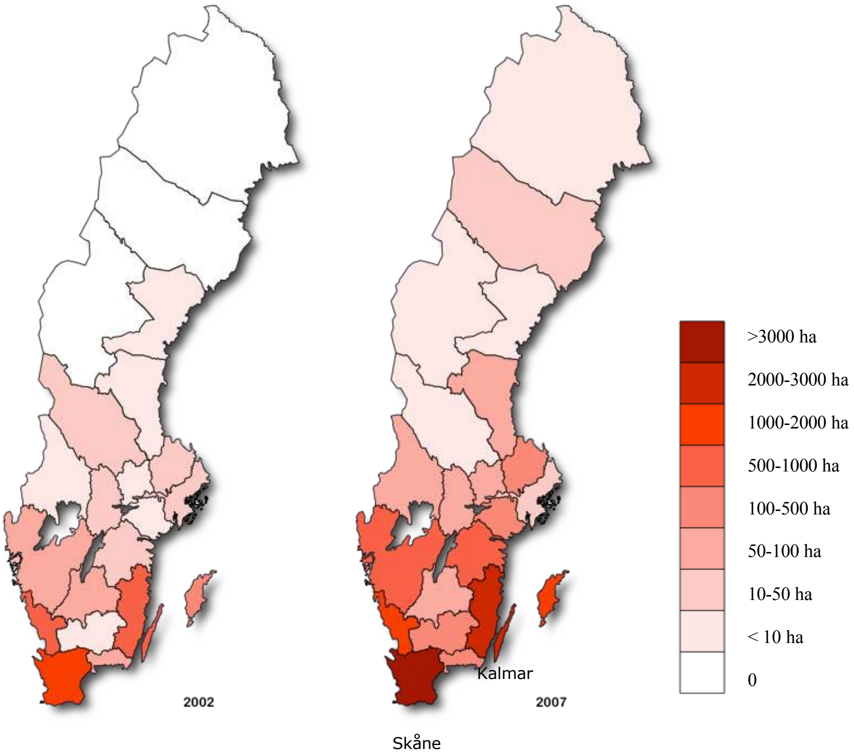


Figure 9. (a) Current climate (average 1961-1990) in Skåne, (b) regional A2 scenario year ~2025 and (c) regional A2 scenario ~2085. (See also fig 18 and 19, p. 50-51).

a)



b)

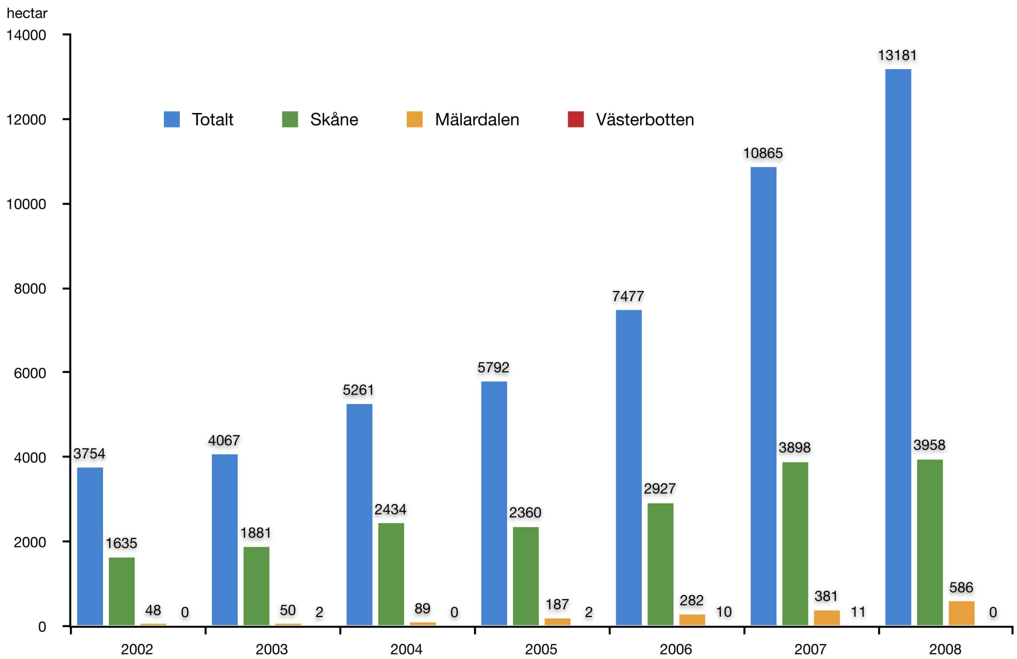


Figure 10 a) and b). Changes in maize area in Sweden in recent years.

Maize greatly benefits from increasing temperatures and it may be grown regularly to maturity in Skåne within this century. New cultivars may speed up this progress since current cultivars often have high water content at harvest, which leads to high costs for drying. The cultivation area of maize has already increased during the 2000s, especially in Skåne and Kalmar county (Fig. 10 a, b). In Denmark cultivation of maize has increased dramatically during recent decades, especially since the year 2000, from 20 000 ha in the1980s to 140 000 ha in 2006.

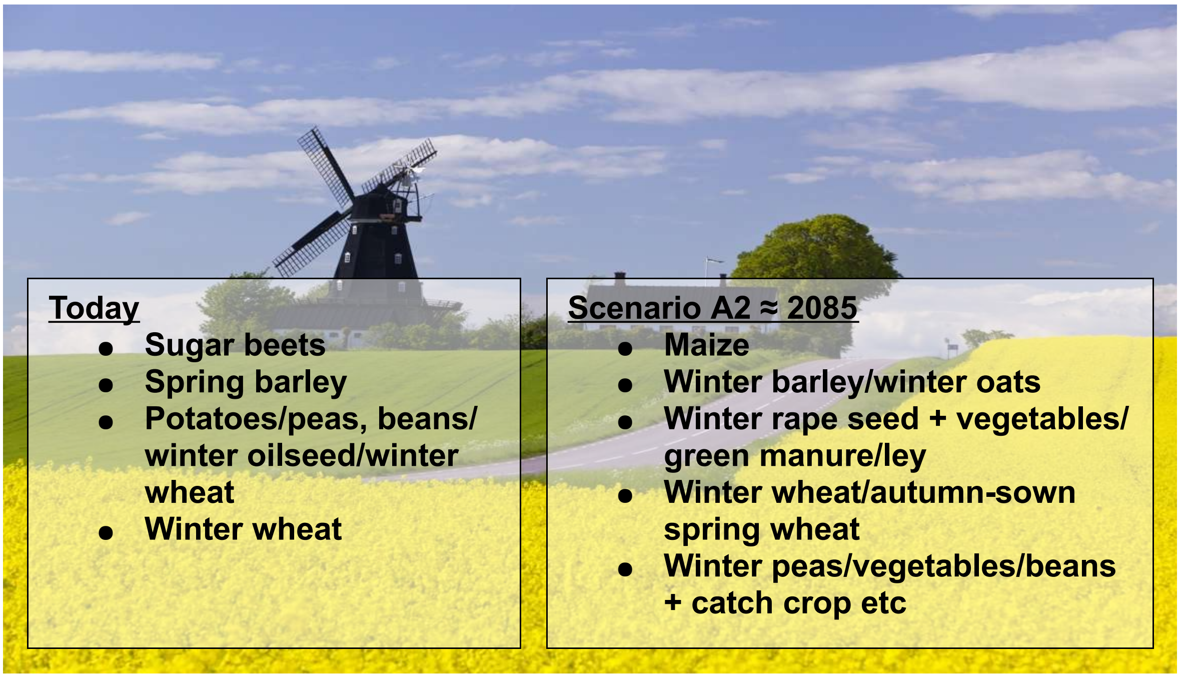
Today rapeseed (mainly winter rapeseed) is grown on about 6% of the arable land in Skåne and there is great potential for increased winter rapeseed cropping. There are crop rotation limitations due to diseases, with recommendations of a maximum 20% rapeseed in a rotation.

Rape seed is a good break crop in cereal-dominated rotations and furthermore it has a large capacity to take up nutrients during autumn, thus reducing the risk of leaching.

It is difficult to predict the cultivation conditions/possibilities for sugar beets in the distant future. More severe summer droughts may negatively influence root crops and increase the need for irrigation.

A growing season almost all year around would probably imply the possibility to grow two crops within one year, one early maturing crop, e.g. winter rapeseed, and then establishing a crop with a short culture time. Also there may be possibilities to grow new kinds of vegetables and legume crops, e.g. different kinds of beans, perhaps soybeans.

In the boxes below we present examples of arable crop rotations today and in the future in the great plains of Skåne.



A prolonged growing season together with higher precipitation entails a need for a green cover throughout the year to prevent leaching. There could be numerous solutions in crop rotation design to achieve this green cover, catch crops, green manure or short-term ley sown under main crops or established after harvest, two short cultures per season or relay cropping (two or more crops grown as intercrops during a part of the cultivation period). It will be important to find cropping solutions for the markedly longer period between crop harvest and time of autumn sowing or sowing of a spring crop next year. For example it may be possible to take a clover-grass harvest already the first autumn if that crop is established in an early maturing crop. The clover-grass biomass could be used either for feed or as raw material to biogas production (see fig. 9, p. 37 and fig, 19, p. 51).

Future climate scenario for Mälardalen

The A2 regional scenario for Mälardalen district predicts a temperature increase similar to that as predicted for Skåne, i.e. about 4 °C at the end of this century (Fig. 12 a-c). During the winter period the average temperatures may not very often fall below zero, with the consequence that winter precipitation will mainly occur as rain. The average precipitation will increase by around 100 mm per year but the rainfall pattern will be reversed compared with the current pattern, the minimum shifting from late winter to early summer, and the maximum shifting from summer to autumn. The late autumn and winter may not be as wet as in south-western Skåne. The growing season might be extended from 185 to 250 days, which is about one month longer than the growing season in Skåne today. Today the growing season in the Lake Mälaren district (Mälardalen) is already on average one or two weeks longer compared with the period 1961-1990.

Consequences for cropping systems in Mälardalen

The area of lay in 2006 covers about one fourth of the agricultural area of Mälardalen (consisting of the counties of Stockholm, Uppsala, Södermanland and Västmanland) (SCB 2007) (Fig. 11). The ley areas are however not evenly distributed and on the plains north of lake Mälaren where arable farms with cereal crop rotations dominate. Spring cereals cover larger areas than winter cereals, despite increasing proportions of winter cereals. Also the cultivation of winter rape seed has increased in recent years.

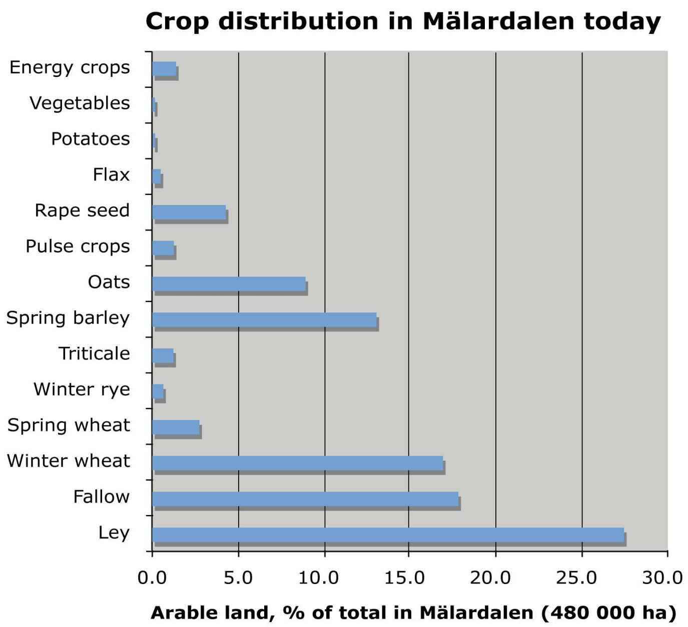
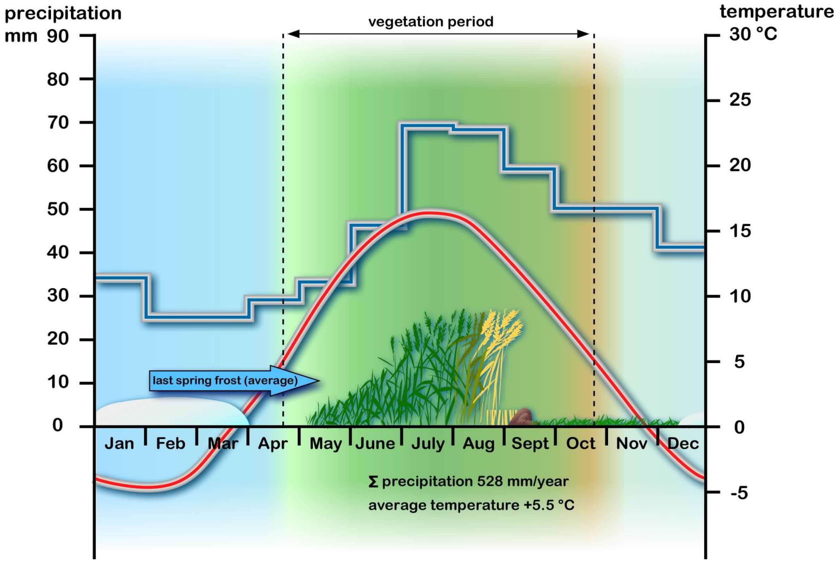
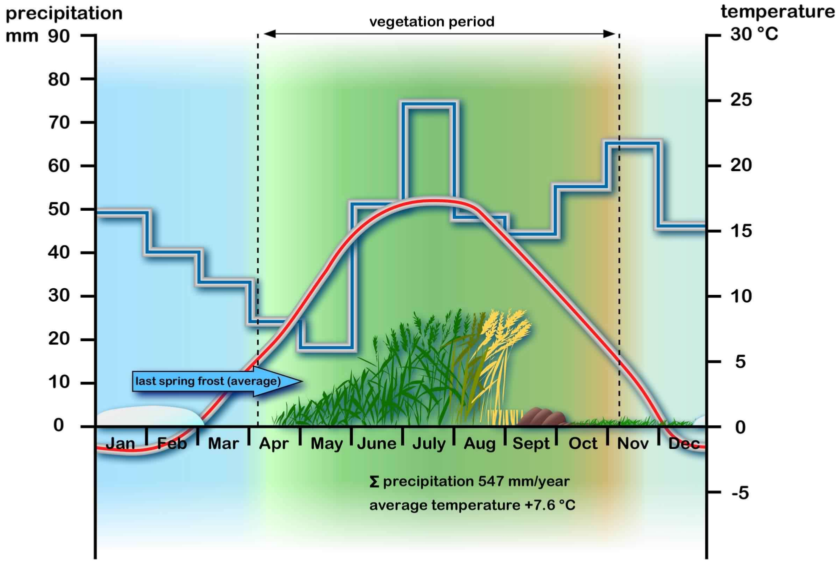


Figure 11. Percentage of arable land in Mälardalen district used for different crops in 2006 (SCB 2007).

a)
Average 1991-1990



b)
A2 ≈2025



c)
A2 ≈2085

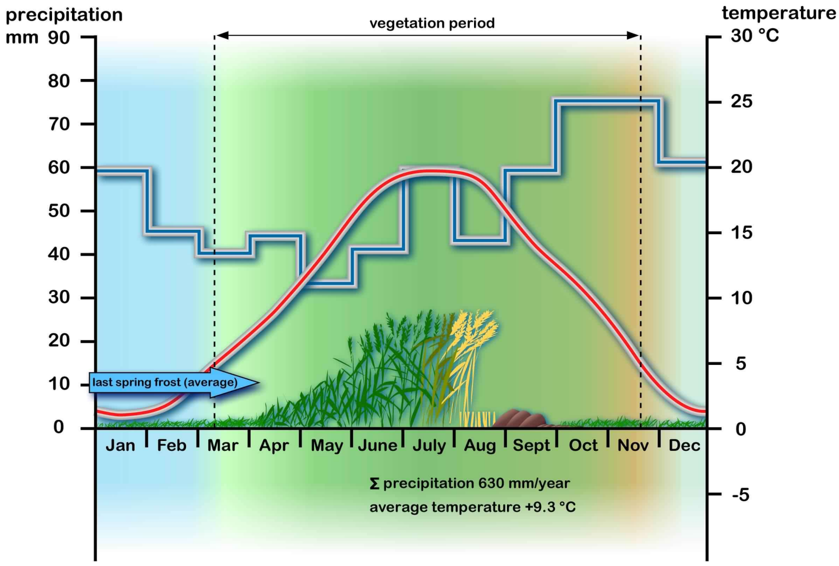
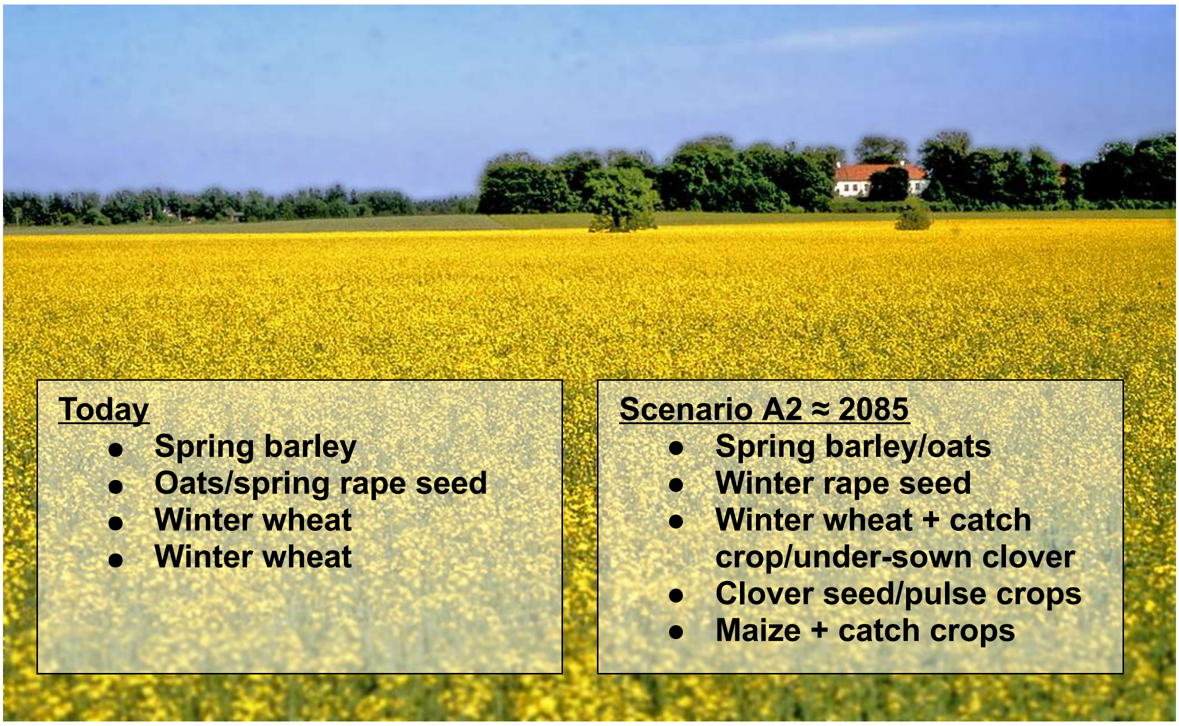


Figure 12. (a) Current climate (average 1961-1990) in Mälardalen district, (b), regional A2 scenario year ~2025 and (c) regional A2 scenario ~2085. (See also fig 18 and 19, p. 50-51).

As in the case of Skåne, we assumed that the future climate conditions of the Lake Mälaren district will favour autumn-sown crops at the expense of spring-sown crops. The cultivation of oil seeds will shift from predominantly spring rape seed to predominantly winter rape seed and winter barley is expected to become common. With a longer growing season, higher temperatures and atmospheric CO_2-concentrations, different kinds of legume crops may have more advantageous growing conditions in the future, such as faba beans, lupins and seed production of clovers. Maize, at least for silage, may also be an important crop for feed in this region and it is not unlikely that new cultivars will even be grown for mature cobs in the middle of this century. Altogether the opportunities in Mälardalen district for more varied arable crop rotations due to climate change are assumed to increase.

In the boxes below we present examples of arable crop rotations that are common today and those that might be common in the future in Mälardalen district.



The temperature may be higher and length of the growing season longer in Mälardalen district in ~2085 than in Skåne today. However, the day length will remain longer during summer and shorter during winter. The dark late autumn and winter together with higher temperatures may negatively influence over wintering of crops. Furthermore, severe over wintering conditions may occur as winter temperatures will often be around zero and snow cover will be rare. At the same time, current yield statistics show that the yield of winter wheat is positively correlated to higher temperatures during winter-spring, January-March (Michael 2002), which is projected in the climate scenario (see fig. 12 p. 41 and fig. 19 p. 51).

Future climate scenario for the coast region of Västerbotten

The A2 regional scenario for Västerbotten shows higher average temperature increases than the more southern scenarios, from 2.7 to 7.0 °C at the end of this century (Fig. 14, p. 44), which is only a little less than current (1961-1990) average temperatures in Skåne. The yearly increase in precipitation is projected to be large, about 200 mm. All months throughout the entire year may get higher precipitation, with the most extreme additions during the winter months. However, the growing season is not projected to increase as much as in the south, and today it still has about the same length as 1961-1990. Nevertheless, the projection shows a vegetation period in Västerbotten of 215 days, i.e. an increase of about a month in spring and a month in the autumn, similar to the growing season in Skåne today.

Consequences for cropping systems in Västerbotten

The current land use in northern Sweden is dominated by ley cropping and ruminant production systems (Fig. 13). The only cereal that covers large areas is spring barley. Energy crops, vegetables and triticale are also grown, but on small areas of arable land.

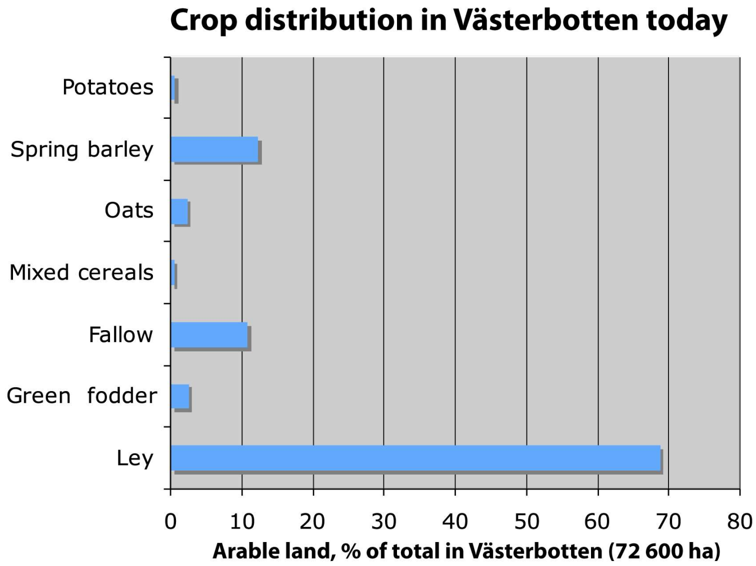


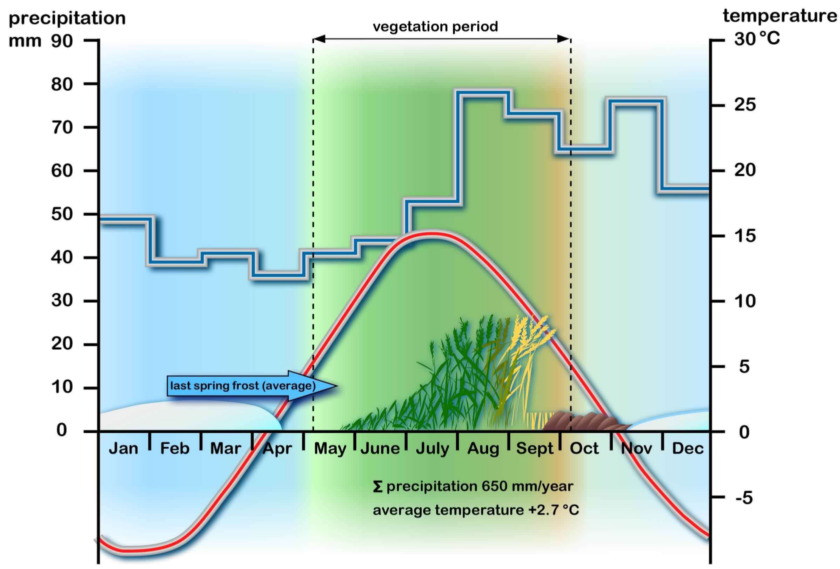
Figure 13. Percentage of arable land in Västerbotten used for different crops in 2006 (SCB 2007).

In a future warmer climate there may be opportunities to grow a number of new species in this region, spring wheat and more oats and also winter cereals, mainly triticale and rye. Furthermore, it may be possible to grow more spring oilseed crops and different kinds of vegetables. Favourable conditions for e.g. more cereal species will increase the possibilities of getting higher on-farm self-sufficiency of feed in northern animal production compared with today.

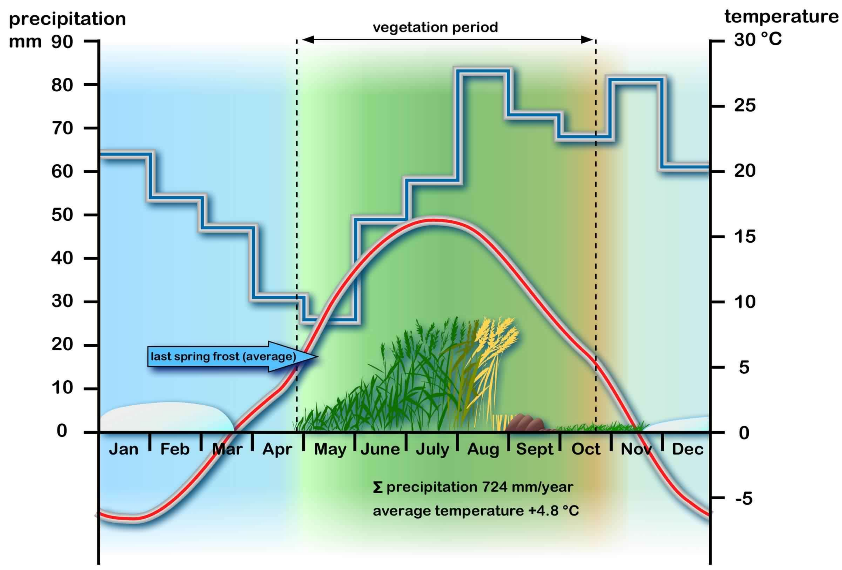
The extended growing season would also permit other crop combinations, e.g. spring barley that will grow to maturity in time to allow establishment of an autumn-sown crop (fig. 19, p. 51). The solar radiation in Västerbotten on a year-round basis is 91-95% of the solar radiation in Skåne. However it is more concentrated in time and the dark winter makes cultivation conditions very different compared with conditions at more southerly latitudes.

The growth potential of ley crops will probably increase and the clover component in the ley may be more competitive in relation to the grass component than in the climate of today, partly caused by higher temperatures and partly by elevated CO_2 concentrations, which will benefit symbiotic N_2 fixation.

a)
Average 1961-1990



b)
A2 ≈2025



c)
A2 ≈2085

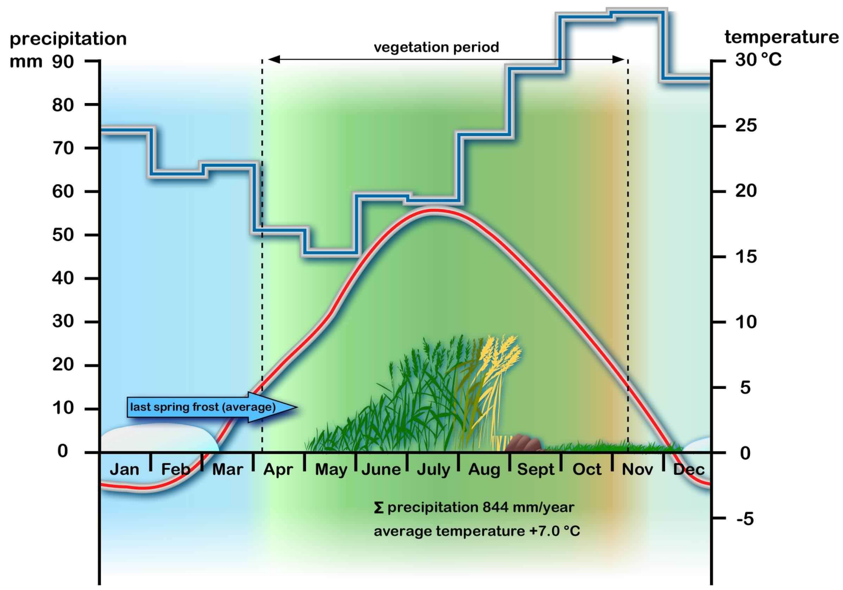
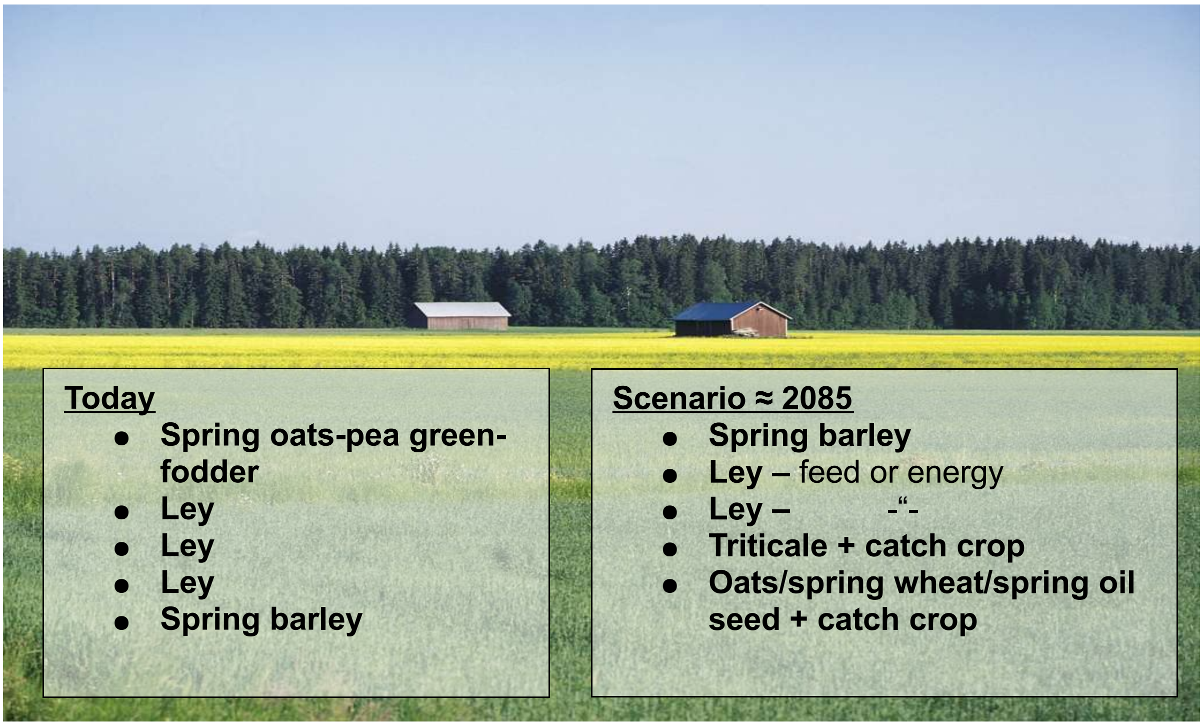


Figure 14. (a) Current climate (average 1961-1990) in Västerbotten, (b), regional A2 scenario year ~2025 and (c) and regional A2 scenario ~2085).(See also fig 18 and 19, p. 50-51).

A major drawback in the future Västerbotten climate may be wet over-wintering conditions causing plant asphyxiation and temperatures fluctuating around zero causing ice-blight. These conditions may shorten the duration of leys. A longer growing period also favours an increased use of pasture in ruminant rearing and less need for winter fodder. However, grazing under wet conditions could lead to trampling damage on pastures and leys. This may favour sheep production at the expense of beef production.

In the boxes below we present examples of arable crop rotations that are common today and that might be common in the future in coastal Västerbotten.



The projected large increases in precipitation during autumn, winter and spring might cause very difficult conditions for establishment of crops, in spring as well as in autumn. This situation may promote perennial crops for feed and for raw material to produce bioenergy. However, new varieties may be needed that can manage to over winter successfully under the new climate conditions.

The projected extended growing season and the higher temperatures, not the least during winter, could entail more severe weed infestation, pest attacks and disease outbreaks. The north of Sweden has been an important producer of among other things, healthy potato seed. This production might be affected to a great extent by virus diseases due to increasing numbers of vector aphids.

Scenarios for nine additional locations

Below, we briefly describe regional A2 and B2 scenarios for nine additional locations with figures on vegetation periods and precipitation patterns (Figs. 15-17) to get a more complete picture over the whole country. The positions of the locations are shown in fig. 4, p. 17. We have chosen these locations in order to cover regional differences within Sweden concerning projected climate changes. In southern Sweden, the vegetation period scenarios of A2 and B2 are fairly similar and possibly not significant in comparison with all other uncertainties influencing the scenarios. Further north, in northern Götaland and Svealand, the start of the vegetation period is about half a month earlier for A2, as compared with the B2 scenario. The largest differences between A2 and B2 scenarios are found in southern Norrland, with about a month earlier start and a few weeks later end of vegetation period for A2 by ~2085. By ~2025, the differences between A2 and B2 are small. Further north the differences between A2 and B2 decrease, due to the temperature increase not being large enough in any of the scenarios to lift the current winter temperatures to above 5 ºC.

The general pattern for the precipitation changes under climate change is an increase during winter, with a maximum change around the end of December, and a decrease during summer, with a maximum change in July and August. This pattern is valid for the ~2085 A2 scenarios for Götaland and Svealand, the pattern being most pronounced from Skåne and northwards along the west coast. The current pattern, of minimum precipitation during late winter and spring and maximum precipitation during July, will shift towards a maximum during winter and a minimum during summer. For Norrland there will be an increase, or no change, in precipitation during summer, tending to develop a minimum in May and a maximum in autumn. The changes from present to ~2085 are not linear. In Norrland the precipitation change will tend to first occur during the cold period (by ~2025). In southern Sweden the decrease in precipitation during summer will first occur in late summer and later shift towards mid summer (by ~2025). There is also a tendency for a decrease in precipitation during late spring and early summer, which will later disappear (by ~2085).

For ~2085, the precipitation increase in Norrland of the B2 scenarios is less pronounced compared with A2. For ~2025, there is a tendency for the increase to be higher for B2, compared with A2. In Götaland and Svealand all changes, increases as well as decreases, are less pronounced for B2 as compared with A2, with the exception of Gotland (Visby) for which B2 and A2 are more similar.

It should be noted, however, that the precipitation scenarios differ substantially depending on the Global Circulation Model (GCM) used for the regional assessments. The results presented refer to the ECHAM4 model (originating from Max Planck-Institute, Germany), which basically results in higher precipitation scenarios than the HADAM3H model (originating from Hadley Center for Climate Prediction and Research, UK) (Eckersten *et al*., 2008a).

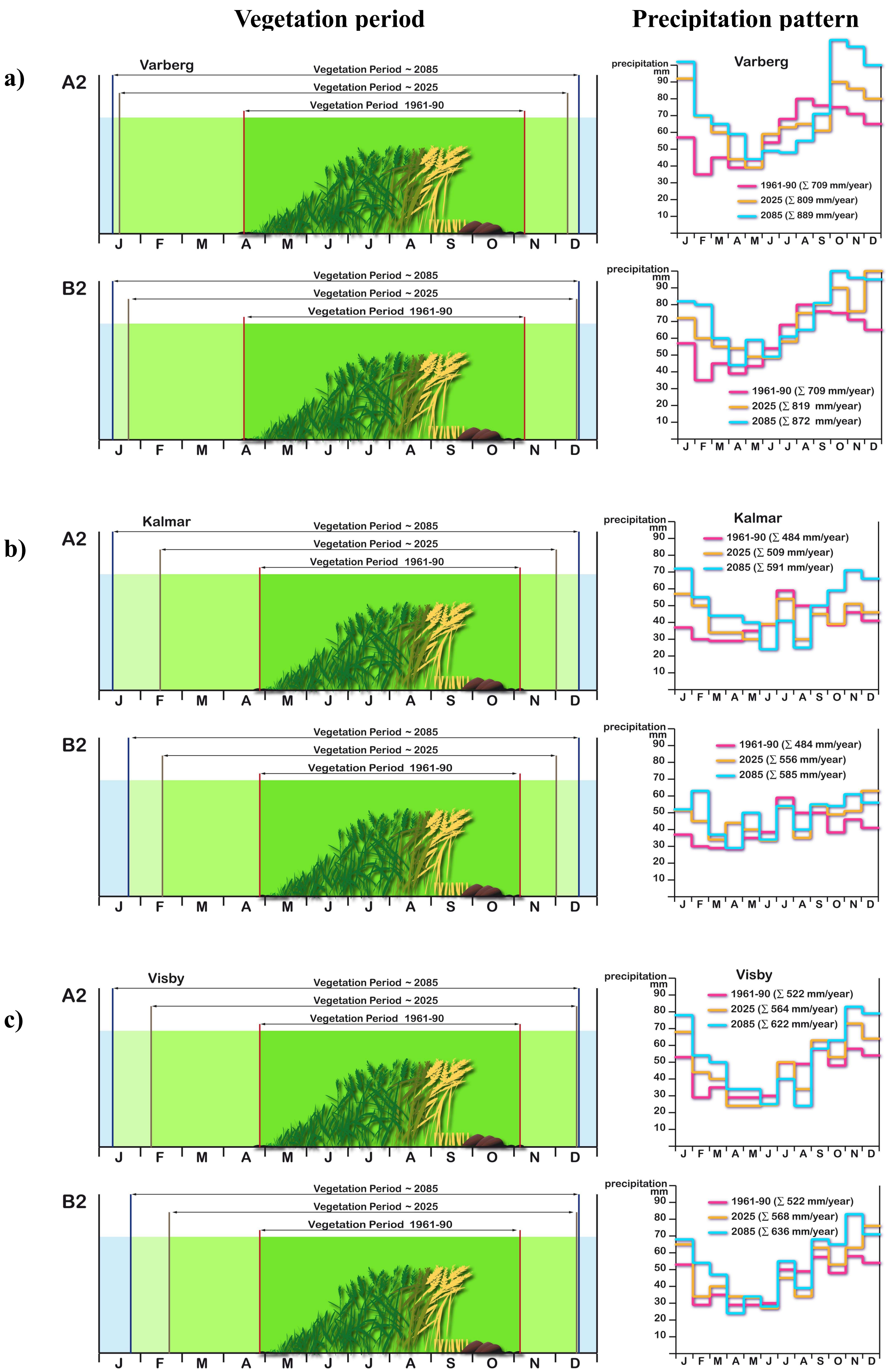


Figure 15. Projections of vegetation period and seasonal precipitation pattern for scenarios A2 and B2 for current climate (average 1961-1990), year ~2025, and ~2085. Three locations are shown: a) Varberg, b) Kalmar and c) Visby.

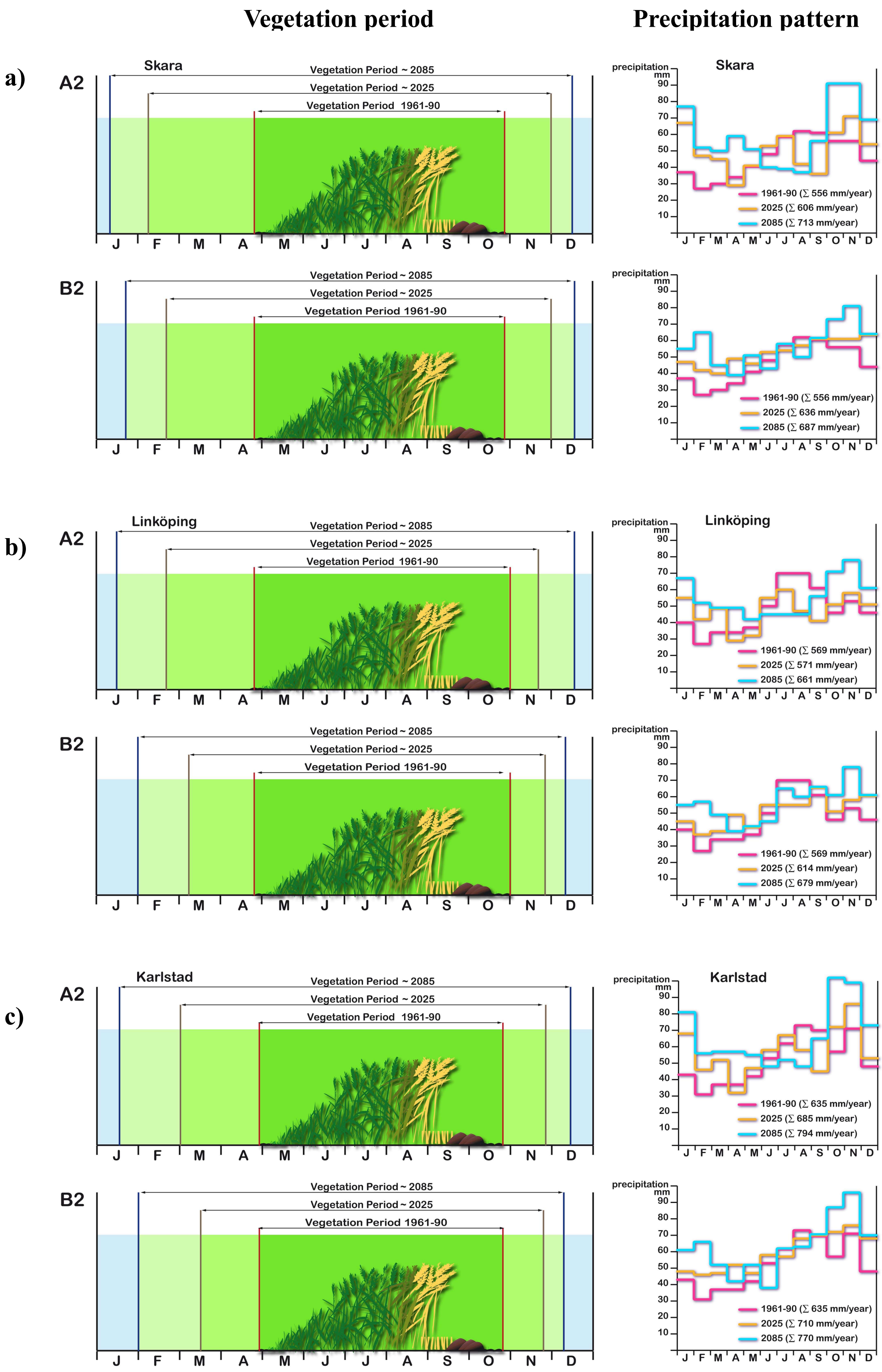


Figure 16. Projections of vegetation period and seasonal precipitation pattern for scenarios A2 and B2 for current climate (average 1961-1990), year ~2025 and ~2085. Three locations are shown: a) Skara, b) Linköping and c) Karlstad.

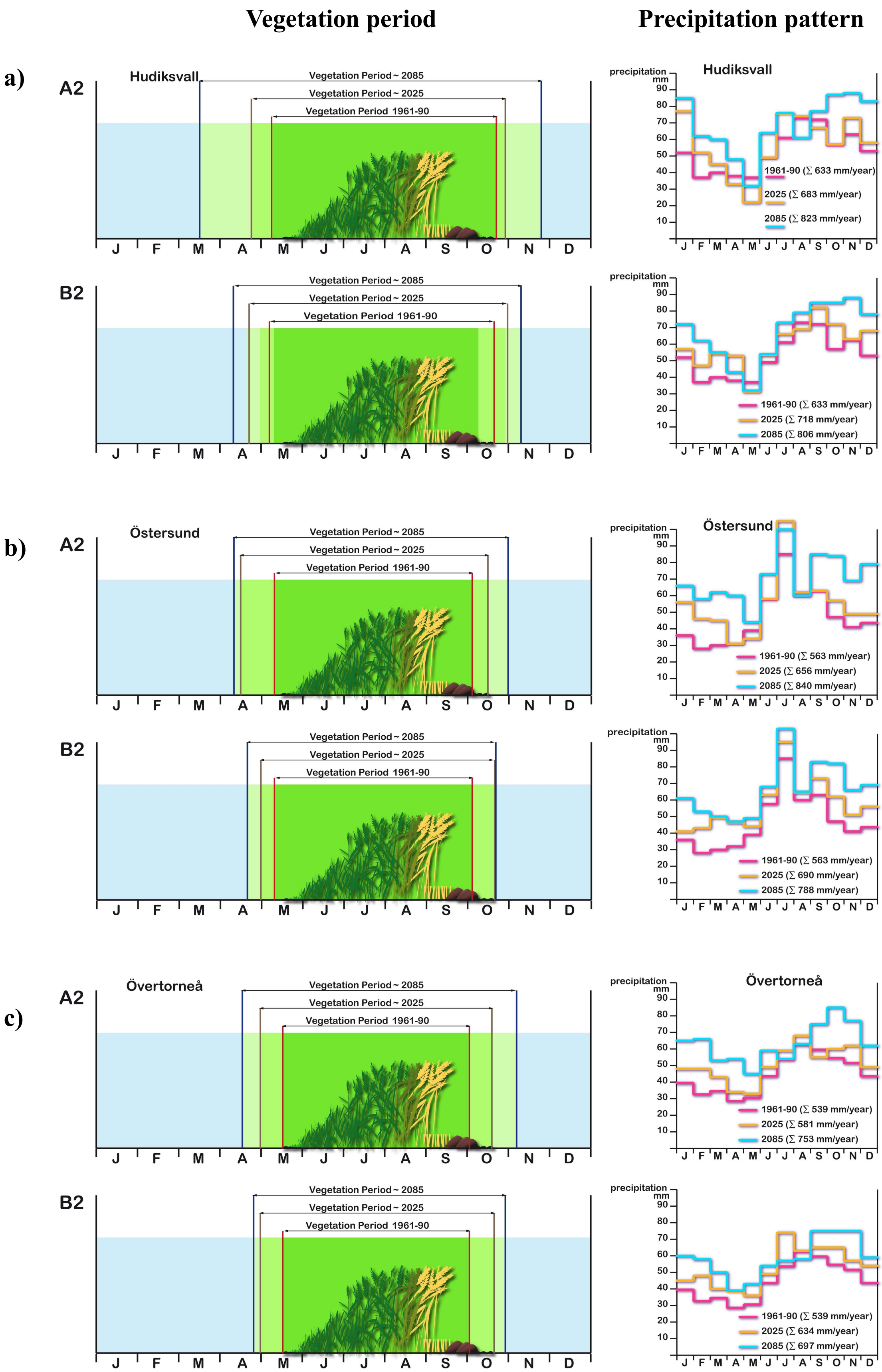


Figure 17. Projections of vegetation period and seasonal precipitation pattern for scenarios A2 and B2 for current climate (average 1961-1990), year ~2025 and ~2085. Three locations are shown: a) Hudiksvall, b) Östersund and c) Övertorneå.

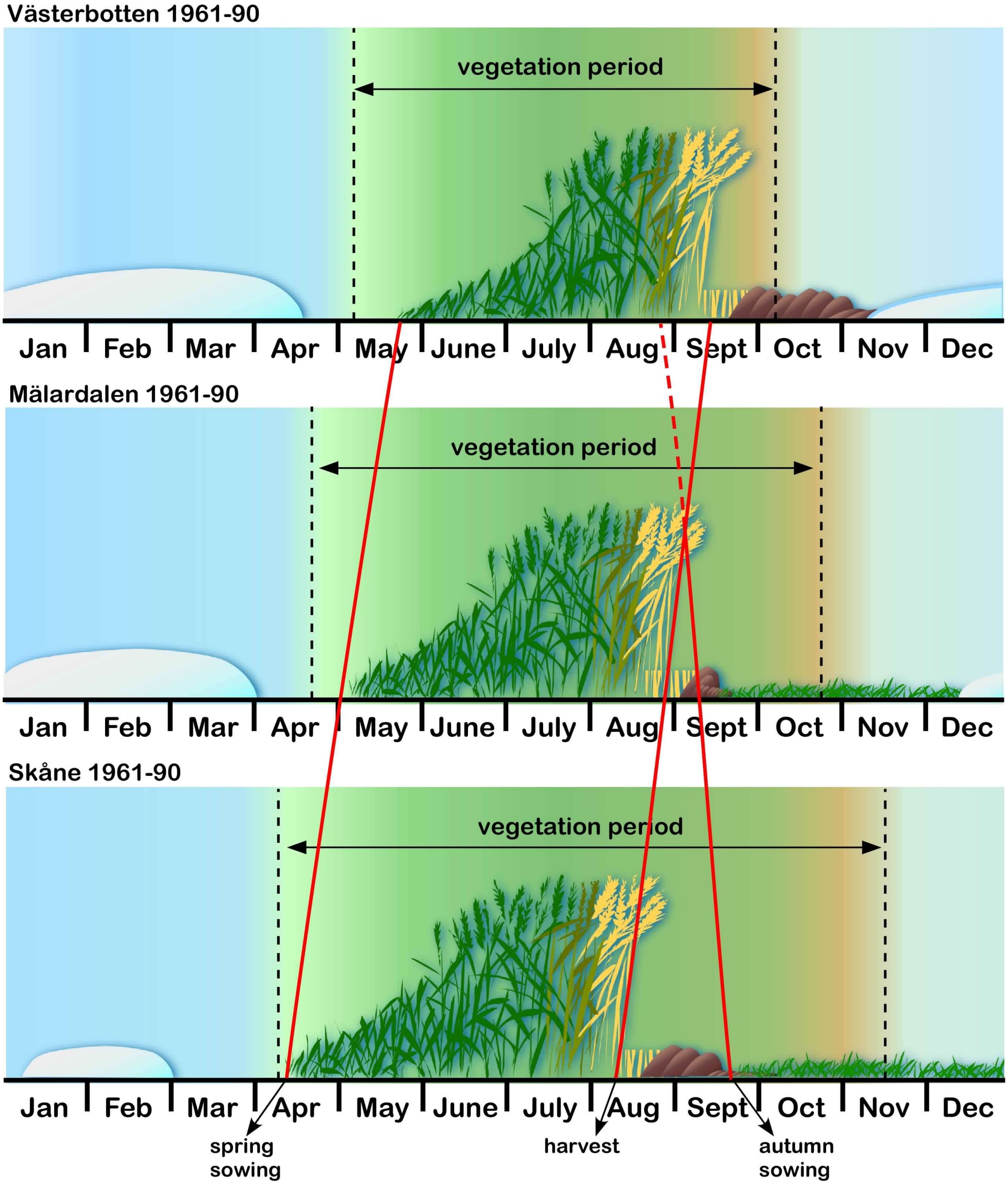


Figure 18. Current vegetation period (average 1961-1990) in Northern (Västerbotten), "central" (Mälardalen district) and Southern (Skåne) part of Sweden, with average time for spring sowing, harvest time and autumn sowing.

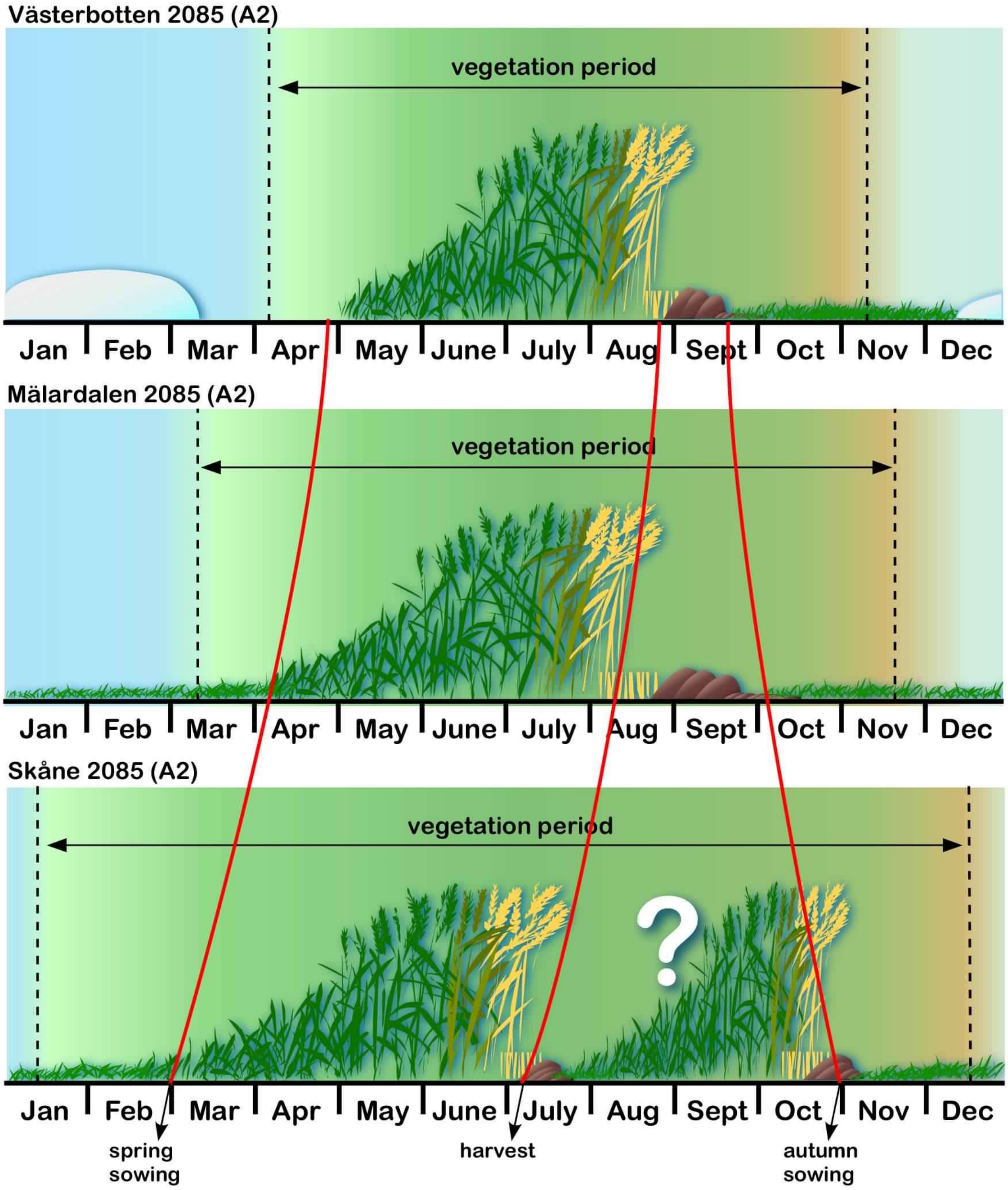


Figure 19. Vegetation period (A2 senario ~2085) in Northern (Västerbotten), "central" (Mälardalen district) and Southern (Skåne) part of Sweden, with expected time for spring sowing, harvest time and autumn sowing.

Concluding remarks on climate scenarios – risks and opportunities

- The conditions for biomass production in Sweden are projected to become more favourable due to future climate change.
- Increased and changed precipitation patterns will increase the risk for leaching of nutrients and might be further pronounced if fertiliser rates increase as a result of potentially larger crop yields.
- Increased temperature and precipitation might involve increased use of pesticides. Mitigation strategies against this increase involve alternative and preventive crop protection measures.
- Issues concerning water resource management, drainage as well as irrigation will be important. Increased precipitation, especially during winter, may put serious demands on drainage. At the same time, enlarged periods of drought increase the need of irrigation.
- Livestock building design should be attended, particularly for more heat sensitive and susceptible types of livestock such as pigs and poultry.
- New crops can be introduced and for instance contribute to better cropping systems and biological and economical diversity in Swedish agriculture.
- Extended vegetation periods in southern Sweden might give room for two crops in one season (fig. 19 p. 51), generating opportunities for development of new cropping systems.
- Extended vegetation periods in northern Sweden will generate opportunities for autumn sown crops (see fig. 19, p. 51).
- Since greater variation in e.g. temperature and wet-drought conditions will be expected, resilient cropping systems need to be developed.
- National plant breeding of cultivars adapted to Nordic climate conditions will be of great importance. The Swedish long-day situation creates unique conditions.
- Sustainable interactions between crop production and animal production need attention, e.g.:
    - More efficient use of livestock manure on crop land
    - “Nitrogen production” on crop land might mitigate GHG emissions

The above risks and opportunities have formed one of the bases of the research suggestions in the proposed research themes in the final section of this report.

Discussion and implications for future research

There is little doubt that the future will bring great challenges for agriculture in Sweden. Climate change in Sweden as well as on a global level will cause changes in the availability and cost of agricultural inputs, alter global food demands and trade patterns, affect technological development, influence new political incentives and make differences in values and attitudes.

Climate change will probably influence agriculture in a number of ways, both directly and indirectly, for example through effects on biological conditions for agricultural production as well as on policy measures. Although climate change may initially be favourable for Swedish agricultural production, it poses serious problems for the environment and for society. Among other things, climate change may increase variations in weather between years, promote greater frequency of extreme weather events and increase disease and pest outbreaks (Eckersten *et al.* 2008a).

A prerequisite for the increase in crop production potential to occur is that the resources needed for higher crop yields, e.g. water, nutrients, fuel/energy and other external inputs, are available at a reasonable cost. The projections of yield increases due to rising atmospheric CO_2 concentrations may not come true if rain deficits reduce the productivity of crops (Cias 2005). Scenarios on future availability of natural resources such as fossil fuel and the implications this has on future agriculture vary greatly. Estimations of future availability of different energy sources, the options for bioenergy production in agriculture and predictions of productivity changes determine, to a great extent, future scenarios of land use for agricultural production. Different possible future paths are presented in the literature review on availability of resources (Johansson 2008) and could be described as a high-energy input scenario versus a low-energy input scenario. The reasons for low external input agriculture in the future are often discussed in two different contexts – external inputs will be too scarce and costly and/or environmental impacts too great to be sustainable. Others suggest that the best solution to meet the challenges of future food supply and at the same time sustain the life-support systems is through an intensive high-input agriculture on the 'best' land in order to save other areas for nature conservation. This future intensification includes genetic modification and increased efficiency of added inputs (Gregory *et al.* 2002). At the same time there is common agreement that we need changes in life-styles to prevent exhaustion of natural resources. We conclude that these diametrically opposed scenarios imply a need for a great variety of research.

Another important fact is that Sweden is part of the global food market and that climate change in other parts of the world, as well as other changes affecting global supply and demand (e.g. altered consumption patterns, improved productivity, changes in demand for bioenergy crops), will also have large effects on Swedish agriculture (Holstein 2008; Johansson 2008). If any of the IPCC high-emission based climate scenarios come true, the projections will involve great threats for the global food supply. For example, dry conditions may lead to large areas of arable land turning into land unsuitable for agricultural production (IPCC 2007b). At the same time, as mentioned above, change in land productivity in other parts of the world is one of the main determinants of the future food supply. Despite being uncertain, productivity will have a great impact on agricultural production and land use (Rounsevell *et al.* 2005, 2006; Abildtrup *et al.* 2006). Under Swedish conditions, options for biomass production for food and also for energy purposes can be further explored. According to Johansson (2006), Swedish agriculture has great potential to produce biomass for energy purposes.

The food production system (agriculture, the food industry and household activities included) contributes a large proportion of total GHG emissions in Sweden, 28% according to Sonesson *et al.* (2005). This needs to be dramatically reduced and at the same time necessary adaptations of agriculture to a future warmer and wetter climate must be made. There are a number of possible ways to decrease the impact of climate change on agricultural production systems, e.g. higher nutrient and energy efficiency, reduced tillage, changed management of organic soils and improved feeding practices (Smith *et al.* 2007). Concerning the whole food system there are a number of other mitigation possibilities, e.g. decreased transportation of food and feed and changes in consumption patterns of the population from a meat-based diet to a more vegetable-based diet (Johansson, 2008).

Agriculture is insufficiently prepared to cope with unpredictability and adaptation to climate change and research needs to develop in many fields to clarify these uncertainties (Lobell *et al.* 2008). The diametrically opposed scenarios for future land use and design of agricultural production systems found in the literature imply a need for a great variety of research. Research in adaptation strategies and mitigation strategies is important. Problems are interlinked and interdisciplinary research will probably be beneficial in solving the complex problems concerning agriculture and the food supply of future populations.

As a result of the FANAN project, we have prioritised six different strategic research themes that we regard as important for strengthening the ability of the agricultural sector in Sweden to meet future challenges. These themes (1-6 below) are more fully presented in Swedish in a separate document (FANAN_Research themes.pdf), which is available on the project website:

http://www2.vpe.slu.se/fanan_vpe:slu/fanan.html.

Theme 1

Future analyses of long-term sustainable land use

During the work within FANAN in workshops and through the literature reviews, we found strong evidence to suggest that extended systems approaches in research need to be strengthened at SLU. Sustainable agriculture has several goals that are strongly interdisciplinary. SLU research encompasses a large part of the knowledge needed to assess the capacity of agriculture to reach these goals.

Agricultural land use is a central factor in achieving the sustainability goals (defined from both production and environmental perspectives), but is also a factor that is strongly influenced by factors other than agriculture. This ‘double nature’ of land use as both a steering factor towards the goals and a response factor to societal development complicates understanding and prediction of land use and its effects. SLU has a central role to play in devising and evaluating scenarios towards possible, desirable and expected development of Swedish agricultural land use. In future analyses, extrapolations are made of current knowledge to future changed conditions that our agricultural systems will face in the future. One part of future analyses comprises the use of different kinds of models. However, existing disciplinary-based models for assessments of climate change effects on the whole agricultural production system and new integrative models need to be tested and developed in order to analyse consequences for the food supply, resource use and environmental impact. During recent decades, considerable progress has been made in developing methodologies for scientifically-based land use assessments for several countries in Europe and elsewhere, and SLU needs to introduce this type of methodology to assess future scenarios for Swedish agricultural land, based on the advanced cross-disciplinary knowledge that exists on Nordic agricultural systems, to which SLU is one of the main contributors.

Land use models are of a complicated nature since the phenomena they are intended to mimic are quite complex. Several different models approaches exist, most of which include links between natural science and social science and in which economics play different roles. Within the models of natural sciences there are different approaches to how to link information from different disciplinary research, on for instance crop production, crop rotation design/-effects, soil science, biodiversity and genetics. It is of great concern that current knowledge about Swedish agriculture will be integrated into land-use assessments so that it contributes valuable information for strategic planning. This knowledge is also important for SLU, so that the university can contribute to the understanding of the development of land use and its effects on the goals of sustainable agriculture.

An important goal of the proposed research theme is to establish the boundaries for research and to identify how to link to other factors that influence land use. In land-use modelling, these boundaries are usually clearly formulated and can be, for example, prices on products and land. In other cases, the land-use modelling is an interactive component of the economic modelling in predicting prices. Research boundaries in the area of land use that is not classified as agriculture land should be clarified, for instance to areas used for forestry or as land used for urbanisation.

Concerning the disciplines that are included in land-use modelling, there is a need to be able to communicate, on the process level, with the ongoing research and to use the information in the integrated assessments. This is usually done in terms of disciplinary modelling. However, the ways of combining models are complicated and include several subjective judgements. The outcome should be a combination of models that are scientifically testable. This work demands close collaboration between the integrated modelling and the disciplinary research, both of which would benefit from each other. The land use assessments could give rise to ideas on the models needed and the disciplinary research could give rise to evaluations of not only the significance of single factors but also to ideas concerning which factors might be important on the land use scale.

Theme 2

Sustainable production systems — crop and animal sciences

Future changes require adjustments in our agricultural systems; agricultural inputs, crop rotations, crop varieties, livestock breeds and production methods. A decreased availability of cheap energy resources will also impose strong changes in production systems. A stronger focus on trade-offs between production and environmental safety are suggested. We have identified the following areas of special interest to reach further sustainability in our future production systems:

Crop production systems

* Nutrient leaching caused by higher winter temperatures and increases in precipitation.
* Problems in relation to probable increased use of pesticides, which is likely to be a consequence of greater problems with weeds, diseases and pests in a warmer and wetter climate.
* Consequences of summer drought — conservation of water resources, new irrigation strategies.
* Efficient use of nutrients in farming systems, which is crucial for high production without increased risks of leaching and e.g. N_2O emissions.
* Systems with reduced use of fossil fuel.

Animal production systems

* Feed production systems, local production as an alternative to e.g. imported soy protein — consequences for production and profitability and at the same time for resource use and environmental burden.
* Feeding strategies to achieve efficient use of feed nutrients — to address production goals as well as environmental concern.
* Production systems with low emissions of methane and dinitrogen oxide.
* Parasite control in a warmer and wetter climate.

Around these key problems we suggest that the research themes could be organised into different work packages which are described below.

Cooling crops — crop-soil interactions

It is important to design production systems and within them cropping systems that increase carbon sequestration in soil/reduce carbon decomposition and at the same time do not increase emissions of GHG. A large proportion of GHG emissions in the food chain come from the cultivation of crops, and cultivation practices also have a large impact on emission levels. Significant sources of N_2O emissions include cultivation of organic soils, N turnover in soils and production of mineral nitrogen fertilisers (Flysjö *et al.* 2008). It is of great importance to efficiently use the circulating nitrogen, e.g. in farmyard manure and different waste products in the food system, in order to reduce import of new reactive nitrogen to agriculture.

Possibilities could be reduced tillage in combination with different new kinds of intercropping, for example, under sown catch crops show promising results and need to be further developed. Important companion research areas are to find sustainable crop protection management strategies for these new cropping systems and investigate their effects on pesticide use. Perennial crops producing large quantities of biomass are expected to promote carbon sequestration in soils, so cropping systems that include more permanent crops/green covers need to be developed.

Long-term field experiments and computer simulations are examples of methodology to investigate the potential of production systems to sequester carbon and reduce emissions of GHG.

Crop breeding — perennial cereals

The ability of crop species to sequester carbon and to take up nitrogen with high efficiency is expected to increase in importance in relation to mitigation of climate change and future decreases in resource availability. Inclusion of more perennial crops in the cropping system could meet these demands. Perennial crops have a number of ecological and environmental advantages compared with annual crops, such as growth throughout the vegetation period, deep rooting depth, good competitive ability against weeds and high capacity to prevent erosion and nutrient leaching.

There are a number of research questions that need to be addressed, both in fundamental and applied science, in order to reach the goal of creating perennial cereal crops. The current position of genetic methods and knowledge regarding perennials provides more favourable possibilities to develop perennial cereals than 10-20 years ago. The new perennial characteristics then need to be integrated with other major quality properties.

Furthermore, other new quality characters could be pointed out in relation to our future analysis. It has been concluded that a meat-based food system requires more energy, land and water resources than a plant-based diet (Pimentel & Pimentel, 2003). If our consumption of meat were to decrease, the question of a high protein quality of vegetable products, e.g. cereals, needs to be addressed. In the Nordic countries we have special solar radiation conditions and future changes involving warm and long autumns together with short days generate a need for crop varieties adjusted to these conditions.

Domestic animal production

There are a number of problems concerning animal production systems and feeding strategies arising in relation to climate change and resource use that have been addressed in FANAN. Here, we conclude that an important climate change mitigation strategy is to integrate feed production and animal production more closely than today. Production systems based on local resources will cut down CO_2 emissions from transport of feed (Emanuelson *et al.* 2006). Soybean grown on the American continent is today a major feed in Swedish production systems and the soybean production systems in Latin America have large negative environmental and social consequences there, e.g. soil erosion, pesticide contamination and health problems of local inhabitants (Rulli, 2007).

Among the Swedish domestic animals, cattle dominate in respect of feed consumption. If the feed for Swedish dairy cows were to be grown in Sweden, this would lead to large increases in cultivation of pulses and oilseed crops. Increased proportions of legume-rich roughage could also partly substitute for imported soybean. However, home-grown leguminous crops have a lower nitrogen turnover efficiency in feed compared with soybean, leading to excess nitrogen, which involves a need to combine these leguminous crops with feed high in energy, such as maize and high-energy species and/or varieties of perennial grasses. To optimise feed use in respect of both economics and low environmental burden, new feeding strategies need to be developed.

A large proportion of the GHG emissions from agriculture world-wide originate from ruminants (FAO 2007). Methane is an unavoidable part of the metabolism of ruminants. However, it is possible to somewhat affect these emissions through, for example, feeding strategy. On the other hand, ruminants play an important role for high biodiversity in the agricultural landscape through grazing (semi-natural grasslands etc.) and we have to balance these trade-offs.

Another important area of research is to find new strategies for increased use of different kinds of grassland. Climate change can result in higher pasture production potential. Natural grassland offers cheap and energy-efficient feed, while the subsequent meat quality has also shown advantages. However, the GHG emissions per kg meat might be higher with a longer rearing period and a lower animal growth rate. Larger autumn rainfall may lead to trampling damage to the pasture and the warmer and wetter conditions could increase the risks of parasite attacks.

In summary, research is needed to balance different desirable achievements in animal production systems, low environmental effects, high biodiversity, good animal care as well as profitability.

Cultivation techniques

New cultivation techniques and crop production systems need to be developed to meet different sustainability goals. These cropping systems need to achieve a reduction in GHG emissions, low nutrient losses, minimum use of pesticides, decreased dependency on fossil fuels and high biodiversity, while also providing quality food in sufficient amounts.

In this work package we have chosen to take relay cropping systems as our starting point to develop more sustainable systems. Relay cropping could be applied in a number of different ways. This is a kind of intercropping where two or more crops are grown together during a part of their life cycle but the harvest is displaced in time. In Scandinavia we use this method to establish perennial leys under sown in cereals. In other parts of the world there are many different intercropping systems in use, e.g. maize and beans, wheat and soybean.

Relay cropping decreases the need for tillage and provides a green cover during a large part of the season, while biodiversity may also be promoted by the system. A new example of relay cropping in Sweden is to sow both a winter and a spring crop in spring, e.g. spring peas/faba beans and winter wheat. Pilot studies have been carried out but the system needs further development to achieve high yields of both crops (Ewa Magnuski, pers. comm.). Research is also needed to find efficient weed management strategies without high use of herbicides.

In the work process the authors have been in contact with: Olle Andrén and Thomas Kätterer, Dept. of Soil Science; Christina Dixelius, Dept. of Plant Biology; Jan Bertilsson, Dept. of Animal Nutrition and Management; and Ewa Magnuski, Dept. of Crop Production Ecology.

Theme 3

Ecosystem services in production systems of the agricultural landscape

Agricultural cropping systems involve the exploitation of services/processes that ecosystems provide and this is not always done in a sustainable way at present. Ecosystem services cover natural processes that are beneficial for society and people. In agricultural production systems a number of ecosystem services are already used and they are often taken for granted (Johansson, 2008). Some examples are biomass production through photosynthesis, control of diseases and pests by natural enemies, wild pollinators beneficial for production of e.g. fruits and oilseed crops and the great importance of earthworms for soil fertility.

As resource-demanding production inputs will be restricted in some way in the future, increased knowledge is needed on how we can use ecosystem services and local resources more efficiently in a sustainable way. Greater knowledge is particularly needed regarding the effects of production systems on the function of ecosystem services following changes in land use and climate. An important part of this theme is to study the effects of climate change on the ability of ecosystems to deliver these services. Sustainability and ecosystem resilience are important concepts in this regard.

We need a better understanding of the dynamics in time and space of organisms involved in production of ecosystem services. An important approach in studying long-term organism dynamics is to conduct scientifically-based monitoring in e.g. long-term field trials.

Interdisciplinary approaches are also necessary in studying the effects of future land use scenarios on ecosystem services.

A number of ecosystem services will be of particular importance in relation to climate change effects on agriculture. There is already evidence of decreasing biodiversity due to intensive land use in agriculture (MA 2007). Future projections show increased demand for agricultural land and also for more intensive production systems giving higher yields (Johansson, 2008). Further decreases in biodiversity may lead to a decreased ability to cope with the effects of climate change. One example is the predicted increase in different pests, which will require a range of organisms that are able to exert biological control. This is important in order to prevent increased use of pesticides.

Can we develop efficient and highly productive land use whereby production systems and methods deliver essential ecosystem services while also supplying the demand for raw materials from existing agricultural land? Or is there a need for solutions where intensity levels are varied by region or over time in order to reach sustainability targets? What solutions can be developed within the framework of/with the aid of market forces?

Examples of important topics include:

- Pollination
- Biological control of diseases, pests and weeds
- Biological nitrogen fixation and mycorrhiza
- Nitrogen reduction in wetlands

- Decomposition of organic material and soil chemical and biological processes involved in soil delivery of crop nutrients
- Biological diversity beneficial for crop production
- Recreation and human health
- Planning of sustainable farming systems that benefit from ecosystem services while also promoting ecosystem services
- The agricultural landscape as a carbon sink.

In the work process the authors have been in contact with: Johan Ahnström, Jan Bengtsson and Riccardo Bommarco, all from the Department of Ecology.

Theme 4

From words to action

Swedish agriculture needs to continually adjust to changing conditions, ecological as well as economic. At the same time, the goals for individual farmers and for society may change over time. Future conditions are more or less uncertain. Regarding the objectives for Swedish agriculture, which can generally be interpreted as 'competitive sustainable agriculture', these may of course also change over time. For example, the goal of being self-sufficient on a national level has changed over time. Hence, the need for future changes to the agricultural system in Sweden depends on the actual changes in conditions and on the potential changes in goals.

It should be noted that some changes will occur 'spontaneously', that is to say, when individual farmers adjust their practices in order to achieve their own goals under new conditions. Other adjustments will require measures from different actors. For example, if the public wants less eutrophication, some incentives (e.g. through policy measures or market demand) may be needed in order encourage farmers to adjust their practices. In order to understand how the agricultural sector will adjust spontaneously and how it can be influenced by other actors, knowledge about how different participants act and interact is needed.

In FANAN, we conclude that the future changes the agricultural sector may encounter within the coming century are of especially great magnitude. Whether these will require changes in policy measures is of course partly a question of normative political considerations, but it is also a social scientific question about how different institutional settings, including more or less policy measures, will actually work under the new conditions. Better general knowledge about how different actors (e.g. producers/farmers, consumers, citizens and politicians) act and interact is needed, regardless of the changes that turn out to be the most crucial in the future.

Knowledge about changing processes, implementation strategies, environmental communication and economic incentives is needed in order to conduct a desirable adjustment of our agricultural production systems and food chains, regardless of what a desirable adjustment will actually look like and how it will be interpreted. This theme is focused on how society and its actors will react and interact when circumstances change. The connections to natural scientific knowledge are of course important, since 'nature' both shapes the conditions for agriculture and is affected by human actions, but the focus in this theme is on understanding how society can make desirable changes to mitigate future negative changes, e.g. severe climate change, and also adapt in a desirable way. However connections between social and natural sciences will be included in theme 1: *Future analyses of long-term sustainable land use*. Since different social sciences partly focus on different parts of the human-societal system and partly offer different answers and explanations as to how and why actors will react and interact, an increased understanding can be achieved by an interdisciplinary approach. Hence, the theme is suggested to be more multidisciplinary (see further down), but mainly with different social sciences involved.

We suggest that the following social sciences and areas of research, which are represented at SLU and partly at other universities, are relevant in this theme:

- Environmental communication
- Action and participatory research
- Rural development
- Agrarian history
- Business administration
- Economics
- Consumer science

In addition, collaboration with other disciplines is important and a research programme should also consider including e.g. psychology, political science, law and philosophy.

The following overall questions are suggested to form the starting point for this theme:

I. How can policy be changed in order to affect the adjustment of the agricultural sector to new conditions?

   a. New circumstances may require adjusted and/or new policy measures. How should agro-environmental policy change when climate and world market prices change?

   b. Better multidisciplinary and interdisciplinary knowledge about policy measures. Combining knowledge from e.g. agrarian history, business administration, environmental communication, rural development and economics will increase the possibilities to understand how new policies are formed and implemented.

II. How can other actors influence the adjustment of the agricultural sector to new conditions?

   a. How can individuals, as citizens and consumers, affect the agricultural sector (which may concern environmental effects, food quality, food safety or global fairness). How are these possibilities affected by a more globalised food market?

   b. How can farmers and food industry adapt in order to improve their competitiveness on a more globalised market, where both production conditions and goals among politicians and consumers are changing? How can collaboration with local consumers be a solution? How can action-orientated and participatory research contribute to answering such questions?

c. How will more fundamental values among citizens and consumers change and how will that affect the conditions for Swedish agriculture?

In the work process the authors have been in contact with: Johanna Björklund and Karin Eksvärd, Department of Urban and Rural Agriculture, Cecilia Mark-Herbert and Janken Myrdal, Department of Economics.

Theme 5

Monitoring of agricultural production

In order to evaluate future models concerning agricultural production, there is a need for relevant data support at both field and landscape level, which can be assessed as regards different aspects. The question is how appropriate these current databases are for the future analyses to which they are expected to contribute.

Monitoring systems for agroecosystems are often poorly developed for parts of biology dealing with functionality, pests, weeds and organisms that supply ecosystem services, etc. The development and application of land use models requires an appropriate knowledge base on production, resource and input requirements, ecosystem services (environmental impact) and economics in order to be more realistic and applicable in analytical work.

Theme 6

Multidisciplinary research network

To achieve effective management of knowledge along the 'food chain', it is necessary to build bridges between researchers and stakeholders, as well as between researchers from different disciplines in order to link together and enhance the whole and the links between different parts in an interdisciplinary way. This is needed to meet the demands of society for broader expertise in the entire 'food chain' in an environmental, resource and climate perspective.

For SLU's part, this means that it is necessary to establish some form of hub to operate in close collaboration with specialists using a systems analysis approach to various scenarios (land use plans) for evaluation of the long-term sustainability of production systems/food systems as regards socio-economic and ecological aspects. This must occur at field, landscape and national levels. This hub should also be responsible for information and communication with researchers, stakeholders and other external actors.

Overall conclusions

In many of the suggested research themes, the need for interdisciplinary approaches and systems analyses is emphasized. The research often needs to be conducted at the ecosystem level and it is also important to integrate the natural and the social sciences. Large research programmes that can synthesize disciplinary projects will promote the solution of future complex problems. It will be necessary to combine empirical research and participatory research with modelling and synthesis work in order to generate good science that is relevant to the challenges of sustainable agricultural management.

Some comprehensive overall conclusions concerning assessments and research needs made within the FANAN project are presented below:

- Climate change and an increasing consumption of energy and raw materials are projected to increase competition for a wide range of global agricultural resources. On the other hand, globalisation, that is to say trade and technology transfer, might lead to adjustment of resource demands.
- One of the greatest challenges is to come to a conclusion about how available agricultural land will suffice for all our needs, food, feed, fibre and bioenergy, while at the same time biological diversity is maintained in the agricultural landscape.
- A way for Swedish agriculture to become competitive on the global food market in the future is to produce high-quality products and also high-value processed products. This implies that cooperation between the agricultural sector and the Swedish food industry needs to be strengthened.
- Research in a large number of scientific fields will be needed to achieve a successful adaptation of agriculture to the presumed climate change.
- Investigations of mitigation options to possible negative consequences of climate change will be of central importance, e.g. increased leaching and increased need for pesticides.
- With changes in climate and increasing resource scarcity in the future, research on design of resilient agricultural ecosystems promoting maintenance of a large number of ecosystem services will be important.
- Research on consumption patterns and life-styles is needed in order to mitigate climate change and achieve sustainable resource use in our food systems.
- Climate change mitigation strategies of the whole food chain will be an important research field, including possibilities for local/regional food systems.
- For a balance between different claims on agricultural land, interdisciplinary research on different land use strategies is important using, for example, scenario analyses that take into account uncertainties, vulnerability and adaptive capacity of social-ecological systems.
- SLU has a central role to play in developing sustainable strategies for agricultural adaptation to future changes. We have therefore suggested that a multidisciplinary research network should be created to meet that demand (theme 6).

Abbreviations

CAP	Common Agricultural Policy of the European Union
CAPRI	Common Agricultural Policy Regionalised Impact
CBM	Swedish Biodiversity Centre (SLU)
CUL	Center for Sustainable Agriculture (SLU)
ECHAM4	Atmospheric general circulation model originaly from Max-Planch-Insitut, D.
EKOL	Department of Ecology (SLU)
EU	European Union
FAO	Food and Agriculture Organisation
FAOSTAT	FAO statistical databas
FINADAPT	Finnish National Strategy for Adaptation to Climate Change
GCM	Global Circulation Model
GHG	Greenhouse gases
HADAM3H	Climate model originaly from Hadley Center for Climate Prediction and Research, UK.
HUV	Department of Animal Environment and Health (SLU)
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IPCC	Intergovernmental Panel on Climate Change
JTI	Swedish Institute of Agricultural and Environmental Engineering
LU	Lund University, SE.
MA	Millennium Ecosystem Assessment
NGO	Non Government Organisation
NRA	Faculty of Natural Resources and Agriculture (SLU)
OECD	Organisation for Economic Co-operation and Development
SCB	Statistics Sweden
SLI	Swedish Institute for Food and Agricultural Economics
SLU	Swedish University of Agricultural Sciences
SMHI	Swedish Meteorological and Hydrological Institute
SOL	Department of Urban and Rural Development (SLU)
SOU	Swedish Government Reports
SRES	Special Report on Emission Scenarios
UNDP	United Nations Development Program
VPE	Department of Crop Production Ecology (SLU)
WTO	Word Trade Organisation

References

Abildtrup, J., Audsley, E., Fekete-Farkas, M., Giupponi, C., Gylling, M., Rosato, P. and Rounsevell, M. 2006. Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. *Environmental Science & Policy* 9 (2), 101-115.

Alcamo, J., van Vuuren, D., Ringler, C., Cramer, W., Masui, T., Alder, J. and Schulze, K. 2005. Changes in nature's balance sheet: Model-based estimates of future worldwide ecosystem services. *Ecology & Society* 10 (2), article no. 19.

Altieri, M. A. 1999. The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems & Environment* 74 (1-3), 19-31.

Bastianoni, S. and Marchettini, N. 1996. Ethanol production from biomass: Analysis of process efficiency and sustainability. *Biomass & Bioenergy* 11 (5), 411-418.

Bengtsson, J., Angelstam, P., Elmqvist, T., Emanuelsson, U., Folke, C., Ihse, M., Moberg, F. and Nystrom, M. 2003. Reserves, resilience and dynamic landscapes. *Ambio* 3

Carlsson-Kanyama, A., Ekstrom, M. P. and Shanahan, H. 2003. Food and life cycle energy inputs: consequences of diet and ways to increase efficiency. *Ecological Economics* 44 (2-3), 293-307.

Carpenter, S. R., Bennett, E. M. and Peterson, G. D. 2006. Scenarios for ecosystem services: An overview. *Ecology and Society* 11 (1), 14.

Cias, P., Reichstein, M., Viovy, N., Granier, A., Ogée, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chenallier, F., De Noblet, N., Friend, A. D., Freidlingstein, P., Grünwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J. M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Sousanna, J. F., Sanz, M. J. and Schultze, E. D. 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature*, 437, 529-533.

Daily, G. C., Ed. 1997. *Nature's Services. Societal Dependence on Natural Ecosystems.* Washington, DC, Island Press.

DeFries, R. S., Foley, J. A. and Asner, G. P. 2004. Land-use choices: balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment* 2 (5), 249-257.

Dukes, J. S. 2003. Burning buried sunshine: Human consumption of ancient solar energy. Climatic Change 61 (1-2), 31-44.

Eckersten, H., Fogelfors, H. and Sigvald, R. 2008. Svensk växtodling i nytt klimat. KliMATfrågan på bordet, p. 199-216. Formas Fokuserar. (In Swedish)

Eckersten, H., Karlsson, S. and Torssell, B. 2008a. Climate change and agricultural land use in Sweden: A literature review. Department of Crop Production Ecology, Swedish University of Agricultural Sciences.

Eckersten, H., Andersson, L., Holstein, F., Mannerstedt Fogelfors, B., Lewan, E., Sigvald, R., Torssell, B. and Karlsson, S, 2008b. Bedömningar av klimatförändringars effekter på växtproduktion inom jordbruket i Sverige (An evaluation of climate change effects on crop production in Sweden). Department of Crop Production Ecology. Swedish University of Agricultural Sciences. (In Swedish with English summary)

Ekman, S. 2005. Frikopplade stöd – konsekvenser för svenskt jordbruk. SLI-skrift 2005:2, 1-28. (In Swedish)

Ekman, S. and Gullstrand, J. 2006. Lantbruket och konkurrenskraften. SLI-rapport 2006:4, 1-110. (In Swedish)

Emanuelson, M., Cederberg, C., Bertilsson, J. and Rietz, H. 2006. Närodlat foder till mjölkkor – en kunskapsuppdatering. Rapport nr 7059-P, Svensk Mjölk (Swedish Dairy Association). (In Swedish)

Ewert, F., Rounsevell, M. D. A., Reginster, I., Metzger, M. J. and Leemans, R. 2005. Future scenarios of European agricultural land use I. Estimating changes in crop productivity. *Agriculture Ecosystems & Environment* 107 (2-3), 101-116.

FAO 2007. Livestock's Long Shadow – Environmental Issues and Options, by Steinfield, S., Gerber, P, Wassenaar, T., Castel, V., Rosales, M. and de Hann, C., FAO, Food and Agriculture Organization of The United Nation, Rome.

FAOSTAT 2003. "FAOSTAT agricultural database collections." from http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture .

Fischer, J., Lindenmayer, D. B. and Manning, A. D. 2006. Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. *Frontiers in Ecology and the Environment* 4 (2), 80-86.

Flysjö, A., Cederberg, C. and Strid, S. 2008. LCA-databas för konventionella fodermedel. SIK-rapport nr 772. SIK, Svensk Mjölk, SLU. (In Swedish)

Gerbens-Leenes, P. W and Nonhebel, S. 2002. Consumption patterns and their effects on land required for food. *Ecological Economics* 42 (1-2), 185-199.

Gregory, P. J., Ingram, J. S. I., Andersson, R., Betts, R. A., Brovkin, V., Chase, T. N., Grace, P. R., Gray A. J., Hamilton, N., Hardy, T. B., Howden, S. M., Jenkins, A., Meybeck, M., Olsson, M., Ortiz-Monasterio, I., Palm ,C. A., Payn, T. W., Rummukainen, M., Schulze, R. E., Thiem, M., Valentin, C. and Wilkinson, M. J. 2002. Environmental consequences of alternative practices for intensifying crop production. *Agric. Ecosyst. Environm*. 88, 279-290.

Gullstrand, J. and Hammarlund, C. 2007. Säljer svenska mervärden på EU-marknaden? SLI-rapport 2007:3. (in Swedish)

Hammarlund, C. 2004. Det svenska jordbrukets konkurrenskraft efter EU-inträdet. SLI-rapport 2004:9, 1-63. (In Swedish)

Harris, J. M. and. Kennedy, S. 1999. Carrying capacity in agriculture: global and regional issues. *Ecological Economics* 29 (3), 443-461.

Hill, J., Nelson, E., Tilman, D., Polasky, D. and Tiffany, D. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences of the United States of America* 103 (30), 11206-11210.

Hirsch, R. L., Bezdek, R. and Wendling, R. 2006. Peaking of world oil production and its mitigation. *Aiche Journal* 52(1), 2-8.

Holstein, F. 2008. Economic globalisation and Swedish agriculture - future changes affecting Swedish agriculture from an economic perspective with special emphasis on globalisation. Department of Crop Production Ecology, Swedish University of Agricultural Sciences.

IAASTD 2008. Executive summary of the synthesis report of the international assessment of agricultural knowledge, science and technology for development (IAASTD) http://www.agassessment.org 2008-05-06.

IPCC 2000. Emission Scenarios. Summary for Policymakers. A Special repport of IPCC working group III: IPCC, Geneva, Switzerland. pp 20. Available at: http://www.ipcc.ch/ipccreports/special-reports.htm 2008-05-05.

IPCC 2007a. Summary for policy makers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B. and Tignor, M. (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC 2007b. Summary for Policymakers. In: Climate Change 2007: Synthesis report (The AR4Synthesis Report) to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch 2008-02-20.

Johansson, S. 2005. The Swedish Foodprint - An Agroecological Study of Food Consumption. *Department of Ecology and Crop Production Science*. Uppsala, Swedish University of Agricultural Sciences.

Johansson, S. 2008. Changes in the global natural resource base relevant for future agriculture in Sweden – A literature review. Department of Crop Production Ecology, Swedish University of Agricultural Sciences.

Johansson, S., Doherty, S. and Rydberg, T. 2000. Sweden Food System Analysis. Emergy Synthesis: Theory and Applications of the Emergy Methodology. *First Biennial Emergy Analysis Research Conference.* M. T. Brown. Gainesville, FL. USA, Department of Environmental Engineering Sciences. University of Florida. Gainesville, FL. USA.

Johnsson, B. 2006. Bioenergi – ny energi för jordbruket. Rapport 2006:1, Jordbruksverket. (In Swedish)

Jordbruksverket 2005. Svenskt jordbruk i siffror 1800—2004. Statistik från Jordbruksverket 2005:6. (In Swedish)

Kommerskollegium. 2006. Economic Implications of the Doha Round. Report 2006-07-10, 1-75.

Lindgren, E., Albin, A. and Andersson, Y. 2007. Hälsoeffekter av en klimatförändring I Sverige. En nationell utvärdering av hälsokonsekvenser för människa och djur. Risker, anpassningsbehov och kostnader. Bilaga 34 i: Sverige inför klimatförändringarna - hot och möjligheter, SOU 2007:60, Bilagedel B, förteckning, bilaga B 32-35. (http://www.regeringen.se/sb/d/8704/a/89334) (In Swedish)

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P. and Naylor, R. L. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science* 319, 607-610.

MA 2005. Millennium Ecosystem Assessment Synthesis Report, Millennium Ecosystem Assessment.

Main, A. R. 1999. How much biodiversity is enough? *Agroforestry Systems* 45 (1-3), 23-41.

Mattson, R. 1978. Jordbrukets utveckling i Sverige. Aktuellt från lantbruksuniversitetet, 258. Uppsala. (In Swedish)

Michael, D. 2002. Höst- och vårveteodlingen på Gotland 1913-1999 och klimatets betydelse för densamma. Projektarbete (B310) vid Institutionen för geovetenskaper/Naturgeografi, Göteborgs universitet; 34 s. ISSN 1400-3821. (In Swedish)

Nonhebel, S. 2005. Renewable energy and food supply: Will there be enough land? *Renewable & Sustainable Energy Reviews* 9 (2), 191-201.

OECD/FAO 2006. OECD-FAO Agricultural Outlook 2006-2015.

OECD/FAO 2007. OECD-FAO Agricultural Outlook 2007-2016.

Pimentel, D. and Pimentel, M. 2003. Sustainability of meat-based and plant-based diets and the environment. *American Journal of Clinical Nutrition* 78 (3), 660-663.

Rulli, J. 2007. United Soya. *The truth about soya production in South America*. Javiera Rulli, coordinator, GRR Grupo de Reflexión Rural.

SCB 2007. Jordbruksmarkens användning 2006. Statistiska meddelanden JO 10 SM 0701. (In Swedish)

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllsiter, T., Pan, G., Romanenkov, V., Schneider, U. and Towprayoon, S. 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture Ecosystems and Environment* 118, 6-28.

Sonesson, U., Mattsson, B., Nybrant, T. and Ohlsson, T. 2005. Industrial Processing versus Home Cooking – An Environmental Comparison between three ways to prepare a Meal. *Ambio* 34, 411-418.

SMHI 2006. Klimat i förändring – En jämförelse av temperatur och nederbörd 1991-2005 med 19961-90, Faktablad 6. (In Swedish)

SOU 2007. Sverige inför klimatförändringarna – hot och möjligheter. Slutbetänkande av klimat- och sårbarhetsutredningen. Statens offentliga utredningar, SOU 2007:60. (In Swedish)

SSNC 2007. Food, Climate and Development. Report from Swedish Society for Nature Conservation, Inte Rio, Stockholm.

Swift, M. J., Izac, A. M. N. and van Noordwijk, M. 2004. Biodiversity and ecosystem services in agricultural landscapes - are we asking the right questions? *Agriculture Ecosystems & Environment* 104 (1), 113-134.

Tilman, D., Cassman, K. G., Matson, P..A., Naylor, R. and Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418, 671-677.

Uhlin, H.-E. 1997. Energiflöden i livsmedelskedjan. Rapport 4732. Stockholm, Sweden., Naturvårdsverket, Swedish Environmental protection Agency. (In Swedish)

Ulgiati, S. 2001. A comprehensive energy and economic assessment of biofuels: When 'green' is not enough. *Critical Reviews in Plant Sciences* 20 (1), 71-106.

UNPD 2005. from http://www.un.org/popin/ .

Wolf, J., Bindraban, P. S., Luijten, J. C. and Vleeshouwers, L. M. 2003. Exploratory study on the land area required for global food supply and the potential global production of bioenergy. *Agricultural Systems* 76 (3), 841-861.