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Agro ecosystems in a changing climate:

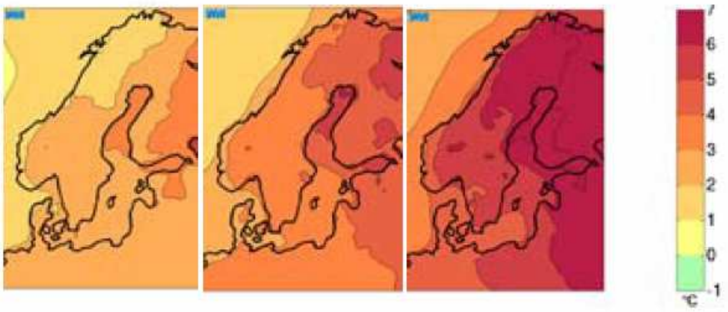

Figure 1. The maps illustrate the years 2020, 2050 and 2080, presenting a temperature scenario for Sweden. (Klimat och sårbarhetsutredningen, 2007a).

Adaptation through crop rotations

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Abstract

Climate change is a phenomenon that affects everyone. It is thus of high relevance to gain knowledge in how the farms that supply society with food will be affected and what adaptations can be made to minimise negative effects on field level. Götaland is expected to have a longer vegetation period in the years 2011-2040, but Southern Sweden is expected to continue to have frost days. The periods with draught spells will probably be longer and the periods of intensive and continuous rain are expected to increase. C3 crops, such as oat and onion, as well as many weeds are expected to respond to an increase in CO_2 concentration and temperature with increased growth. Crops with unlimited growth, such as carrot and sugar beet are expected to respond most in accumulation of weight. Plant nutrient content is likely to change, with a decrease in protein as the CO_2 concentration increase. A change in pest and prey population is expected, which makes it highly relevant to create habitats for the prey. Diseases spread by insects, such as viruses, are believed to increase in extent. Water logging and leaching will have to be addressed as heavy rainfall is expected. A survey among farmers showed that many problems on the field level could be reduced with changes in crop rotation, or by adjustments in the surroundings. Some farmers are already using techniques and crops to decrease problems that are expected to worsen, and in the present study, several adjustments were suggested that could further improve their situation.

Sammanfattning

Klimatförändringar är ett fenomen som påverkar alla. Det är därför av viktigt att nå kunskap om hur lantbruket, som försörjer samhället med livsmedel, kommer att påverkas av förändringarna och om hur negativa effekter på fältet kan minskas. Götaland förväntas få en längre vegetationsperiod under åren 2011-2040, men hela södra Sverige förväntas att även fortsättningsvis uppleva frostdagar. Perioder utan nederbörd kommer troligen bli längre, och perioder med ihållande och stor nederbörd bli längre. C3 grödor, som till exempel havre och lök samt många ogräs förväntas svara med ökad tillväxt vid stigande CO_2 koncentration och temperatur. Växter med obegränsad tillväxt, som morot och sockerbeta kommer troligen ackumulera mest vikt. Växtnäringsinnehåll kommer troligen att förändras, med en minskning av proteininnehåll som en konsekvens av ökad CO_2 koncentration. Förändringar i skade- och nyttoinsektspopulationer förväntas, vilket gör det mycket relevant att skapa habitat som gynnar nyttoinsekter. Virussjukdomar som sprids av insekter, kommer troligen öka i omfattning. Vattenmättnad, erosion och läckage kommer att behöva åtgärdas, eftersom kraftigare nederbörd väntas. En enkätundersökning bland lantbrukare visade att många problem i fält kunde minskas genom förändringar i växtföljd eller genom förändringar i omgivningen. Vissa lantbrukare använder redan tekniker och grödor för att minska problem som förväntas bli större och i detta examensarbete föreslås flera förändringar för att ytterligare förbättra situationen.

Introduction

Climate change is a phenomenon that affects everyone, and even if we succeed in radically reducing our collective greenhouse gas emissions, we still face a climate change due to the natural inertia of the global ecosystem (IPCC, 2008). It is thus of high relevance to gain knowledge about how the farms that supply society with food will be affected, and which adaptations that can be made on the fields and their surroundings to reduce negative effects of the climate change.

Aim and objective

The first objective of this master thesis was to present a review over what is known about how expected climate change will affect the agroecosystem. The second objective was to present practices that are known today that have the potential of decreasing negative effects of climate change on the farming system. These practises were aimed to be used in making suggestions for three realistic crop rotations that can be used in order to optimize farming and the use of ecosystem services. To facilitate survival of beneficial insects there was a focus on organic farming. In order to reach the aim, the study was focused on the following questions:

- Which climatic changes are we to expect in the different regions of Southern Sweden?
- How will the scenarios affect the agricultural environment?
- Are the farmers already preparing and how?
- How can we reduce the negative impact on the farms and on the surrounding environment more than what has been done already?

Definitions

The start of the vegetation period has been defined as when the day mean temperature is +5 ^{o}C after 1st of January, as the seeds of several agricultural crops germinate at that temperature (Porter & Gawith, 1999). The end of the vegetation period has been defined to the day when mean temperature is below +5 ^{o}C before 31st of December.

A crop rotation is a planned cycle of crops on a field. The choice of crop species and cultivars in the sequence is based on many specific factors that are taken into account in order to achieve a healthy development of the crop and a large harvest of good quality. The specific factors include crop family orientated pest and pathogens, morphology of the crop affecting weed population and aggressiveness, structure effect on the soil through root depth, different nutrient need and in some cases addition of nutrients to the soil, organic waste left on the field at harvest etc (Båth *et al.* 1999).

The botanical term indeterminate growth refers to growth that is not terminated in contrast to determinate growth that stops once a genetically pre-determined structure has completely formed. Thus, a plant that grows and produces flowers, fruit or seeds until killed by frost or some other external factor is called indeterminate.

Abbreviations

CUL	Centre for Sustainable Farming at the Swedish University of Agriculture (Centrum för Uthålligt Lantbruk vid Sveriges Lantbruks Universitet).
IPCC	Intergovernmental Panel of Climate Change of the United Nations.
SMHI	Swedish Meteorological and Hydrological Institute (Sveriges Metereologiska och Hydrologiska Institut).
RCAO, RCA3 and EA2	Regional climate models used by SMHI, Rossby centre.

MATERIALS AND METHODS

A study of climatic scenarios presented by SMHI was made to answer the first question in aim and objectives. A review of research in climate change and the expected effect on agro ecosystems relevant for southern Sweden was made. In order to gain knowledge whether farmers are already experiencing changes in weed, pest and disease population due to climate change a selection of farmers was asked to participate in a survey. They were also asked if they were already using tested techniques that are suggested and expected to reduce some negative consequences of climate change. The presented results from the review of current research, as well as empiric experience from the farmers, are used as the basis for suggestions of farming scenarios with focus on crop rotation that are given in this thesis.

Extracting relevant climate data

The climate scenarios A2 and B2 that are presented in the chapter ‘*Global climate scenarios’* are based on global emission scenarios presented by IPCC. The climate scenarios have been elaborated in regional climate models by SMHI, Rossby centre. SMHI divides Götaland into seven areas, based on meteorological observations of similar trends in climate, see figure 2. The numbers represent the following areas:

Figure 2. Division of Götaland according to meteorological data. SMHI, Rossby centre, 2008.

1 Southwest
2 Southeast inland
3 Northwest inland
4 North east inland
6 Gotland
17 Öland and East coast
18 West coast

The regional information that is presented in the chapter ‘*Regional scenarios for Southern Sweden’* was extracted from climate maps, text and personal communication with the climate expert Rummukainen on the behalf of SMHI. When obtaining the relevant maps at the web page of SMHI, the region was set to Ut-scand, the template to ECHAM4_RCA3, the driver to A2 and B2 respectively, the medium was set to web. The climate variable varied according to the parameter of interest, for example it was set to T2m_nVegPeriod5 for obtaining maps of the beginning and end of the vegetation period with a temperature limit at 5 ºC as a daily mean, when measured 2 m above the soil. For a complete list of the abbreviations used by SMHI, see the reference labelled 'Klimatvariabler (2007)'.

Some information has been achieved from the Swedish government report "Climate and Vulnerability" (Klimat och sårbarhetsutredningen). All results presented from the computer model of SMHI are compared to the mean value from 1961-1990.

Review of research

A review of changes that the agroecosystem is likely to be exposed to, according to international researchers, is presented in the first chapter. The review includes information from publications in scientific journals, publications from governmental institutions such as Swedish Board of Agriculture (Statens jordbruksverk), the County Administrative Board (Länsstyrelsen) and Extension office (Hushållningssällskapet) as well as literature on vegetable production.

Questionnaire to farmers

A questionnaire was presented to farmers, agricultural research centres and farm schools representing the geographical differences in the study, see appendix 1. The aim of the questionnaire was to gain general knowledge about the prevailing cropping systems and what obstacles are experienced by the farmers in the field.

The recipients of the questionnaires were selected on the basis of personal contacts and from a publication of research centres by CUL. The intention was to cover each of the seven regions of southern Sweden with at least one farm and one research centre. The intent of including both types of enterprises was to gain information from farmers that base their income on plant production and specialists in different fields of agricultural research, respectively.

The farms and research centres were initially contacted by telephone or by a personal visit, and all agreed on participating. The questionnaire was sent out with fax or per e-mail, according to the preference of each person. Of 16 agricultural centres there were 12 that handed in their reply: 6 farmers, 8 agricultural research centres and 2 farm schools. For a map with the names and locality of the farms see figure 6. The questionnaire was sent back by fax, e-mail and by ordinary mail.

Only weeds, diseases or pests common on more than one farm were brought up in the result part. Farms with more than 40% cereals in the crop rotation were separated from the others, since weed populations were observed to be highly dependant on the character of the main crop. This percentage was set after observing a clear divergence in weed populations.

Cropping systems

Climatic data together with the answers in the questionnaire provided the guidelines for priorities in the chapter with discussion, where three crop rotations with surrounding agro ecosystems are presented. The cropping systems represents actual areas with different climatic conditions, different problems that needed to be solved and have some assumptions being made. Scientific publications, literature as well as the Swedish government report "Climate and Vulnerability" (Klimat och sårbarhetsutredningen) present some general guidelines that influenced the result.

Limitations

Climate scenario data was only available from SMHI for scenario A2 and B2, as described in *'Background'.* This limits the exactness of the climate information, if future emissions exceed the expectations. SMHI are currently working on scenarios that present higher emissions (Rummukainen, 2008). The scenarios do not take into account the possible change of the flow of the Gulf Stream.

The present study was limited to Southern Sweden, with a border at the landscapes Halland, Västergötland, Östergötland and Gotland, see figure 2. The farms that were included in the survey, referred to in '*Materials and methods'*, employed organic cropping systems, with one exception. The motivation for choosing an organic approach, both for the farms participating in the survey and in the suggested crop rotations, was based on the assumption that energy is likely to become scarcer in the close future, why farming will have to become more energy efficient and rely more on ecosystem services (Björklund, 2008). Furthermore, the government has a goal of reaching at least 20% certified organic production of the national Swedish farmland in 2010 (Jordbruksdepartementet, 2006). Some of the methods to reduce the negative effects of the climate change in organic farming, for example regarding leaching, are also transferable to conventional cropping systems.

The included farms in the survey focused on plant production for human consumption, although some produced fodder in exchange for animal manure from neighbouring animal farms, and others produced animal feed to sell on the open market. The choice of focus was mainly based on two reasons. Firstly, fewer resources are used in vegetable production as compared to fodder and animal products in respect to water, fertilizer and energy. In addition, less climate gas is emitted from the production of plants than animal products (Schindler, 2002; Holm, 2000; Mosier, 1997). Secondly, a decrease in demand of animal products has the potential of liberating approximately 1.4 million hectares of farm land in Sweden (SCB, 2008) to grow other crops than fodder, for example to produce energy.

BACKGROUND – FUTURE CLIMATE SCENARIOS

According to the IPCC (2008), climate change is any "*change in climate over time whether due to natural variability or as a result of human activity*". It is general consensus among IPCC researchers that increases in atmospheric concentrations of greenhouse gasses (mainly CO_2, CH_4, N_2O and O_3) since pre-industrial times have led to a warming of the surface of the earth. During the last 250 years, the atmospheric concentrations of CO_2, CH_4 and N_2O have increased by 30%, 145% and 15%, respectively. The emissions are mainly due to the use of fossil fuels, but changes of land use as well as agriculture are also major sources of emissions, see table 1 (Moiser, 1997).

Table 1. Three anthropogenic greenhouse gasses with sources, effect on climate and decomposition. IPCC, 1995 through Moiser, 1997; Soane & van Ouwerkerk, 1994.

Gas	**Global warming potential compared to CO_2**	**Mean atmospheric lifetime (years)**	**Part of the Global warming**	**Agricultural source**	**Sink**
CO_2	1		50 %	Forest made into arable land.	Reforest, return to grassland or wetland. Increased usage of crops with high root carbon production, reduced tillage etc.
CH_4	24,5	12-17	25 %	20 % of global emissions originate from ruminant animals and animal waste. Wetlands, rice production, landfills and the soil.	Oxidation to CO_2 in the atmosphere
N_2O	320	120	5 %	Microbial denitrification and nitrification in the soil when soil is water saturated and fertilised with ammonium.	Photolysis in the stratosphere

Difficulties in modelling the future climate

There are many uncertainties when models are made and used to predict the climate. We do not know the future extent of emissions that will be released, only assumptions can be made. The variation in future emissions of CO_2 depending on scenario and climate modelling system can be seen in figure 5. Natural variability and uncertainty in the response of the climate system together with limited knowledge of how natural sources for carbon sequestration will react to a higher temperature necessitates the use of a number of different initial conditions and a range of climate modelling systems to estimate different possible future scenarios (Christensen Hesselbjerg, 2005). Depending on future emission and technical development, the temperature change at the end of the century is expected to be between 1.1 and 6.4 °C. (Klimat och sårbarhetsutredningen, 2007b)

Global climate scenarios

The climate scenarios of the IPCC are based on socio-economical scenarios. The scenarios represent different paths of demographical, social, economical and technical development for the main factors that emit climate gasses. Four main scenarios of development have been described as A1, A2, B1 and B2, see figure 3. An important difference between the main scenarios is the grade of globalisation, which is assumed to strongly affect the global economical and technical development, with a subsequent effect on emissions. There is an emphasis on economic growth in the A-scenarios while the B-scenarios consider a more sustainable development. There are also many other scenarios that have been modelled and thereby result in quite different future scenarios. The degrees of temperature increase vary largely depending on the expected emission scenarios, see figure 4.

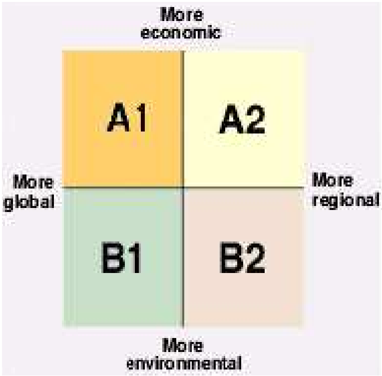

Figure 3. The different scenarios are based on diverse development of the global societies. IPCC 2000.

IPCC and SMHI have chosen to use scenario A2 and B2 in simulation models, to represent two developments that may occur. Below follows a brief presentation of the two. Scenario A2 represents a heterogenic world with large variation in regional development. The global population continues to grow due to an uneven and slowly converging fertility pattern. The economical growth per capita and the technology development are more fragmented and slower than in the other scenarios. In this scenario, the carbon dioxide emissions continue to increase and the temperature change reaches 3.4 °C at the end of the century. Scenario B2 presents a development based on local ecological, social and economical sustainability, with a regional focus. The population increases, but not as fast as in scenario A2. The economical development is good, but not remarkable, and the

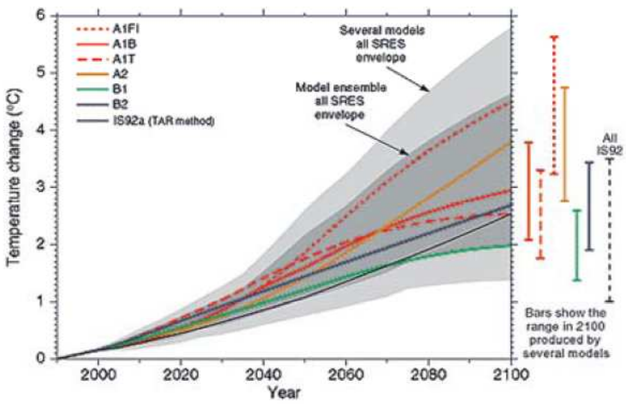

Figure 4. Global temperature change according to the different emission scenarios. IPCC, 2001.

technical development is not as fast as in the A1 and B1 scenario. In this scenario, the emissions are slowly increasing leading to a temperature increase of 2.4 ºC at the end of the century.

National climate changes

The warming in Sweden is expected to be higher than the global average. One of the main reasons for this is the expected decrease in the thickness of the snow cover and its persistence (Klimat och sårbarhetsutredningen, 2007c). The winter climate in large parts of Sweden is expected to show similarities to the one in northern France today, since an increase by 1.5–2.5 ºC is expected in 2020 and by 2.5-4 ºC around 2050, see figure 1. In 2080, Götaland is expected to receive an temperature increase of 5-6 ºC, while large parts of the northern Sweden is expected to obtain an increase of 6-7 ºC, according to the RCA3-EA2 climate model of SMHI.

A large increase in annual precipitation is expected during autumn, winter and spring. The rains will be more intensive and frequent. At summertime there will most likely be a warmer and dryer climate, especially in the southern parts (Klimat och sårbarhetsutredningen, 2007d). Regarding wind patterns, it is unsure to what extent they will change (Klimat och sårbarhetsutredningen, 2007e), but a general increase of wind speed by 1-2 m/s in Götaland is expected (SMHI, 2008).

Regional climate scenarios for southern Sweden

The figures of table 2 and 3 show the interval of the results from both A2 and B2 scenarios in the specific regions. The fusion was made due to the uncertainty to what scenario will actually be the most accurate in the future. Another reason is that the difference in climate change is small between the two scenarios in the years 2011-2040. The numbers in parenthesis is the comparative value of 1961-1990.

Temperature

All of the seven areas in Götaland are expected to continue having frost spells in the years 2011-2040 even though they are expected to occur less frequently as compared to 1961-1990, see table 2. The growth seasons can generally be expected to become longer. The vegetation period can be expected to be longest in the southwest area, since the start of the vegetation period is expected in January and the end in November-December. The amount of frost days per year is expected to 10-40, with the last occasional spring frost between February and the beginning of April. Gotland is the area with the second longest growth period expected. The vegetation period is expected to start in February and end in December, with occasional frost in February-March. (SMHI, 2008)

Table 2. Temperature related parameters presented for the different regions in Götaland, based on the RCA3 model for 2011-2040. The value within parenthesis is the mean for 1961-1990. SMHI, 2008.

Number of area	**Region**	**Frost days per year**	**Last spring frost (days after 1 Jan)**	**Start of vegetation period (days after 1 Jan)**	**End of the vegetation period (days after 1 Jan)**
1	Southwest	10-40 (20-60)	45-105 (75-105)	0-30 (15-75)	330-360 (330-360)
2	Southeast inland	30-50 (50-70)	75-105 (90-120)	30-60 (75-105)	330-345 (300-345)
3	Northwest inland	20-50 (40-60)	60-105 (105-120)	30-60 (75-105)	330-345 (315-345)
4	Northeast inland	40-50 (50-70)	75-105 (105-120)	30-75 (90-105)	315-345 (300-330)
6	Gotland	20-40 (30-40)	60-75 (90-105)	30-60 (90-105)	345-360 (330-345)
17	Öland and East coast	30-50 (50-70)	60-105 (90-120)	15-75 (60-120)	330-345 (300-345)
18	West coast	10-60(30-70)	60-105 (75-90)	0-90 (45-120)	315-360 (300-345)

Precipitation

Long periods without precipitation in spring are historically common in Sweden. The phenomenon is expected to continue with the variance of 8-18 continuous days without rain for the years 2011-2040 in the region, see table 3. The west coast and Gotland is expected to have the longest dry spells (12-18 days) and thereafter comes the southeast inland, the east coast and Öland (10-14 days). The shortest draught period is expected in the northeast and southeast inland (8-12 days). In summer, the region is expected to have dry spells from 6 to 16 days. Gotland and the west coast are expected to continue having the longest dry spells (10-16 days) just as in spring. The southwest area and parts of the east coast and Öland are also expected to have a long dry period (8-12 days). The northeast and the southeast inland are expected to get the shortest dry period in the future (6-10 days). (SMHI, 2008)

Even though dry periods are expected to be longer in many areas it is expected that the total annual rainfall will increase in most parts of the investigated region. The amount of days with continuous daily precipitation over 10 mm during winter is expected to increase in all areas, with the largest increase in the western areas of the region. The length of the rainy period is longest for northwest inland, west coast and south west (4-12 days). The shortest rain period is expected in Gotland, the east coast and Öland (2-6 days).

Table 3. Precipitation related parameters are presented for the different regions in Götaland based on the RCA3 model for 2011-2040. The value within parenthesis is the mean for 1961-1990. SMHI, 2008.

Number of area	**Region**	**Longest dry spell in spring (days)**	**Longest dry spell in summer (days)**	**Continuous days with >10 mm rain in winter**
1	Southwest	10-14 (10-14)	8-12 (6-10)	4-10 (2-6)
2	Southeast inland	8-12 (10-14)	6-10 (6-8)	4-8 (2-4)
3	Northwest inland	8-14 (8-14)	6-12 (6-10)	6-12 (4-8)
4	Northeast inland	8-12 (10-14)	6-10 (6-10)	2-8 (2-6)
6	Gotland	12-16 (14-16)	12-16 (10-14)	2-4 (2-4)
17	Öland and East coast	10-14 (12-14)	8-12 (8-10)	2-6 (2-4)
18	West coast	12-18 (12-16)	10-14 (10-12)	4-10 (4-6)

RESULTS – EFFECTS ON THE FARMING SYSTEM

Plant production is based primarily on photosynthesis, and thus dependent on incoming radiation. However, the potential for production is also greatly dependent on temperature and water access. The temperature limits the duration of the period when growth is possible (Rötter & van de Geijn, 1999). The temperature also directly affects several processes linked with the accumulation of dry matter (leaf area expansion, photosynthesis, respiration etc.). Soil water availability may affect the duration of growth through effects on leaf area duration and the photosynthetic efficiency through stomata closure. In northern countries, such as Sweden the length of the growing season is limited by climatic constraints, such as late spring and early autumn frosts, as well as solar radiation availability (Olesen 2002).

Effects of climate change on crop and weeds are similar as they directly depend on $CO_{2,}$ temperature, water and nutrients, and expected effects of climate changes on these are presented in its own subchapter. Another area that will be affected by climate changes is pests and diseases. Some pests will be able to winter as winter temperatures rise, but effects will also be seen on the predator populations. Details are given in the subchapter '*Pests and diseases*'. Finally, the climate changes are expected to affect soil related issues, for example, mineralization and soil erosion. These effects are analysed in the subchapter '*Soil issues'*.

Crops and weeds

Carbon dioxide (CO_2) is one of the most important building stones in plants, so what happens as the concentration is increasing? The first subchapter brings up nutritional changes in plants and differences between species in their response. The second subchapter goes deeper into differences of how plants respond depending on if they exhibit C3 or C4 photosynthetic pathways. As the response to draught partially depends on the photosynthetic pathway the following subchapter discusses evaporation and water stress. The chapter continues describing growth strategies of determinate or indeterminate crops, as well as their adaptability to potential stress conditions. Maturation of the crop depends on temperature and day length which is why the influence of the photoperiod is discussed in the second last subchapter. The effect of climate change on weeds will be discussed lastly. Vernalization will not be brought up as is not expected to affect crops negatively in Götaland (Klimat och sårbarhetsutredningen, 2007f).

Influence of elevated CO_2 concentrations

Photosynthesis in plants converts carbon dioxide and water into sugars, driven by the energy of the radiation of incoming light (Rötter & Van de Geijn, 1999). With access to adequate amounts of light and water, higher CO_2 concentrations leads to higher photosynthetic rates in most plants, which in turn leads to an increase of leaf area, biomass and yield (Allen, 1990).

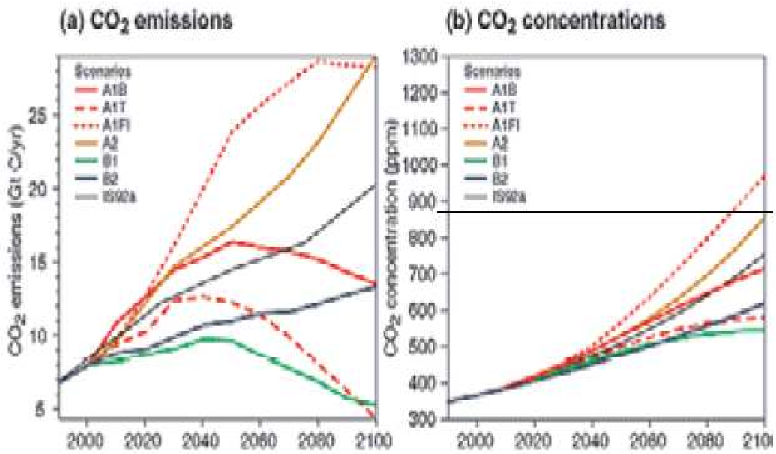

Figure 5. Carbon dioxide emissions and atmospheric concentration scenarios. IPCC, 2000.

Before the industrial revolution the concentration of CO_2 was 180-269 ppm (Teiz & Zeiger, 2002), but it has exceeded 380 ppm as of today (Tans, 2008). The most moderate emission scenario presents a further increase to approximately 550 ppm at the end of 2100 (IPCC, 2000), see figure 5.

Plants grown in an environment with elevated CO_2 conditions can construct and maintain biomass with less energy. It leads to a higher C/N ratio with a lower content of protein and minerals in the plant tissue (Coakley *et al.* 1999; Bunce, 1994). Plants that have symbiosis with bacteria fixating nitrogen from the air may benefit more from a CO_2 increase than non-fixing species if soil nitrogen is a limitation. This has experimentally been found to lead to larger nitrogen inputs to grass-clover pasture (Cure *et al.* 1988).

Different effects of increased CO_2 levels on C3 and C4 plants

Most agricultural crops including carrot, cabbage and wheat exhibit the C3 carboxylic pathway (Calvin cycle) for CO_2 fixation. The C3 pathway coexists with the photo respiratory pathway (Rötter & Van der Geijn, 1999). C3 plants tend to thrive in areas where sunlight intensity and temperatures are moderate, the carbon dioxide concentration is around 200 ppm or higher, and there is good water access (Long, 1991). In greenhouse experiments with low light conditions simulating the winter season with elevated CO_2 concentrations, a major response in increased growth has been observed in C3 plants as compared to C4 plants (Patterson, 1995). Some studies have observed a 30-60 % faster growth with a CO_2

concentration of 600-700 ppm, although some plants only exhibit only a temporarily enhanced growth (Teiz & Zeiger, 2002).

C4 plants have evolved and adapted to drought, high temperature and nitrogen limitation. They have adaptations that allow them to grow in areas where carbon dioxide levels are limited and photosynthesis is almost saturated at present levels of CO_2 concentrations (Patterson *et al.* 1999). Thus growth is not expected to increase with an elevation in CO_2 concentration. Plants which use C4 metabolism include maize, sorghum, finger millet and amaranth.

An increase in CO_2 concentration appears to reduce temperature induced stress, as the earlier measured lower or higher optimum temperature is exceeded (Sionit *et al.* 1981). Temperature optimum for C3 photosynthesis is expected to increase by 3 °C at an elevated level of CO_2 up to 500 ppm. Another increase of 5 °C is expected at 650 ppm (Long, 1991). A side effect of elevated summer temperatures is higher evaporation, which potentially induces draught (Rounsevell *et al.* 1996).

Evapotranspiration and water stress

One of the most consistent responses of plants to elevated CO_2 concentrations is decrease in stomata conductance by a partial closure. It occurs in both C3 and C4 species and significantly decreases water loss by leaf transpiration (Rötter & Van der Geijn, 1999). The minimum leaf water potential is higher in CO_2 enriched plants, which indicates that the extra photosynthate facilitates osmotic adjustment (Patterson, 1995). This effect leads to an improved performance and yield of both C3 and C4 plants, even when they are in conditions of mild stress (Rötter & Van der Geijn, 1999).

Water is essential for the photosynthesis, plays a key role in transpiration and maintains the turgor pressure. Plants generally obtain 70% of the moisture and nutrient requirements from the top half of the root system, since that part of the root system is the densest. Water loss is always higher in the upper soil levels due to evapotranspiration to the air. Some plants adapt to draught by increasing root growth to reach deeper soil layers for example artichoke and asparagus, while other more shallow rooted vegetables, such as potato and onion, are totally dependant on irrigation during draught periods (Nonnecke Libner, 1989).

Effects on determinate or indeterminate crops

Another key factor that affects the development and response to climate change in plants is whether it has a determinate or indeterminate maturation strategy. Maturation is controlled by day length, but might be disturbed or enhanced by a change in temperature. For determinate crops, for example cereals, rapeseed, pulses and onion, warming can reduce the duration of crop growth and hence decrease yield (Tubiello *et al.* 2000, Olesen & Bindi, 2002). On the contrary, warming stimulates growth and increase yield in indeterminate species such as root vegetables and maize. Energy crops, such as willow, *Salix spp.* and elephant grass, *Miscanthus spp.*, are generally indeterminate and will be favoured by conditions that extend the growth season, increasing the light and water use efficiencies. For willow production in the United Kingdom a temperature increase of 3 ºC has shown the potential to increase yields by up to 40% (Olesen & Bindi, 2002).

Influence of photoperiod

Plants grown under reduced light conditions have fewer palisade layers and lower levels of chlorophyll. The spongy mesophyll layers have larger intercellular spaces and are generally more succulent. Some plants, for example leaf vegetables such as such as lettuce (*Lactuca sativa*), celery (*Apium gravolens*) and mâche (*Valerianella locusta*) are generally considered to be of higher quality and more tender when grown in periods with reduced light (Nonnecke Libner, 1989).

Weeds

Global warming and other climatic changes will affect weed growth, phenology, and geographic distribution in a similar way as for the main crops. Higher CO_2 concentration will stimulate photosynthesis and growth in C3 weed species, as well as increase water use efficiency in all weed species (Patterson, 1995). Increased rhizome and tuber growth in perennial C3 weeds is a likely response to elevated CO_2 concentrations. This has the potential to increase the difficulty of controlling perennial weeds mechanically as well as chemically. As an increased winter temperature facilitates wintering of insect populations the effectiveness of biological control of weeds could increase (Patterson *et al.* 1999).

Pests and diseases

This subchapter presents how insect populations, both pest and predator, are likely to respond to the expected changed conditions by alterations in the reproduction cycles and populations dynamic. Several insects can transmit diseases which will further be discussed in the last part.

Pests and their predators

Agricultural systems most commonly have an annual change in crop. It creates a modified and unstable habitat that favours migratory insects that have higher reproduction rate than more stationary pests (Southwood & Comins, 1976). There are a series of changed conditions that are likely to increase insect populations. A warmer climate is the most obvious, since it allows a greater number of reproductive cycles. Warmer winter temperatures may also allow pests, for example the Colorado beetle (*Leptinotarsa decemlineata*) and Western corn root worm (*Diabrotica virgifera virgifera*), to winter in areas where they are now limited by cold (Patterson *et al.* 1999), see table 4. Increased levels of atmospheric CO_2 may affect insect feeding activity through effects on host plant physiology and chemical composition (Patterson, 1995). Actual insect distribution under climate change will also depend on host distributions, competition with existing species, adaptability to new conditions and the presence of natural enemies in the area (Patterson *et al.* 1999). A change in insect predator populations is also likely to occur with a mean temperature increase. Lady birds (*Coccinella septempunctata)* has been observed to increase the reproduction rate resulting in a population increase of 250% on a wheat crop, as compared to 10% by the aphid *Sitobion avenae* in studies where temperature has been increased from 17 ºC to 22 ºC (Triltsch *et al.* 1996). Some pests, such as aphids, act as vectors of plant viruses.

Table 4. Examples of insects that risk becoming a problem due to milder winters and dryer summers

Insect	**Crop preference**	**Reference**
Colorado beetle (*Leptinotarsa decemlineata)*	Potato	Nonnecke, 1989; Sigvald, 2001
Bird cherry oat aphid (*Rhopalosiphum padi)*	Spring barley, cherry	Hansen Monrad, 2005
Green peach aphid (*Myzus persicae)*	Potato and sugar beet	Sigvald, 2001
Root knot nematode (*Meloidogyne hapla)*	Carrot, clover, potato, onion	Coakley, 1999; Juhlin Albertsson, 2008
Western corn root worm (*Diabrotica virgifera virgifera*)	Maize	Hansen Monrad, 2005

Diseases

Climate change has the potential to modify host physiology and resistance, as well as to alter stages and rates of development of the pathogen. Elevated concentrations of CO_2 are believed to result in a denser plant canopy. When it is combined with increased humidity, it is likely to promote foliar diseases such as rust, powdery mildew, leaf spot and blights. Moreover, there will most likely be a shift in the geographical distribution of host and pathogen. The mechanism of pathogen dispersal, suitability of the environment for dispersal, survival between seasons and changes in host physiology and ecology in the new environment will largely determine how quickly pathogens become established in a new region (Coakley, 1999). Many diseases have been rare in Sweden as compared to England or southern Europe. In the case of aphid spread viruses (BYDV) it has been due to the cold autumns that makes them inactive and thereby less prone to spread the pathogen (Sigvald, 2001). Elevated winter temperatures are likely to give higher survival rate for the aphid, which can reproduce early and severe the virus incidence. Changes may occur in the type, amount and relative importance of pathogens affecting a particular crop. It would be more pronounced for pathogens with alternate hosts. Durability of plant resistance may be affected as pathogens will have more time to evolve aggressive races (Coakley, 1999).

Crops already growing in marginal conditions are exposed to chronic stress that makes them vulnerable to both pests and disease outbreaks. High temperatures have also been observed to inactivate temperature-sensitive resistance to stem rust in some annual oat cultivars. In contrast, lignification of cell walls in various species has been induced by elevated temperatures and function as a barrier towards fungal pathogens (Coakley, 1999).

Nevertheless there are some pathogens that do not benefit from an elevation in CO_2, such as the pathogenic fungi on fruit trees *Colletotrichum gloeosporioides* and barley powdery mildew (*Erysiphe graminis)*. Both become less aggressive as the conidia of the former have been observed to have delayed or reduced germination and the rate of primary penetration has been reduced in the latter. It has also been suggested that the fungi *Verticillium spp.* also would decrease in warmer and more humid soils (Coakley, 1999). Another physiological change that is to the advantage of the crop is the decrease of stomata density which diminishes sites for infection by pathogens entering by that passage. The increase of plant carbon and decrease in nitrogen due to higher concentrations of CO_2 has indicated a general decrease in frequency of powdery mildew infections in the crop (Thompson, 1993).

Soil issues

Soils are densely populated by micro organism that brakes down plant debris to nutrients which thereafter is taken up by the plants. A change in respiration rate has been measured as CO_2 concentration has been increased. The consequences are discussed in detail in the following subchapter. The soil micro life affects nutrients and soil particles that may move through the soil horizon or on the soil surface, depending on soil type and nutrient as well as precipitation rate. The following subchapter goes into the details. Soil structure in addition to increased precipitation has the potential to either increase or decrease water saturation of soils and make soil management unsuitable in some moments. The last chapter will present a further analysis.

Increased mineralization

Soil organic matter plays a key role in building and sustaining soil fertility, affecting physical, chemical, biological and hydrological soil properties. Increased precipitation, temperature and CO_2 concentration are likely to increase the turnover rate of organic matter. Soil organisms have relatively broad temperature optima and are thus not believed to be greatly affected by a small increase in temperature. However, they have been found to be affected by elevated atmospheric CO_2 concentrations, as a reduction in respiration rate of some microbes responsible for decomposition has been measured (Koizumi *et al.* 1991). They are also indirectly affected since the higher concentration results in more organic litter, fine plant roots as well as a change in soil moisture (Rounsevell *et al.* 1999). This may lead to build up of inorganic nitrogen in the soil at winter time, when there is a limited vegetation growth to absorb the nutrients (Brisson *et al.* 2005). The combination of increased precipitation and the transport of nitrate as well as phosphorus from arable land to fresh water sources may increase (Arheimer *et al.* 2005; Mattsson *et al.* 2004; Reilly, 1999). Increased amount of inorganic nutrients promotes summer algal growth, which in turn increase the concentration of cyano bacteria, zooplankton and detritus (Arheimer *et al.* 2005). This is especially relevant for farms on the eastern side of Götaland. The nutrients follow streams and rivers that end us in the Baltic Sea, which has had problems with eutrophication for many years and agriculture is believed to have a large potential in decreasing their emissions.

Erosion and leaching

Nutrients can move through the soil profile or on the soil surface as the intensity of the rain exceeds the infiltration capacity of the soil or if the water table reaches the soil surface. It is made worse by poor drainage, low humus content and poor aggregation structure of the soil (Nätterlund, 2006). Surface run off and loss of clay particles is expected to lead to increased risk for phosphorous leaching as it is bound to clay particles to a large extent (Nätterlund, 2006; Ulén, 2002) There is also higher risk of leaching of organic contaminants and micro organism to the aquifers in these soils when fertilising with sewage sludge or animal manure, as it is severely affected by cracking and later swelling (Rounsevell *et al.* 1999; Söderberg, 2006). It has been observed that leaching and surface run off has lead to an increased acidification through depletion of basic cat ions (Brinkman, 1990). Leaching of nitrogen from agriculture is expected to increase by 10-70% mainly due to the expected increase in precipitation rates. The extent of the increase depends on the rise of CO_2 emissions, the grown crop, the concentration of applied nutrients and the soil type (Arheimer, *et al.* 2005; Eckersten *et al.* 2001). The effect on soils depend largely on parameters such as soil type, degree of sloping, choice of crop, hydraulic conductivity, protection zones and tillage techniques being used (Nätterlund, 2006).

Water logging

Water saturation of soil can lead to suffocation in most crops. It creates an anaerobic process of organic nitrogen, which results in production of greenhouse gasses such as N_2O and CH_4 (Mosier, 1997). It can also accelerate ferrolysis as a result of reduction in the soil (Brinkman, 1990). Fe reduction and oxidation causes clay transformations resulting in decreased cat ion exchange capacity (Rounsevell *et al.*, 1999).

Management constraints

The weather directly affects the ability to manage soils and crops when it would be optimal from other perspectives. Soil workability is one of the key factors determining the spatial distribution of crops in Europe. Soil compaction can occur, if tillage and traffic is performed when the soil is too wet (Soane & van Ouwerkerk, 1995; Rounsevell *et al.* 1999). This means that currently wet areas would benefit from a drier climate in terms of machinery workdays (Rounsevell *et al.* 1996). One of the most important restrictions in the more humid parts of northern Europe is the availability of dry weather conditions for harvesting cereal grains. An advantage is that warmer climate in summer is likely to result in earlier harvests (Olesen & Mikkelsen, 1985).

QUESTIONNAIRE TO FARMERS

In order to widen the base of knowledge of what obstacles are experienced in different agricultural systems today and what adjustments are being made already a questionnaire was sent out to farmers in Götaland. There was a liberate intension to include farms with as much geographic spread as possible in the region, see figure 6. This chapter starts with a presentation of the weeds that the farmers had most problems in suppressing and includes a presentation on alternative crops in the agroecosystem. The following subchapter presents the most common pest problems and what crop was most severely affected. The last part presents the most severe diseases.

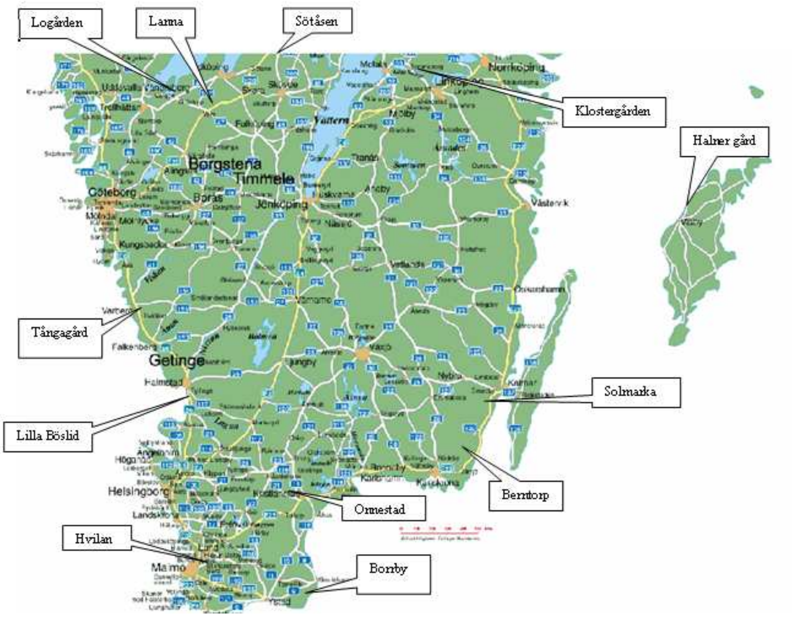

Figure 6. The map of Southern Sweden shows the locality of the farms that replied to the survey. Illustration modified from Eniro, 2008.

Crops and weeds

Farmers were asked what weeds presented the biggest problem and which main crop was most affected. They were also asked if they had observed a change in weed populations during the last 10 years. It became clear that farms with more than 40% cereals in the crop rotation had largest weed problems and a smaller divergence in weed population than the cropping systems with less homogenous rotation. It was further asked how many farmers already have experience from growing plants for energy purpose to find out if they had experienced any obstacles. The last part of the subchapter presents the answers concerning the use of catch crops and perennial vegetation found in the field surroundings, such as border zones and windbreaks.

Cereals as a main crop

Some of the most common weed species in crop rotations with a domination of cereals have been selected through mechanisation of harvest. It is due to the resemblance of the weed seeds to the cereal seeds in both size and weight which makes it difficult to separate them. They have also developed a morphological strategy that makes them favoured by a domination of cereal cultivation and soil management (Statens utsädeskontroll, 2004). Quack grass (*Elytrigia repens*) was the most common weed on the farms. It was experienced as the most noxious weed in winter rapeseed (*Brassica napus spp. napus*) and thereafter in spring wheat, see table 5. Thereafter followed thistle (*Cirsium arvense*) with the cultivation of lupine (*Lupinus spp.)* suffering most. Black bindweed (*Fallopia convolvulus*) and false mayweed (*Tripleurospermum perforatum*) was reported as the most noxious in lupine and winter rapeseed cultivation by two farms. No consistent trend in weed population change related to climate change could be seen from the replies.

Table 5. The most noxious weed species on farms with more than 40% cereals in the crop rotation, most affected crop and number of farms experiencing the problem.

Species	**Most affected crop**	**Number of farms having problems with the weed**
Quack grass (*Elytrigia repens*)	Winter rapeseed, spring wheat	5
Creeping thistle (*Cirsium arvense*)	Lupin	3
Black bindweed (*Fallopia convolvulus*)	Winter rapeseed, lupin	2
False mayweed (*Tripleurospermum perforatum*)	Lupin, winter rapeseed	2

Mixed vegetables and cereals

A crop rotation with more emphasis on vegetables is often more varied in soil management and morphology of the different crops. This led to a large variation in reported weed populations of each farm and only a few have the same noxious weeds. It was more dependants on the local climate and the soil type. The two weeds that were reported as most common were false mayweed (*Tripleurospermum perforatum*) and fat hen (*Chenopodium album*), see table 6. They occurred in slow growing root vegetables like sugar beet (*Beta vulgaris*) and carrots (*Daucus carota*) and in nitrogen fixating crops with limited shadow effect such as peas (*Pisum sativum*) and lupine (*Lupinus spp.)*. The second most common weeds were thistle (*Cirsium arvense*) and nightshade (*Solanum physalifolium & S. nigrum*). Both occurred most frequently in open crops like onion (*Allium cepa*) and vegetable crops as sugar beet and carrot. Some farmers on the east coast and in the south western area reported a change towards larger populations of nightshade (*Solanum physalifolium & S. nigrum*) during the last 10 years. When the autumns have been rainy the potato (*Solanum tuberosum*) haulm has died earlier from late blight, which has led to a general increase in weed populations according to farmers.

Table 6. The most noxious weed species on farms with a domination of vegetables in the crop rotation, most affected crop and number of farms experiencing the problem.

Species	**Most affected crop**	**Amount of farms having problems with the weed**
False mayweed (*Tripleurospermum perforatum*)	Vegetables, lupine, sugar beet, carrot	3
Fat hen (*Chenopodium album*)	Lupine, sugar beet, sweet pea, carrot	3
Creeping thistle (*Cirsium arvense*)	Onion, sugar beet, carrot	2
Green and/or black nightshade (*Solanum physalifolium/S. nigrum*)	Vegetables, onion	2

Energy crops

3 out of 12 farms grew crops that were used for energy production of which one consists of perennial poplar (*Populus spp.).* The other two grew pasture as a part in the crop rotation on ordinary agricultural land. Two farms reported an interest in growing energy crops in the future.

Catch crops and border zones

The farmers reported the use of a wide variety of manure sources from rest products from biogas production, animal manure of different composition, starch potato water to chalk flour. The diversification makes it complicated to estimate mineralization, uptake by the crop and the risk for leaching of nutrients in the individual crop rotations. Many of the farms used catch crops at the time of the survey or have previously tried, while others only uses winter growing crops to absorb nutrients during winter. Of eight farmers that have used catch crops, five reported problems with ryegrass (*Lolium perenne).* Three of them had severe problems with weed infestation, as no mechanical control could be done in the autumn when the catch crop grows. Two had problems with ryegrass becoming a weed in succeeding crop. One farm was using mustard (*Sinapsis alba*), and reported it to function well. Finally, two were using ryegrass and reported good results.

Eight farms used border crops, consisting of pasture or meadow species. One used marshland in order to absorb leaching nutrients. Some of them cut the grass on a regular basis. The width of the border zones were between 6-24 m.

Windbreaks

Four out of the 12 farms used some kind of windbreak hedges. One farm used sea-buckthorn, (*Hippophaë rhamnoides)* a nitrogen fixating species which produce a commercial fruit, as well as Japanese rose (*Rosa rugosa)* and black currant (*Ribes nigrum)* that does not have symbiosis with nitrogen fixating bacteria. Another farm uses traditionally pruned avenues with willow (*Salix spp.)* with the purpose of decreasing soil erosion. None of the reported species are wintergreen, which otherwise have an increased potential to slow down wind and soil particles all through the year.

Pests

Aphids (*Aphidoidea*) were by far the most common problem pest, as reported by 9 of 12 farms, table 7. They are likely to have been of various species, since many different hosts were reported. The pollen beetle (*Meligethes aenus*) was the second most common pest and it has a broad range of *Brassicaceae* family members as a host crop. The leaf hopper (*Empoasca fabae*) was only reported to present a problem in potato (*Solanum tuberosum*). The larva of the large white butterfly (*Pieris brassicae*) was only observed to be a problem in white cabbage (*Brassica oleracea* var. *capitata*). The larvae of the carrot rust fly (*Psila rosae*) only caused damages in carrot (*Daucus carrota*). All pests that have been reported as most severe had wings in the adult stage, which facilitates emigration to new habitats. Insects that are reported to have increased during the last 10 years are leaf hoppers in potato grown in the south western area.

Table 7. The pest that present the most severe problem and its main host crop. The amount of farms that made the statement.

Species	**Main crop**	**Amount of farms having problems with the pest**
Aphid (*Aphidoidea*)	Oat, lettuce, broad bean, cereals, sugar beet, sweet peas, potato, hybrid rye	9
Pollen beetle (*Meligethes aenus*)	Winter rapeseed, broccoli, mustard	4
Leaf hopper (*Empoasca fabae*)	Poatato	3
Large white (*Pieris brassicae*)	White cabbage	2
Carrot rust fly (*Psila rosae*)	Carrot	2

Diseases

Several farmers were of the opinion that late blight (*Phytophtora infestans*) in potato (Solanum tuberosum) has become more aggressive and that it affect the crop earlier than before, see table 8. The second most common disease was powdery mildew *(Erysiphe graminis)* in cereals (*Gramineae*). Root rot (*Aphanomyces euteiches*) infecting sweet peas (*Pisum sativum*), clover rot (*Sclerotonia trifolium*) affecting leguminous perennials in the pasture and leaf spots of varying fungal pathogen species in cereals were reported as troublesome. Two farms reported that the infestation of root rot in clover and sweet peas has increased the last 10 years.

Table 8. The most troublesome diseases, most affected crop and number of farms reporting the problem.

Disease	**Most affected crop**	**Amount of farms having problems with the disease**
Late blight (*Phytophtora infestans*)	Potato	4
Powdery mildew *(Erysiphe graminis)*	Cereals, hybridrye, barley	3
Root rot (*Aphanomyces euteiches*)	Sweetpeas	2
Clover rot (*Sclerotonia trifolium*)	Pasture	2
Leaf spot diseases	Cereals, barley	2

DISCUSSION – TO MITIGATE THE EFFECTS OF THE CLIMATE CHANGES

In this chapter various aspects of agriculture that will be affected by the climate changes are discussed, and a review of what is presently known to ease some of the effects is presented. Methods that can maintain or improve harvests are discussed in the subchapter '*Crops and weeds'*. Recent investigations in management of some of the pests and diseases are brought forward in the following subchapters. Thereafter, a presentation on methods that have the potential to reduce leaching of plant nutrients and decrease soil erosion follows. Lastly, three main problematic scenarios are identified, each in different areas of Götaland representing different problem types. For these scenarios, suggestions for suitable crop rotation in the field and the surroundings are presented.

Crops and weeds

Different methods can be used to take advantage of the prolonged growth season and thereby increase the production. For example, this can be made through winter grown crops, by intercropping or by introducing new species that are adapted to the new climate as well as new trends in our society. On the other hand, crops are likely to suffer from reduced rainfall and a change in growth season due to increased temperature in summer, especially in the west coast, Gotland, east coast and Öland, while weeds often are more adaptable. Various techniques can be used to decrease evaporation, which is discussed briefly. The use of perennial crops gives the advantage of a well developed root system and provides habitat to various beneficial organisms. Some possibilities are presented through the subchapter. The control of four weeds that was reported as most noxious by the farmers of the survey is discussed lastly.

Change in growth period

The vegetation period in Götaland is expected to start approximately 15-60 days earlier as compared to the mean value for 1961-1990, while the end is expected approximately 15-30 days earlier, see figure 3. This implies that the vegetation period practically never ends, for example in the south-western Sweden and in parts of the west coast. It will probably be possible to plant or sow spring crops much earlier than what has been historically possible, if the soil is dry enough to be managed without risk for compaction. This can be an advantage for short-season cultivars of cereals that allows them to mature before the hottest and driest part of the summer (author). Air and soil temperature when sowing spring wheat need to exceed 4.6 ºC and 5 ºC, respectively according to a study by Porter & Gawith (1999). These temperatures are expected to be exceeded in January for the south-western area. On the other hand, winter cereals need low temperatures soon after emergence to winter well (Harrison & Butterfield, 1996). This will lead to later sowing, as compared to the sowing date of today.

Even if the temperatures in some coastal areas generally are expected to allow crops to grow all year around, frost will continue to limit plant growth. It would consequently be advantageous to plant fast developing vegetables that grow well under low light intensity conditions before or after the main crop, if these can be protected from frost. One viable method is to cover the crop with fibre cloth or plastic tunnels during periods when frost risk is prevailing. Another possibility is to irrigate with sprinkler systems to increase temperature when there is an occasional frost alert (author). A technique with high ridging has been used for late winter or early spring planting of sweet maize and vine in California. The ridges run north-south with the seeds or the plants placed on the southern side of the ridges. Another possibility is to establish early plantings on the lee side of a north-south running hill (Nonnecke, 1989). The method can be used in Swedish cropping systems in Götaland to avoid damage from occasional frost.

New annual crops

Much knowledge can be gained from other parts of the world that have a climate similar to that Götaland is expecting and thus have employed a food production system adapted to the climate (author). It is important though, to take into account the climatic origin of the new crop. Bengtsson of The Swedish Garden Society (Riksförbundet Svensk Trädgård) gives the example of plants adapted to the stable continental climate in Siberia that will be less healthy and resistant to pests when the thaw and frost occur unevenly, as expected in Southern Sweden (2007).

Asian leaf vegetables have a fast development rate and are hardy to several degrees below zero, which prolongs the harvest period at winter and early spring. They are ready to harvest within 2-4 months, in contrast to Brussels sprouts and cauliflower which develop slowly. Most Asian leaf vegetables are short day plants, which makes them likely to induce flowering if they are seeded in spring or early summer. As many of them are of the family *Brassicaceae* they attract many pests. However, most pests can be avoided if the plants are well covered with a textile or cultivated under tunnels. Late planting further reduces the insect problem by avoiding the spring and summer insect-peak (author). Most species are of the “cut and come again” type and which makes them suitable for a long continuous harvest (Fogelberg, 2007).

Several on-going studies are investigating crops that are likely to attain more interest in the future. One example is annual energy crops. The diversification of species allows an additional variation in the crop rotation that can be better adapted to soil conditions, future water access and management input (author). Hemp (*Cannabis sativa*), cocksfoot (*Dactylis glomerata*) and winter triticale (*Triticosecale wittmack*) has been shown to have the highest growth productivity of six annual species tried in an experiment in Germany. They have achieved 9.4-11.8 tonnes of dry matter per hectare on sandy soil. A reduced application of nitrogen fertilizer, to 75 kg/ha from 150 kg/ha, only reduced the harvest by 6%. A total exclusion of fertilizer for six years produced a crop that still yielded 20-40% of the original yields. Since the crop was harvested with the weeds there was no notable loss from absent weed management. No pest treatment was used at any time (Scholz & Ellerbrock, 2002). Using unfertilized energy crops growing in strips at the borders of the field to capture nutrients can be interesting as the crop responded well to a limited supply of nutrients (author).

Another interesting crop is New Zealand spinach, since it is draught hardy after being established, and it does not have many known pests (Philips & Rix, 1995).

Water management

Götaland is expected to experience a general dry spell of 8-12 days in spring and 6-16 days in summer, see table 3. Gotland and the west coast are expected to have the longest periods without precipitation, which makes irrigation a highly relevant issue, especially on sandy soils (author). In high value crops such as potato (*Solanum tuberosum*), drip irrigation can be the most efficient technique to achieve a high yield and efficient water use (Ekelöf, 2006). By reducing tillage and maintaining crop residues in the field, organic matter in the soil increases, providing a structure for larger water holding capacity. In cases where a short summer fallow is needed for weed control, it is made in a dry period not only to dry out the weeds, but also to save water in irrigation dams for high-value crops. As winter precipitation is expected to increase in all regions there are possibilities to lead drainage water to irrigation dams. A wide array of techniques for microclimate modification, such as windbreaks and different intercropping systems, can also be employed to improve water use (author).

Intercropping

Intercropping refers to a combination of crops of different species growing in the same field at the same time. A well-designed intercropping system has the potential to supply parasitoids and predators of pests with food and habitat (author). Dicke *et al*. describes how the host plant may be protected from insect pests by the physical presence of other plants that may provide a camouflage or a physical barrier. It can also be the odour of some plants that disrupt the searching behaviour of pests or attract carnivorous insects (2006). Altieri & Nicholls further states that the effect of these factors will vary according to the spatial and temporal arrangements of the crops and the intensity of crop management (1999).

Perennial crops

Perennial crops can take many forms and have many functions. They can be lignose energy crops, biannual or older pastures, windbreaks, protection zone vegetation, orchards, solitary trees etc. The main reason for their establishment is often connected with direct economical return or to capture nutrients and slow down erosion, while ecosystem services is just a bonus. By actively favouring biodiversity through improved habitats a strong reduction of pests can be noticed in the crop. These habitats can be pasture, meadow, created marshland, vegetation growing at islets in the field, border zones and other perennial vegetation in close proximity to the field.

Pasture

Pasture often consists of a mixture of grass species and nitrogen fixating species. It can be annual, but is more commonly grown during several years and it is common practice to cut the growth several times per season to control budding weeds (author). The green biomass has traditionally been used as fodder and mulching, but has started to become a valuable energy source in the production of biogas (Svensk Växtkraft, 2008; Bioenergiportalen, 2008).

Biodiversity often benefits from pasture, if grassland is not already dominating the area. According to Söderberg *et al.* (2006), trimming pasture can have a negative impact on biodiversity, since it risks disturbing wildlife during reproduction and reduces the supply of flowering herbs. Thus, it is important to gain knowledge in timing of the cutting to achieve the optimal results (author).

From pasture on marginal land to production of perennial energy crop

To make the largest energy return from growing crops for production of energy it is most rational on land in the close proximity to a bio energy production plant or use the product on the farm. Degraded and marginal land as well as permanent pasture could gain a higher value by producing energy. To use land more efficiently it would be rational to establish alder (*Alnus spp.),* willow *(Salix spp.)* and poplar *(Populus spp.)* on soils that are often water saturated (author). Poplar has showed high production compared to a wide range of other woody perennials, even with very low fertilisation rate (75 kg nitrogen per hectare). Another positive side effect has been the most efficient weed depression due to large leaves in mature poplar. It also has the advantage of being the energy plant species with the lowest emission at combustion (Scholz & Ellerbrock, 2002).

Potential development of protection zones

The vegetation growing on the protection zone function as a form of catch crop with the difference that the vegetation is perennial and is established at the borders of an adjacent water source. There is also often a need of a perennial zone at other field borders, around electricity poles or around drainage wells. The aim is to absorb nutrients that are mobile and stabilize soil (Nätterlund, 2006). Protection zones often serve as turning zones for the farmer, and are therefore likely to have a soil structure that is more compacted than the rest of the field. Several farmers in the survey are already using perennial grass or meadow species of different composition as catch crops at the field border. The result of the questionnaire shows that the protection zones have a width that often exceeds 6 m, thus a development of the external areas of the border zone could be possible. Ecosystem care is often not enough to set of land, as there are economical restrains on the farm. Thus, it is of interest to establish crops that make a higher economical return in combination with lower growing grass. It would need to be a crop that can stay healthy and produce a good harvest with the supply of nutrients that leach out from the field. Deep root systems that can stand growing in compacted soil without producing invasive suckers are properties that would be of high relevance, as well as being harvested with a minimum of disturbance of soil and vegetation. Interesting herbaceous species are rhubarb (*Rheum rhabarbarum*), globe artichoke (*Cynara scolymus*), asparagus

(*Asparagus officinalis*) and raspberry (*Rubus idaeus*). Other options are fruit bearing windbreak hedges (author).

Windbreak plantations

The effectiveness of a windbreak depends on its external structure, such as height, orientation, continuity, width and cross-section shape. It is also determined by its internal structure, which is characterised by vegetative surface area and the shape of individual plants (Brandle *et al.* 2004). It is optimal to combine different functions when choosing the plant material. It might be evergreen and reasonably frost hardy, which can make it an effective windbreak even during winter. The bushes may prefer light shadow or direct sun, have symbiosis with nitrogen fixating bacteria and produce attractive berries for commercialisation (author). Many insect predators are favoured by plants that flower early or very late in the season and produce large amounts of pollen (Wäcker, 2004).

Weed control

The traditional way of decreasing weeds before pesticides made an entrance in agriculture was based on a combination of several management practices and the choice of crop rotation.

- Annual crops were alternated with perennials and crops with varying morphology were combined.
- Pasture strongly competed with the weed.
- Farmers were choosing competitive species and cultivars.
- Sowing density and timing varied.
- Harrowing was done between seeding and emergence.
- Row hacking and harrowing was made in the growing crop.

(Fågelfors, 2003)

These methods can still be used with good results on most weeds, but as climate change is likely to increase growth rate in weeds, efforts need to be made as soon as a problem has been identified. The following subchapters will discuss management practices on species level for four of the most noxious weeds according to the farmers of the survey. Several of these methods have been used in the setup of the crop rotations in the final subchapter.

Creeping thistle, *Cirsium arvense*

Thistle can spread by seeds, but the main spread in the field is made by runners. Storing nutrients in the roots is expected to promote growth as CO_2 is increasing (author). Several continuous years of pasture should preferably be cut back 3 times per season as the thistle is starting to bud to give the best results in decreasing the energy stored in the root. Rahbek Pedersen & Dock Gustavsson suggests that by using winter growing crops a further decrease of the thistle is accomplished, as the crop have time to develop a deeper and thus more competitive root system (2007).

Quack grass, *Elytrigia repens*

The rhizomes of quack grass grow closer to the soil surface in a pasture, which facilitates bringing them up to the surface when the pasture is broken, according to Rahbek Pedersen. To achieve the best effect against weeds the pasture should be opened in dry weather and followed by a short summer fallow to dry out the rhizomes efficiently. A short summer fallow can obviously also be used after harvest of a short season cultivar (author). The fallow can preferably be succeeded with winter rapeseed or a catch crop that absorb the mineralised nutrients faster than the quack grass. It is generally advised to use competitive crops, such as for example rye, winter wheat or winter rapeseed (Rahbek Pedersen & Dock Gustavsson, 2007).

False mayweed, *Tripleurospermum perforatum*

False mayweed is an annual weed in Sweden, but is expected to become biannual as it is in Great Britain today (author). It has a deep taproot and can germinate both in spring and autumn. It is advised that cutting the pasture in spring, as false mayweed starts budding is the most efficient way of disturbing the vegetative phase. Crops that are row hacked further decrease the population by disturbing germinating seeds, while winter wheat and rapeseed should be avoided in the crop rotation (Baldersbrå, 2005).

Fat hen, *Chenopodium album*

Fat hen is another annual that most often germinate in spring. The seeds are long lived in the soil. Crop rotations with morphologically diverse crops have been showed to have the potential to reduce the soil seed bank and abundance of fat hen (Teasdale *et al.* 2004).

Pests and diseases

Many small biotopes for animals, plants, fungi and micro organisms can be found in agro ecosystems. They are all key components regulating nutrient cycling, decomposition and natural control of pests in cropping systems with an ecological approach. The type and abundance of diversity will vary in different agro ecosystems depending on age, structure and management. Systems that are more diverse and perennial generally present an advantage in ecosystem services, compared to highly simplified, input-driven and disturbed systems, such as annuals grown in a homogenous field (Altieri & Nicholls, 1999). Many biotopes found by stone walls, field islets, piles of stone, small open ditches or tree avenues have disappeared through rationalisation of agriculture, but now have received legal protection through environmental laws. By providing habitats to insect eating birds, smaller carnivorous mammals and parasites or parasitoids, less damage will be made on the crop from the pest. If fields are made more fragmented and perennial habitats with low disturbance are established in the surroundings of the agroecosystem an improved protection of the crop is likely to be achieved. Fields that are already large and homogenous can be made more heterogeneous by intercropping with strips of perennial energy crops, which will have the additional benefit of acting as windbreaks (author).

This chapter will deal with five of the pests that have become an increasingly severe problem in the crops, according to farmers in the survey. It will be discussed how management of the field and crop can create an agro ecosystem that repels the insects or at least make their predators and parasitoids get an advantage. The last part of the chapter will discuss how five diseases that have made severe infections on the crops of the farms can be approached in the context of climate change.

Aphids (family *Aphidoidea*)

There are many types of aphids and farmers of the survey reports increasing trouble in various crops. It is likely to be due to faster reproduction cycles and wintering (author). Various studies have shown that the first populations of aphids feeding on cereal in spring can be significantly reduced by polyphagus predators, such as several beetle species, spiders and earwigs. As the predators are significantly larger than the prey, the feeding is very intensive. Even so, the generation time of many predators is often a year as compared to the much faster rate of the aphid (Öberg, 2007; Southwood & Comins, 1976). The emigration of predators is likely to be limited in large fields, as several of the species lack wings. It is thus of high relevance to make intentional field design that produce predator habitats for high survival and facilitate access to the whole field (author).

Leaf hopper (*Empoasca fabae*)

The leaf hopper seems to be an increasing problem in potato (*Solanum tuberosum*) in areas with longer dry periods (author). Several predators eat the nymphs and adults, such as the spiders (*Araneae*), mites (*Acari*) and it is also attacked by a pathogenic fungi. Various life stages are exposed to predation and parasitism but even so do not appear to play a significant role in the population dynamics of the leaf hopper (Hogg & Hoffman, 1989). It has been showed in experiments that less leaf hoppers are found on the potato plants with smaller row spacing than 96 cm. This is possibly due to a larger population of the predatory bug, *Orius insidiosus* on denser canopies (Mayse, 1983). It can be concluded that a population decrease can be expected by supplying habitats to predators, even if more specific research is needed (author).

Pollen beetle (*Meligethes aenus*)

Various farmers in the survey have reported severe problems with the pollen beetle in mainly winter rapeseed, but also other members of the *Brassicaceae* family, see table 7 (author). Several parasitoids of the pollen beetle have been found in the Nordic countries. The natural parasitoids have been found to decrease the adult generation of the pollen beetle to 30% as a mean in a large survey covering Finland. This was found out after heavy pesticide use directed at aphids had decreased the natural enemy populations severely (Hokkanen, 2006). To enhance control of the pollen beetle, without affecting the parasitism of for example *Phradis interstitialis* and *P. morionellus,* repelling crops such as lavender (*Lavendula angustifolia*) can be used according to Cook *et al.* (2007). This result makes it interesting to try intercropping lavender with rapeseed and other *Brassicaceae* species to see if an effect can be observed (author).

Large white (*Pieris brassicae*)

The large white butterfly has been reported as one of the most difficult pests in white cabbage (*Brassica oleraceae*) by the farmer in the present survey. It is possible to decrease the feeding by covering the crop with a cloth or tunnel. Another approach is to improve the survival of parasites and parasitoids of the pest (author). The parasitoid *Cotesia glomerata* has been showed to be attracted to oregano (*Origanum vulgare*) and ground elder (*Aegopodium podagraria*) out of 11 common agricultural plants, which both produced sufficient amount of pollen to assure a high survival rate of the adult insects. Plants that had a repellent effect was red clover (*Trifolium pratense*), bush vetch (*Vicia sepium*) and yarrow (*Achillea millefolium*) (Wäckers, 2004), thus should preferably not be left growing in the field or at the edges of cabbage (author).

Late blight (*Phytophtora infestans*)

Late blight is caused by fungi and is one of the most severe diseases in agriculture worldwide, with potato as main host. Several farms in the survey reported the pathogen as the most difficult disease in cultivation of potato, see table 8 (author). Earlier infections in the growth season of more severe character are thought to be caused by adaptations through sexual reproduction of the spores. Sporangias are formed mainly in conditions with moderate heat (~20 ^{o}C) and high humidity (>90% Rh) (Andersson, 2007). An earlier start of the growth period can give the plant enough time achieve a strong growth and to set tubers, but the expected increase of extreme weather might just as well continue to favour the pathogen. There are cultivars that show partial resistance to late blight that could be used to a higher extent (author).

Powdery mildew (*Erysiphe graminis*)

Powdery mildew is a problem in various cereal species according to several farmers in the survey (author). Rye is a cereal species that is rarely infected severely by powdery mildew (Rahbek Pedersen, 2004), which makes it an interesting species for the crop rotation. Pasture without susceptible grasses have the potential to further increase the potential of limiting the fungi (author). As an increase in C:N ratio in the plant tissue is expected as a consequence of increased CO_2 concentration (Thompson, 1993), a natural decrease in the severity of the infection of powdery mildew in the future is likely (author).

Root rot (*Aphanomyces euteiches*)

Root rot is a fungus that mainly makes serious infections on sweet pea (*Pisum sativum*). The effect of the pathogen is often stronger when peas are grown on humid and compacted soil. Sweet pea is known to be more sensitive to compaction than many other crops, such as cereals (Grath & Håkansson, 1997). Thus, cultivation of sweet peas may not be recommended in areas with clay soils that are likely to get an increase in precipitation (author).

Clover rot (*Sclerotonia trifolium*)

The most susceptible crop to fungal infection by clover rot is red clover (*Trifolium pratense*), but several other biannual or perennial members of the family *Fabaceae* are susceptible, such as alfalfa (*Medicago sativa*) and birdsfoot trefoil (*Lotus spp.*). The pathogen infects the plant in winter when humidity is high and the temperature below 0 ºC, but the damage is seen in spring. Annual nitrogen fixating crops are believed to have some resistance against the fungi (Ögren, 2008), which makes the infection of the pathogen likely to depend more on the species composition in the crop rotation than climate change (author).

Leaf spot diseases

Leaf spots can originate from several pathogenic fungi and have a large host range among cereals and grass weeds, as well as grass species used in pasture. It is thus of high relevance with a varied crop rotation, healthy seeds and resistant cultivars. Rye is a cereal species that is rarely infected severely by leaf spots (Rahbek Pedersen, 2004) which makes it a sanitary crop in the rotation. Pasture without susceptible grasses would further increase the potential of decreasing the fungi through crop rotation (author). Humid conditions favour infections (Statens utsädeskontroll 2004), which makes it likely to assume that there will be a change in the severity of the disease depending on if the area is expected to receive a decrease or increase in precipitation during the growth period (author).

Reducing soil erosion and leaching of nutrients

This chapter contains a brief presentation of soils that are prone to water saturation and erosion, as well as soils that risk leaching. The subchapter is followed by a presentation of other soil related issues, such as compaction and reduced tillage. A change in nutrient management is discussed briefly as the agroecosystem respond differently with an increase in concentration of CO_2 in the atmosphere. The following subchapters describe winter growing crops briefly, thereafter follows a review of catch crops that have the potential of absorbing leaching nutrients after the harvest of the main crop. The choice of main crop can also have an impact on creating a good soil structure. The last part of the chapter will describe the potential of combining different techniques to optimise the reduction of leaching nitrogen and phosphorous.

Risk soils of Götaland

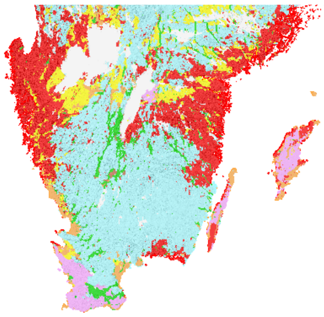

Figure 7. The soil types of Götaland.
Turquoise: Silt
Red: Thin or uneven soil cover
Purple: Clay silt
Yellow: Clay
Beige: Sand
Brown: peat
Lantmäteriverket, 2008

Autumn, winter and spring precipitation is expected to increase in most parts of south Sweden. This creates an increased risk of water logging in areas with a high clay content, high water table and/or poor drainage. Soils vary largely in composition on most farms, but from figure 7 a general idea can be made of the areas that are likely to get more problems with water logging. The yellow areas with high clay content are mostly found in the northern parts of east and west inland of Götaland, close to the biggest lakes. As the soils get saturated, water and soil particles move on the soil surface and erode to the surrounding water sources (author). A well functioning drainage system improves infiltration and decrease soil surface run off (Nätterlund, 2006). The drainage water should ideally be taken care of in irrigation dams as summer precipitation is likely to decrease. Another option is to lead it to an established marshland or to a perennial energy producing vegetation with crops such as alder (*Alnus spp.),* willow (*Salix spp.*), poplar *(Populus spp)* or even bamboo (*Phyllostachys spp.*), that can absorb the nutrients. Soils with low water storage capacity, typically sandy soils need to be addressed in order to reduce leaching and erosion to the surroundings. Areas with this type of soils are coloured beige in the figure. They can be seen along the south-western coast, the south-eastern coast, parts of Öland and Gotland (author).

Soil related issues

When and how farmers manage the soil has an impact on the soil structure that creates the holding capacity of water and nutrients. It is of great importance to avoid driving on the field when the soil is water saturated as it risk compacting the soil for a long time, which decrease root development and water infiltration. Conservation tillage is the practice of leaving some or all of the crop residues from the previous season on the soil surface. It does not only limit fuel use, but may protect the soil from wind and water erosion and retain moisture by increasing soil organic matter. Evaporation is thereby reduced and the infiltration and retention of water from rainfall is increased. Management choices largely determine if agricultural soils will act as a source, sink or neutral with respect to greenhouse gasses (author), as the soil has the potential of storing approximately twice the amount of carbon present in the atmosphere (Eswaran *et al.* 1993). An example of a successful long term experiment on increased carbon storage in the soil was made by Mahboubi *et al.* (1993). Soil organic carbon content was shown to increase by 85 % after 8 years on a clay loam soil following introduction of reduced tillage. If, or when, the field is ploughed Nätterlund (2006) suggested the practise of ploughing perpendicular to the slope, which has the potential of slowing down the water movement.

Nutrient management

Nutrient management will need to be adapted to changes in the turnover of nutrients in soils, including losses and an increased uptake proportional to the increase in growth. There are a range of management options that will affect the utilisation of fertilisers and manure, including fertiliser placement and timing, changed crop rotations and use of cover crops (author).

Winter grown crops

Many crops such as cereals, rapeseed and pasture can grow at winter and absorb nutrients. As soon as the temperature is high enough to allow growth, recently mineralised nitrogen in the soil is absorbed and is thus prevented from leaching (author).

Catch crops

A catch crop is a secondary crop that is established in the growing main crop before or after harvest. It absorbs excess nutrients, thus decreasing leaching, and slows down erosion while growing. The optimal morphology of the catch crop is preferably a fast growing and deep rooted herbaceous species (author). It is important that the crop is easy to establish and that it does not produce seeds in autumn in order to avoid it becoming a weed problem, according to Pålsson (2006). Many species have these properties and are recommended as catch crops according to the Swedish Board of Agriculture. All grasses (except cereals) are recommended, as well as clover (*Trifolium spp.*), alfalfa (*Medicago sativa*), vetch (*Vicia spp.),* goat's rue (*Galega orientalis*), bird's foot trefoil (*Lotus corniculatus*), phacelia (*Phacelia tanacetifolia*) and white mustard (*Sinapsis alba*) (Söderberg *et al.* 2006). Phacelia is an annual herb that develops a very deep root system. Both the perennial vetch and phacelia leaves large amounts of organic matter in the field. The two species has an input of approximately 2.0 tonnes organic matter per hectare (Sleutel *et al.* 2007), which provides a good soil structure. As phacelia is of the *Boraginaceae* family, which is not common in agricultural crops, it is not likely to suffer from the same pest and diseases as the main crops (author). Clover (*Trifolium spp.)* has the potential of both capture and produce nitrogen. The most extensively used catch crop is English ryegrass (*Lolium perenne*) which has the potential of reducing nitrogen losses even more effectively than clover (Askegaard & Eriksen, 2008). It is often sown in spring, at the same time as the main crop, which often is a taller growing cereal (Johansson, 2007). As several of the farmers in the survey reported rye grass becoming a weed in the following year it should ideally be followed by a strongly competitive crop (author).

Two species that have been drawing the attention as potentially interesting catch crops are white mustard (*Sinapsis alba*) and fodder radish (*Raphanus sativus var. oleiformis*), and they are becoming increasingly popular for various reasons (author). Fodder radish develops a several meters deep tap root that absorb nutrients from a very deep soil horizon. By using cultivars that are resistant to the beet cyst nematode (*Heterodera schachtii),* a sanitary effect of the soil can be achieved. Neither white mustard nor fodder radish will have time to set seed and become a weed as they die when temperature drops below zero (Pålsson, 2006).

Increasing soil organic carbon through the choice of main crop

The choice of crops with an extensive root system and large quantities of crop residues will contribute to carbon storage and an improved soil structure (author). Growing perennial energy crops show the greatest potential for carbon storage in soil, of various management practises on arable land that have been investigated by Smith *et al.* (2000). Thereafter follows natural woodland regeneration and no-till farming. The three land management strategies integrated (not in the same field at the same time) has the potential to meet the commitment of the European Union to reduce emissions of CO_2 to 92 % baseline (1990) levels. The calculations were made with the assumption that 10% of arable land in fallow could be set aside for the purpose of growing energy crops and/or trees.

Combined methods give the best result

Johansson (2007) specifies that pasture, catch crops and winter grown crops (titled crop distribution in figure 8), has the largest impact of all the suggested methods on decreasing leakage of nitrogen. A winter grown crop has showed to be the single most effective strategy to reduce phosphorous leaching, see figure 8. It can possibly be explained by reduced particle erosion (author).

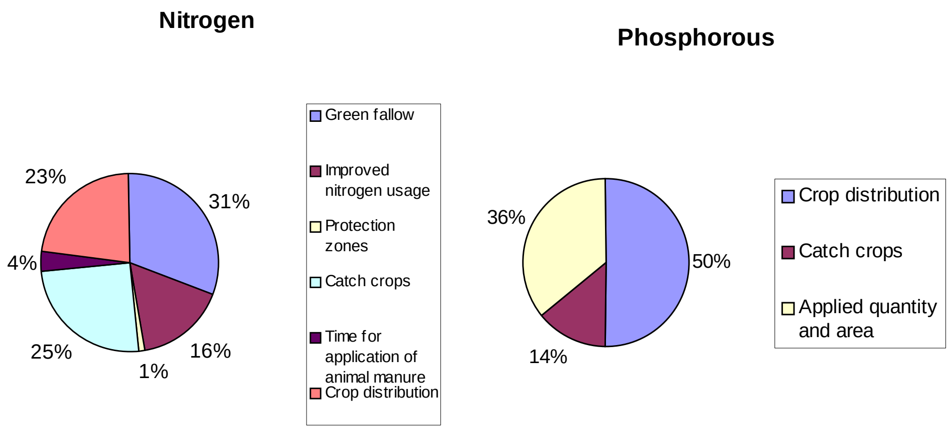

Figure 8. Presenting the methods that have contributed to a decrease in leaching nitrogen and phosphorous in recent trials in Sweden. (Modified from Johansson, 2007).

A study by Larsson et al. (2005) showed that a single management measure can only decrease nitrogen leaching by 5-8 %, but by combining a late opening of the pasture in autumn, using a winter catch crop, spring plough, apply the organic manure in spring and use a spring sown crops it is possible to obtain a reduction of 21%. The investigations suggest that there are many methods that can be used in the same field at different times of the crop rotation, with a large impact on the reduction of leaching nutrients to the surrounding ecosystem (author).

Suggestions for crop rotations

Three main problematic scenarios were identified for different areas of Götaland, with the expected future climate changes and the problems experienced by the farmers of the survey taken into consideration. The first to be addressed has an increased risk of a prolonged dry period in spring and summer. The second has an increased risk of leaching and soil erosion. The third has a focus on the most noxious weeds, according to the farmers of the survey. The weed scenario is expected to get worse as there is an expectancy of increased growth with elevated CO_2 concentrations and wintering of weeds. The following scenarios with subsequent crop rotations should be seen as examples that can be varied extensively.

Farming system 1; Draught hardy crops

Climate: Draught prone spring, high summer temperatures with long dry spells and mild winters. Vegetation period, based on temperature, starts somewhere between January to March and ends between November and December, see table 2
Specific area: West coast, Gotland, South west, the East coast and Öland
Identified risks: There is a risk of water stress, thus irrigation of high value crop is necessary. NaCl present in varying concentrations in the soil due to maritime exposure. Leaf hoppers, large white and aphids are often a problem.
Assumptions: It is assumed that the farm has access to a local market or fast delivery and sales of fresh greens of a large variety.

Comments
The border zones are preferably populated by a combination of oregano (*Origanum vulgare*), ground elder *(Aegopodium podagraria)* and grass to optimize survival of predators and parasitoids that feed on pest like large white in crops of the *Brassicaceae* family (Wäckers, 2004). The fields are rather long than squared to facilitate border emigration by predatory insects, spiders and to provide pollen for adult parasitoids (author).

Pepper plants are transplanted to a warm soil in the end of spring or beginning of summer of the first year, see table 9. There are several varieties that grow well in Canada today, such as sweet pepper *(Capsicum annuum),* as they set fruit quite early. Rye (*Secale cereale*), can be used as a catch crop of nutrients until the soil is sufficiently warm to plant the pre-germinated tubers of sweet potato (*Ipomea batatas*) the second year. There are varieties grown in England today as annuals, until the frost terminates the haulm. It has a high tolerance to draught, heat and salt stress (Leendertz & England 2003). Adzuki beans (*Phaseolus angularis)* are seeded in spring of the third year in soils with a neutral to low pH. It grows in the shape of a bush and provides the soil with nitrogen. Asian baby leaves are transplanted to the field and can be harvested all through the winter as they are quite frost hardy. They are followed by New Zealand spinach (*Tetragonia tetragonioides*) in the fourth year, which is also eaten as a leaf vegetable, but preferably cooked. It grows well in a dryer climate and also in cloudy conditions. As the plant gets more fibrous at the end of the season it can be mulched down with garlic (*Allium sativum*) planted underneath. The garlic sprouts in early spring of the fifth year and is harvested in summer. If there is a weed problem or severe draught it can be positive to leave the field in short summer fallow (author). Broad beans (*Vicia faba*) can be established in autumn to supply the succeeding crop with nitrogen, a practice in England. Potatoes are set in February and harvested as early potato to avoid late blight. They are established with a narrower distance than 96 cm in order to encourage the predatory bug *Orius insidiosus* to control the leaf hoppers (Mayse, 1983). As the potato cultivation is terminated early it is an advantage if it is succeeded with winter rapeseed (*Brassica napus sspp. napus*) that has a several meter deep root that can absorb leaching nutrients. It should preferably be intercropped with strips of lavender (*Lavandula angustifolia*) to decrease pest problems with the pollen beetle (Cook *et al.* 2007). The lavender can, if possible by management means, stay in the field even after the rape seed is harvested in July of the seventh year. It will than serve as a protective crop for the establishment of the leguminous, draught hardy perennial alfalfa (*Medicago sativa*) combined with the weed competitive grass cocksfoot (*Dactylis glomerata*). The lavender flowers can be harvested during the two years of growing the green manure (author).

Table 9. Farming system 1 with draught resistant crop rotation

Year	**Spring**	**Summer**	**Autumn**	**Winter**
1	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)	Pepper (*Solanaceae*)	Pepper (*Solanaceae*)+ rye (*Poaceae*)	Rye (*Poaceae*)
2	Rye (*Poaceae*)	Sweet potato (*Convolvulaceae*)	Sweet potato (*Convolvulaceae*)	Sweet potato (*Convolvulaceae*)
3	Adzuki bean (*Leguminosae*)	Adzuki bean (*Leguminosae*)	Asian baby leaf (*Brassicaceae*)	Asian baby leaf (*Brassicaceae*)
4	New Zeeland spinach (*Aizoaceae)*	New Zeeland spinach (*Aizoaceae)*	New Zeeland spinach (*Aizoaceae)*	Garlic (*Liliaceae*)
5	Garlic (*Liliaceae*)	Garlic (*Liliaceae*)	Broad beans *(Fabaceae)*	Broad beans *(Fabaceae)*
6	Early potato *(Solanum tuberosum)*	Early potato *(Solanum tuberosum)*	Winter rapeseed (*brassicae*)+lavender (*Lamiaceae*)	Winter rapeseed (*brassicae*)+lavender (*Lamiaceae*)
7	Winter rapeseed (*brassicae*)+lavender (*Lamiaceae*)	Winter rapeseed (*brassicae*)+lavender (*Lamiaceae*)	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)
8	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)	Lavender (*Lamiaceae*) +alfalfa (*Fabaceae*)+ cocksfoot (*Poaceae*)

Farming system 2; Reduce leaching

Climate: Frequent precipitation in all seasons with the beginning of the vegetation period in January to March and with end in November to December. Longest period with heavy rain is two to twelve days. The period without precipitation is from six to ten days.
Specific area: Northwest and northeast inland, west coast and parts of southwest areas.
Identified risks: Soil erosion and nutrient leaching risk with eutrophication as a consequence.
Assumptions: The farm has sand and silt soils with low humus content.

Comments

The borders need to be populated with deep rooted perennials that develop early in the season in order to absorb leaching nutrients and make a physical barrier to eroding soil. By establishing Jerusalem artichoke (*Cynara scolymus*) or asparagus (*Asparagus officinalis*) in combination with rye grass (*Lolium perenne*) a high value product is marketable in early spring (author).

The crop rotation starts with pasture containing ryegrass (*Lolium perenne*), chicory (*Cichorium intybus*), vetch (*Vicia spp.)* and alfalfa (*Medicago sativa*), in order to build up a humus and nutrient rich structure that have an increased capacity of storing water and nutrients through aggregate structures (author). The pasture is opened in spring of the second year followed by seeding oat *(Avena sativa)*, see table 10. It has a good ability to use the mineralized nutrients and competes well with weeds (Rahbek Pedersen, 2004). It is succeeded with red fescue (*Festuca rubra*). Carrot (*Daucus carota*) and celeriac (*Apium gravolence*) are seeded in spring of the third year. Rye (*Triticum spelta*) is seeded thereafter as it develops an extensive root system and develops well even with low nitrogen levels in the soil. It also competes well with weed (Rahbek Pedersen, 2004). Red clover (*Trifolium arvense*) is established in the cereal crop in the fourth year in order to harvest the seeds the year after. It is opened in the sixth year to establish in spring potato (*Solanum tuberosum*), as the soil warm up. White mustard (*Sinapsis alba*) is seeded as a catch crop. It can have a sanitary effect on beet cyst nematode and capture nutrients during winter (Pålsson, 2006). Sugar beet (*Beta vulgaris*) is seeded in early spring and left to grow on the field until it is harvested in late autumn or winter. In spring of the seventh year spelt wheat (*Triticum spelta*) is seeded with an intercrop of pasture (author).

Table 10. Crop rotation for farming system 2 with the aim of reducing leaching.

Year	Spring	Summer	Autumn	Winter
1	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)
2	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*) + oat (*Poaceae*)	Oat (*Poaceae*) + short fallow	Red fescue (*Poaceae*)	Red fescue (*Poaceae*)
3	Carrot (*Apiaceae*) and celeriac (*Apiaceae*)	Carrot (*Apiaceae*) and celeriac (*Apiaceae*)	Carrot (*Apiaceae*) and celeriac(*Apiaceae)* + winter rye (*Poaceae*)	Winter rye (*Poaceae*)
4	Winter rye (*Poaceae*)	Winter rye (*Poaceae+*) red clover (*Fabaceae*)	Red clover (*Fabaceae*)	Red clover (*Fabaceae*)
5	Red clover to seed (*Fabaceae*)	Red clover to seed (*Fabaceae*)	Red clover to seed (*Fabaceae*)	Red clover (*Fabaceae*)
6	Red clover (*Fabaceae*)+ potato (*Solanaceae*)	Potato (*Solanaceae*)	Potato (*Solanaceae*) + white mustard (*Brassicaceae*)	White mustard (*Brassicaceae*)
7	White mustard (*Brassicaceae*) + sugar beet (*Chenopodiaceae*)	Sugar beet (*Chenopodiaceae*)	Sugar beet (*Chenopodiaceae*)	Sugar beet (*Chenopodiaceae*)
8	Spelt wheat (*Poaceae*)+ ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Spelt wheat (*Poaceae*) + ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Ryegrass (*Poaceae*), chicory (*Asteraceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)

Farming system 3; Weed control in traditionally cereal dominated crop rotation

Climate: Cool autumns and cold winters. Vegetation period starts in February to march and ends in November to December.
Specific area: Northeast and northwest inland, southeast inland.
Identified risks: The frost limits the growth season. Need to control weeds as quack grass and thistle. Aphids and pollen beetle are problematic, as well leaf spots and mildew in cereals.
Assumptions: It is assumed that the farm has access to a local market or fast delivery and sales of fresh greens of a large variety. It is also assumed that the farm have access to machines for the management surrounding each crop.

Comments

Both rhubarb (*Rheum rhabarbarum*) and Globe artichoke (*Cynara scolymus*) are hardy crops with deep taproots that can be combined with the lower growing ryegrass (*Lolium perenne*) at the border zone (author).

The third example starts with the maturation of an established rye (*Secale cereale*), as it is competitive against many weeds, see table 11. Red clover (*Trifolium arvense*), chicory (*Cichorium intybus*), melilot *(Melilotus spp.)*, vetch (*Vicia spp.)* and alfalfa (*Medicago sativa*) is established in the growing main crop and can be cut back several times per season as the thistle is starting to bud. The intentional exclusion of grass in the fallow is due to the susceptibility to mildew and leaf spot diseases in many species (author). The quack grass is effectively decreased by a short fallow in summer after the rhizomes are brought up to the surface to dry out (Rahbek Pedersen, 2008). The winter rapeseed established thereafter, has the potential of absorbing the released nutrients with its deep root system (author). It is intercropped with lavender (*Lavandula angustifolia*), as it has been shown to have repelling effect on the pollen beetle (Cook *et al.* 2007). The lavender flowers are harvested after the rapeseed and thereafter terminated to sow winter wheat. The wheat (*Triticum aestivum*) absorbs access nutrients efficiently after nitrogen mineralizes from the pasture and rapeseed. It is intercropped with white clover (*Trifolium repens*) that continues growing after the main crop is harvested in year five. Strips of clover are opened up to establish the fast growing baby leaf vegetable mâche (V*alerianella locusta*) as an intercrop. The mâche leaves are harvested continuously until the vegetation period stops. The clover pasture is cut in spring in order to control thistle populations in the spring of the sixth year. The seeds from are harvested and the crop continues to grow during the following winter. It is terminated just before the establishment of potato (*Solanum tuberosum*) in the spring of the seventh year (author).

Table 11. Crop rotation 3 for a farming system with emphasis on cereal production and weed control

Year	**Spring**	**Summer**	**Autumn**	**Winter**
1	Winter rye (*Poaceae*)	Winter rye (*Poaceae*) + red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa	Red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)
2	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)
3	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*)	Pasture with red clover (*Fabaceae),* chicory (*Asteraceae*), melilot (*Fabaceae*), vetch (*Fabaceae*) and alfalfa (*Fabaceae*) Short fallow.	Winter rape (*Brassicaceae*) with lavender (*Lamiaceae*)	Winter rape (*Brassicaceae*) with lavender (*Lamiaceae*)
4	Rapeseed (*Brassicaceae*) with lavender (*Lamiaceae*)	Rapeseed (*Brassicaceae*) with lavender (*Lamiaceae*). Short fallow.	Winter wheat (*Poaceae*)	Winter wheat (*Poaceae*)
5	Winter wheat (*Poaceae*) + white clover (*Fabaceae)*	Winter wheat (*Poaceae*) + white clover (*Fabaceae)*	Mâche (*Valerianaceae*) + white clover (*Fabaceae)*	Mâche (*Valerianaceae*) + white clover (*Fabaceae)*
6	White clover (*Fabaceae)* for seed production	White clover (*Fabaceae)* for seed production	White clover (*Fabaceae)*	White clover (*Fabaceae)*
7	White clover (*Fabaceae+)* Potato *(Solanaceae)*	Potato *(Solanaceae)*	Potato *(Solanaceae)*+ winter rye (*Poaceae*)	Winter rye (*Poaceae*)

CONCLUSIONS

Climate is changing and the temperature in Sweden is likely to increase even more than the global mean. Even so, it can be expected that high yields and good quality can be obtained if the agroecosystem is adapted through the introduction of crops that are better suited for a warmer climate, and techniques are adopted to assure long term soil fertility, decreased energy use and clean water.

The four questions asked in the introduction are replied in brief here.

Which climatic changes are we to expect in the different regions of Southern Sweden?
The climate changes in Southern Sweden are expected to give a warmer climate, with the largest effects on winter temperatures. It is expected that periods of heavy rain will be more common, as well as the length of dry spells. Large differences in the extent of the changes are expected in the different regions, mainly due to geographical position. A large difference in local climate can be observed within the regions, due to the features of the landscape and its different components.

How will the scenarios affect the agricultural environment?
Agricultural crops have developed different strategies depending on their origin, which leads to different response to climate change. A prolonged vegetation period and increased CO_2 concentration has been showed to lead to a larger increase in growth and accumulation of biomass for C3 plants and indeterminate crops, than for C4 plants and determinate crops. The possibilities to grow winter crops such as various leaf vegetables will probably increase. Weeds are also expected to have faster maturation cycles and develop increased rhizome growth. Longer periods without precipitation will favour crops, as well as weeds, with a deep root system.

It is expected that many insects, that is both pests and predators, will have a greater number of generation cycles and to winter to a larger extent. A change in species is likely to occur. Aphids are an example of insect species that is expected to have increased generations and an extended active feeding period. As it can be a virus vector the disease is expected to be more frequently occurring. Many fungi species are expected to become more common as autumns are expected to be warmer.

Depending on soil type there is a risk that the expected intense winter rains will lead to water logging, soil erosion and leaching of nutrients.

Are the farmers already preparing and how?

Many of the farmers that took part of the survey were already using catch crops as well as border zone vegetation, and had established marshland to absorb leaching nutrients and slow down soil erosion. Windbreaks hedges were used on some farms to optimize the local climate. Several of the farms grew plants that were used for energy production.

How can we reduce the negative impact on the farming and on the surrounding environment more than what has been done already?

The first step when planning for reducing negative impacts of the climate change is to identify the change in climatic parameters for the farm in question. Based on climatic data, research on expected change in the agroecosystem and the problems experienced in the farms of the survey, three representative scenarios were identified and suggestions for modifications were made.

For areas that are likely to experience an increase in the length of dry spells, crops with deep root systems or other adaptations to draught were introduced. However, a well functioning irrigation system, preferably drip irrigation, will probably be necessary to employ in some crops. As pests are expected to winter, perennial habitats in the agroecosystem for their predators and parasitoids were suggested.

Areas that expect to receive the largest increase in precipitation in winter were suggested to use winter grown crops and catch crops with a deep, or in other ways extensive, root system. Management constrains due to wet soils are expected to be the limiting factor for the establishment of spring grown crops. To achieve additional absorption of nutrients in the field, various deep rooted perennials growing in the border zone were suggested.

The last scenario presented was a crop rotation with various weed, pest and disease problems due to faster and more efficient weed growth and additionally pest and pathogen reproduction in a warmer climate. A mix of cereals, root vegetables, leaf vegetables and pasture was suggested to decrease the populations of many weeds. Various competitive crops with extensive growth both over and under the soil surface were suggested. Actively choosing plants for intercropping and border zones has the potential of favouring natural predators and parasitoids. Crops with better disease resistance were also suggested.

An increasingly high demand of food and energy crops is likely, as many countries already have suboptimal climate for farming and will be less fortuned than the Swedish farms in a warmer climate. It is highly relevant to continue research in the field of specific relationships between host, prey and predator and how this can be used to enhance biodiversity and use ecosystem services for food and energy production as climate is changing. Research in the field of perennial, multi-functional crops in the border zone is of interest for optimizing agriculture. Pasture excluding grasses is yet another area where knowledge is limited at present. The effect on weeds, growth after trimming and C/N content in the harvest depending on composition of species in the pasture are of interest for future research. In order to address relevant problems directly affecting the farms and to reach out with new climate or management information, communication between farmers and researchers is essential. Management practices, which aim to optimise agro ecosystems that are self controlling to a large extent, have the potential to add extra value to the products if consumers are informed.

REFERENCES

Allen, L.H. Jr. (1990) Plant responses to rising carbon dioxide and potential interactions with air pollutants. J. *Environ. Qual.* Chapter 19, Pp. 15–34.

Altieri M (1995) *Agroecology, the science of sustainable agriculture*, Intermediate Technology Publications.

Altieri M.A & Nicholls C.I (1999) Biodiversity in agro ecosystems, *Biodiversity, ecosystem function and insect pest management in agricultural systems*, CRC Press, Florida, U.S.A. Pp. 69-84.

Arheimer B, Andreasson J, Fogelberg S, Jahansson H, Pers C B, Persson K. (2005) Climate Change Impact on Water Quality: Model Results from Southern Sweden, *Ambio,* Vol 34, No 7, pp. 559-566.

Ascard J & Hansson M (2008) *Ekogrönsaksodling*, nr 2, Jordbruksverket. Available only in Swedish.

Askegaard, M. & Eriksen, J. (2008) Residual effect and leaching of N and K in cropping systems with clover and ryegrass catch crops on coarse sand. *Agriculture, Ecosystems and Environment.* Chapter 123, pp. 99-108.

Baldersbrå – råd I praktiken (2005), Jordbruksinformation 14, Statens Jordbruksverk. Available only in Swedish.

Belair G. & Parent L.E. (1996) *Using crop rotation to control Meloidogyne hapla chitwood and improve marketable carrot yield*, Congrès ASHS Annual Meeting N^{o}91, Corvallis, Ore. , ETATS-UNIS (07/08/1994), Canada, chapter 31:1, pp. 29-57 (16 ref.), pp. 106-108.

Bengtsson R (2007) *Ny zonkarta?* Riksförbundet Svensk trädgård, seminar, 2007. Available at the Internet, <www.tradgard.org/ny_zonkarta.pdf>, cited 12.03.2008. Available only in Swedish.

Bioenergiportalen (2008) Available at the Internet <www.bioenergiportalen.se/?p=1499&m=972>, cited 2008.04.03.

Björklund J. (2008) researcher, CUL, Uppsala. Personal communication.

Brandle J.R, Hodges L, Zhou X.H (2004) New vistas in Agroforestry, *Windbreaks in North American agricultural systems,* Kluwer Academic Publishers, Dordrecht, Netherlands. Pp. 65-77

Brisson N., Gervois S., Diaz R. and Benoit M. (2005) Climate change and crop management - Looking towards the past and the future, NJF conference, Odense Denmark

Bunce, J.A. (1994). Responses of respiration to increasing atmospheric carbon dioxide concentrations. *Physiol. Plant.* Chapter 90, pp. 427–430.

Båth B., Stintzing Richert A. & Ögren E (1999) *Växtföljden och odlingssystemet vid ekologisk odling av frilandsgrönsaker*, Jordbruksinformation 20, Jordbruksverket. Available only in Swedish.

Christensen Hesselbjerg J. (2005) Danish Meteorological Institute, Third Japan-EU Workshop on Climate Change Research, Regional Climate Modelling- PRUDENCE and ENSEMBLES, Yokohama

Coakley, S.M., Scherm, H., Chakraborty, S. (1999). Climate change and plant disease management. *Annu. Rev. Phytopathol.* Chapter 37, pp. 399–426.

Cook S. M, Jonsson M., Skellern M.P, Murray D.A, Anderson P, Powell W (2007) Responses of *Phradis* parasitoids to volatiles of lavender, *Lavandula angustifolia* - a possible repellent for their host, *Meligethes aeneus*. *Bio Control*, vol 52, chapter 5, pp. 591-598.

CUL, SLU, available at the Internet <www.cul.slu.se/english/contact/index.asp>, cited 2008-06-07.

Cure J.D, Israel D.W, Rufty T.W. (1988) Nitrogen stress effects on growth and seed yield on nodulated soybean exposure to elevated carbon dioxide, *Crop Science,* chapter 28, pp. 671-677.

Den virtuella floran (2008), available at the Internet <http://linnaeus.nrm.se/flora/> cited 2008.02.01-2008.05.05. Available only in Swedish.

Dicke M, van Loon J.J.A, Schoonhoven L.M. (2006) *Insect-Plant Biology,* 2nd edition, Oxford University Press Inc, New York. P. 421.

Eckersten H., Blombäck K., Kätterer T & Nyman P. (2001) Modelling C, N, water and heat dynamics in winter wheat under climate change in southern Sweden. *Agriculture, Ecosystems and Environment,* chapter 86, pp. 221-235.

Ekelöf J. (2006) *The influence of drip irrigation on potato crop,* bachelor project in horticulture, SLU, Available at the Internet <http://ex-epsilon.slu.se/archive/00001354/>,cited 2008-04-22.

Eswaran H.L, Van den Berg E, Reich P. (1993) Organic carbon in soils of the world, *Soil Sci. Soc. Amer. J.,* chapter 57, pp. 192-194.

Fogelberg F (2007) *Globala kostvanor på lokal nivå-hur avspeglar det sig i svensk odling?,* NJF konference, 2007. Available only in Swedish.

Fågelfors H. (2003) Vägar till hållbar livsmedelsproduktion, seminar in Stockholm arranged by Naturvårdsverket, Mat 21, CUL, SLU, Formas. Available at the Internet <www.mat21.slu.se/publikation/pdf/referatNV.pdf>, cited 2008.05.03. Available only in Swedish.

Grath T. & Håkansson I (1997) *Ärtrotröta problem på packad och fuktig mark,* Fakta Mark/Växter, 5, SLU. Available only in Swedish.

Hansen Monrad L (2005) *Will climate change give rise to increasing pest problems in agricultural crops*? NJF conference, 2005, Odense, Denmark.

Harrison, P.A. & Butterfield, R.E., (1996) Effects of climate change on Europe-wide winter wheat and sunflower productivity. *Clim. Res.,* chapter 7, pp. 225–241.

Hogg D.B & Hoffman G. D (1989) Potato leafhopper population dynamics, *Entomological Society of America,* chapter 72, pp. 26-34.

Hokkanen H.M.T (2006) Phradis morionellus on Meligethes aeneus: long-term patterns of parasitism and impact on pollen beetle populations in Finland. *Bulletin OILB/SROP,* vol 29, chapter 7, pp 187-191.

Holm J. (2000) *Mat, milj och rättvisa,*Förbundet Djurens Rätt, Götene, p. 70. Available only in Swedish.

IPCC (2008) Available at the Internet <www.ipcc.ch/> Cited 2008-03-14

Juhlin Albertsson M.L (2008) Crop production advisor at Hushållningssällskapet, Kristianstad. Personal communication.

Johansson H (2007) Flera orsaker till minskat kväveläckage, *Miljö trender,* nr 4, 2007. Available only in Swedish.

Jordbruksdepartementet (2006). *Ekologisk produktion och konsumtion - Mål och inriktning till 2010,* Skr. 2005/06:88**,** Regeringskansliet. Available at the Internet <http://www.regeringen.se/sb/d/1603/a/61179>, cited 2008-06-07. Available only in Swedish.

Koizumi H, Nakadai T, Ursami Y, Satoh M., Shiyomi M., Oikawa T. (1991) Effect of carbon dioxide concentration on microbial respiration in the soil, *Ecol.Res.* chapter 6, pp. 227-232.

Klimat och sårbarhetsutredningen (2007a), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Chapter 3.5, p. 161. Available only in Swedish.

Klimat och sårbarhetsutredningen (2007b), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Chapter 6.1. Available only in Swedish.

Klimat och sårbarhetsutredningen (2007c), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Chapter 3.5.1. Available only in Swedish.

Klimat och sårbarhetsutredningen (2007d), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Chapter 6.1. Available only in Swedish.

Klimat och sårbarhetsutredningen (2007e), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Chapter 3.5. Available only in Swedish.

Klimat och sårbarhetsutredningen (2007f), Statens offentliga utredningar, Riksdagen. Available at the Internet <www.sou.gov.se/klimatsarbarhet/rapporter.htm>, cited 2008-02-21. Available only in Swedish.

Klimatvariabler (2007), only available in Swedish, available at the Internet, <www.smhi.se/sgn0106/leveranser/index_utr.htm>, cited 2008-06-07. Available only in Swedish.

Lantmäteriverket (2008), Sveriges Geologiska Undersökningar, Jordartskarta, Available at the Internet <www.tanzania.sgu.se/sgu/sv/service/kart-tjanst_start.htm#jord>, cited 2008.05.02. Available only in Swedish.

Larkcom J. (1998) *Oriental vegetables*, 2nd edition, Butler and Tanner Ltd, London, Great Britain, p. 232.

Larsson M. H., Kyllar, K., Jonasson, L. & Johnsson, H. (2005) Estimating Reduction of Nitrogen Leaching from Arable Land and the Related Costs. *Ambio* Vol. 34, No. 7, pp. 538-543

Leendertz L. & England J. (2003) *The garden – Sweet potato (Pomea batatas),* Royal horticultural society, Great Britain. Available at the Internet <www.rhs.org.uk/Learning/Publications/pubs/garden0303/rootveg.htm >, cited 2008.05.05.

Long, S. P. (1991) Modification of the response of photosynthetic productivity to rising temperature by atmospheric $C0_2$ concentrations: Has its importance been underestimated? *Plant Cell Envir.* Chapter 14, pp. 729-739.

Mahboubi A.A, Lal R., Faussey N.R (1993) Twenty-eight years of tillage effects on two soils in Ohio, *Soil Sci. Soc. Amer. J., chapter* 57, pp. 507-512.

Mattsson L, Ulén B, Aronsson H, Torstensson G (2004) Svårt förutsäga utlakning i växtföljder, *Fakta jordbruk,* nr 11. Available only in Swedish.

Mayse M.A. (1983) Cultural control in Crop Fields: A Habitat Management Technique**,** *Environmental Management*, chapter 5:1, pp. 15-22.

Mosier A.R., (1997) Soil processes and global change. *Biol. Fertil. Soils,* chapter 27, pp. 221–229.

Nonnecke Libner I.B. (1989) *Vegetable production,* Van Nostrand Reinhold, New York, p. 657

Nätterlund H. (2006) *Åtgärder för att hindra ytvattenerosion*, Greppa näringen, HIR Malmöhus, Hushållningssällskapet. Available only in Swedish.

Olesen J. E & Bindi M (2002) Consequences of climate change for European agricultural productivity, land use and policy, *European Journal of Agronomy,* chapter 16, pp. 239-262.

Olesen J.E., Jensen T., Petersen J., (2000) Sensitivity of field-scale winter wheat production in Denmark to climate variability and climate change. *Clim. Res.*, chapter 15, pp. 221–238.

Olesen, J.E. & Mikkelsen, S.A., (1985) A meteorological model for calculating the moisture content of ripe spring barley. Part II: model results. *Acta Agric.Scand.*, chapter 35, pp. 369–374

Patterson D.T, Westbrook J.K, Joyce R.J.V, Lindgren P.D and Rogasik J. (1999) Weeds, insects and diseases, *Climatic change*, chapter 43, pp. 711-729

Patterson, D.T., (1995) Weeds in a changing climate. *Weed Sci.*, chapter 43, pp. 685–701.

Philips R. & Rix M. (1995) *Vegetables*, Macmillan Reference Books, London.

Porter, J.R. & Gawith, M. (1999). Temperatures and the growth and development of wheat: a review. *Eur. J. Agron.*, chapter 10, pp. 23–36.

Pålsson O. (2006) Senap och rättika som fånggrödor, Jordbruksverket, Jönköping. Available only in Swedish.

Rahbek Pedersen T. & Dock Gustavsson A.M (2007) Rotogräs-råd I praktiken, Jordbruksinformation 2, Statens Jordbruksverk. Available only in Swedish.

Rahbek Pedersen T. (2004) *Odlingsbeskrivningar – Spannmål.* Kurspärmen ”Ekologisk växtodling”, Jordbruksverket. Available only in Swedish.

Reilly J. M. (1999) Climate change and agriculture: the state of the scientific knowledge, *Climate change*, chapter 43, pp. 645-650

Rounsevell, M.D.A., Evans, S.P., Bullock, P. (1999). Climate change and agricultural soils: impacts and adaptation. *Clim. Change* chapter 43, pp. 683–709

Rounsevell, M.D.A., Brignall, A.P., Siddons, P.A. (1996) Potential climate change effects on the distribution of agricultural grassland in England and Wales. *Soil Use Manage.*, chapter 12, pp. 44–51.

Rummukainen M. (2008), professor in meteorology and climate expert, Rossby centre, SMHI. Personal communication.

Rötter R. & Van de Gejin S.C. (1999) Climate change effects on plant growth, crop yield and livestock, *Climatic change*, chapter 43, pp. 651-681.

SCB (2008), Statistiska central byrån, *Åkermarkens användande 2006*, Available at the Internet <www.scb.se/templates/tableOrChart____37583.asp>, cited 2008.05.10, last revised 2007.07.11. Available only in Swedish.

Schindler D (2002) 'Ecology' in Campell N & Reece J. B. (2002) *Biology*, pp. 1198-1221.

Scholz V & Ellerbrock R (2002) The growth productivity, and environmental impact of the cultivation of energy crops on sandy soil in Germany, *Biomass and Bioenergy*, chapter 23, pp. 81-92.

Sigvald R (2001) *Miljötrender*, nr 3-4. Skadedjurs eventuella ökning vid klimatförändring. Available only in Swedish.

Sionit N., Strain B. R. & Beckford H.A (1981) Environmental controls on the growth and yield of okra. I. Effects of temperature and of CO2 enrichment at cool temperature, *Crop Sci.*, chapter 21, pp. 885-888.

Sleutel S., De neve A., Hofman G. (2007) Assessing causes of recent organic carbon losses from cropland soils by means of regional-scaled input balances for the case of Flanders (Belgium), *Nutr. Cycl. Agroecosyst.*, chapter 78, pp. 265-278.

SMHI (2008) Availiable at the Internet <www.smhi.se>, Cited: 2008.01.20.

Smith, P., Powlson, D.S., Smith, J.U., Falloon, P.D., Coleman, K., (2000). Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. *Global Change Biol.*, chapter 6, pp. 525–539.

Soane, B.D. & van Ouwerkerk, C. (Eds.), (1994). Soil compaction in crop production. *Developments in Agricultural Engineering,* vol. 11. Elsevier, Amsterdam.

Southwood & Comins (1976) A synoptic population model, *The journal of animal ecology,* chapter 45, no 3, pp. 949-965.

Statens utsädeskontroll (2004) Fältbesiktningspärm, *Ogräsproblematik-svårrensade ogräs.* Available only in Swedish.

Svensk Växtkraft AB (2005) *Biogas i tanken – ett naturligt val,* Västerås. Available at the Internet <www.vafabmiljo.se/filarkiv/Pdf/vk2.pdf>, cited 2008.05.10.

Söderberg T, Bång M., Ericson A., Eriksson L., Hamilton C., Linderholm K., Norell B., Rydberg I. and Sjödahl M. (2006) *Miljöeffekter av träda och olika växtföljder – rapport från projektet CAP:s miljöeffekter*, Jordbruks verket, Rapport 2006:4. Available only in Swedish.

Tans P, (2008) National Oceanic and Atmospheric Administration, Earth system research laboratory, USA. Available at the Internet <http://www.esrl.noaa.gov/gmd/ccgg/trends/>, cited 2008.05.21.

Thompson T (1993) The effect of host carbon dioxide, nitrogen and water supply on the infection of wheat by powdery mildew, *Plant cell environment,* chapter 16, pp. 687-94

Teasdale J. R, Mangum R.W., Radhakrishnan J. & Cavigelli M.A (2004) Weed seedbank dynamics in three organic farming crop rotations, *Agron. J.*, chapter 96, pp. 1429-1435.

Teiz & Zeiger (2002) *Plant Physiology,* 3rd edition, Sinauer Associates INC, Sunderland, USA. P. 690.

Triltsch H, Freiber B, Rossberg D (1996) Temperatur-Schlüsselfaktor für Nutzlingsleistungen im Wintereizen? *Mitt. Biol. Bundesanst. Land Forstwirtsch.* 321:447 (abstr.) in Coakley, S.M., Scherm, H., Chakraborty, S. (1999). Climate change and plant disease management. Annu. Rev. Phytopathol., chapter 37, pp. 399–426.

Tubiello, F.N., Donatelli, M., Rosenzweig, C., Stockle, C.O., (1999). Effects of climate change and elevated CO2 on cropping systems: model predictions at two Italian locations. *Eur. J. Agron.*, chapter 13, pp. 179–189.

Ulén, B (2002) Svävande partiklar för fosforn till havet. *Fakta Jordbruk*, nr 6. SLU, Uppsala. Available only in Swedish.

Wäckers F. L. (2004) Assessing the suitability of flowering herbs as parasitoid food sources: flower attractiveness and nectar accessibility, *Biological control,* chapter 29:3, pp. 307-314.

Öberg S. (2007) Spiders in the Agricultural Landscape- Diversity, Recolonisation, and Body Condition, doctoral thesis, Faculty of Natural Resources and Agricultural Sciences, Department of Ecology, Uppsala, *Acta Universitatis Agriculturae Sueciae,* 2007: 25.

Ögren E. (2008) advisor in agriculture, Hushållningssällskapet. Personal communication.

Öhberg H. (2008) *Studies of the persistence of red clover cultivars in Sweden – with particular reference to Sclerotinia trifolium***,** doctoral thesis. Faculty of natural resources and Agricultural science, Department of Agricultural Research for Northern Sweden, Umeå.

APPENDIX 1.

Questionnaire for farmers or personnel at research stations in Götaland

Namn:

Gatuadress:

Postnummer & ort:

Telefonnummer:

A. Grödor

Gårdens totala areal odlad mark (ha): ______________________________

Välj ett skifte och beskriv växtföljden ut på gården (ange art, sort och användningsområde)? Om det finns fler än en växtföljd anteckna de övriga på separat papper.

2008______________________________
2007______________________________
2006______________________________
2005______________________________
2004______________________________
2003______________________________
2002______________________________

Kommentera gärna varför ni valt att lägga upp växtföljden i den angivna ordningen. Tex markburna sjukdomar, ogrässanerande effekt, kväveberikande, mullhaltshöjande etc.

Odlas grödor som inte ingår i växtföljden? Ange även perenna grödor.

Finns läplanteringar (ange art)? ______________________________

Ogräs

Vilka är de svåraste ogräsen i odlingen (ange arter)?

Vilka grödor har de största ogräsproblemen?

____

____

Har problemogräsen förändrats jämfört med för ca 10 år sedan?

____

____

Sjukdomar och skadedjur

Vilka sjukdomar och skadedjur är problem i de olika grödorna i växtföljden?

____

____

____

____

____

____

____

____

Har problembilden förändrats jämfört med för ca 10 år sedan?

____

____

Jordmån och gödsling

Vilken jordmån dominerar? Finns stor variation mellan skiftena?

____

Har markkartering gjorts? ____________________År för analys?______________________

Vilka är de högsta respektive lägsta värdena för de olika ämnena och pH på gårdens skiften?

P-Al:______________________________K-Al: ________________________________

pH:______________________________

Vilken typ av gödsel används?____

____

____

Utlakning

Används fånggrödor eller mellangrödor för att minska utlakning? ______________________

Om ja, vilka är de (art, sort)?

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Har de inneburit något problem?

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____

Används ogödslade kantzoner för att minska utlakning?__________Bredd? _____________

Odlas kantzonen (ange art och sort) eller är den av vild ängsmarks karaktär?

____

Bevattning

Finns möjlighet till bevattning? ______________________________

Vilken teknik används, tex ramp, kanon eller dropp?

____

Hur mäts bevattningsbehovet? ______________________________

B. Energigrödor*

Om energigrödor ingår, vilka är de (ange art och sort)?

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____

Hur används grödan?

____

Odlas energigrödor på ordinarie odlingsmark eller för annan odlin olämplig mark (tex översvämnings- eller stenig mark)?

____

Har ni upplevt några problem i odlingen?

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*Definitionen av en energigröda i den här enkäten är en växt som odlas med avsikt att någon del av plantan kommer användas för biogas-, etanol- metanolproduktion, förbränning, fastbränsle eller liknande. Den kan vara både perenn och annuell.

C. Framtid

Fungerar dagens växtföljd/er eller finns det behov av utveckling för att minska återkommande problem?

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____

Finns det behov av att optimera gödslingen ytterligare?

____

____

Skulle det vara av intresse att odla nya ätbara grödor som är mer lämpade för torka eller tidvis översvämning?______________________________

Om ja, gäller detta även för en perenn gröda?

____

Om energigrödor inte redan odlas, är det av intresse att införa dem i odlingssystemet?

____

Har du något övrigt att tillägga?

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