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Horticultural cropping systems meet scenarios of changing climate

by

Klara Ekengard

Fakulteten för landskapsplanering, trädgårds- och jordbruksvetenskap

SLU-Alnarp

ABSTRACT 3

SAMMANFATTNING 4

1 INTRODUCTION 5

1.1 BACKGROUND 5
1.2 METHOD 5

2 GLOBAL WARMING – FUTURE SCENARIOS 6

2.1 CLIMATE SCENARIO 6
2.1.1 GLOBAL PERSPECTIVE 6
2.1.2 CLIMATE IN SWEDEN 2080 7
2.2 EFFECTS FOR HORTICULTURE AND AGRICULTURE 8

3 PLANT PHYSIOLOGICAL RESPONSE 11

3.1 CARBON DIOXIDE 11
3.1.1 CARBON DIOXIDE UPTAKE – THE CELL LEVEL 11
3.1.2 EFFECTS FOR PLANT GROWTH – THE PLANT LEVEL 14
3.2 WATER AVAILABILITY 16
3.2.1 WATER IN PHOTOSYNTHETIC REACTIONS –THE CELL AND PLANT LEVEL 16
3.3 TEMPERATURE 17
3.3.1 PHOTOSYNTHESIS – THE CELL LEVEL 17
3.3.2 PLANT GROWTH AND DEVELOPMENT – THE PLANT LEVEL 17
3.3.3 TEMPERATURE STRESS AND WATER STRESS – HEAT, WATER DEFICIT AND FLOODING 18
3.4 EFFECTS FOR CROP YIELD – THE CANOPY LEVEL 19

4 PEA AND STRAWBERRY PRODUCTION IN A CHANGING CLIMATE 22

4.1 PEAS 22
4.2 STRAWBERRIES 24

5 DISCUSSION AND CONCLUSIONS 28

6 REFERENCES 31

Abstract

This Bsc thesis describes the consequences of a changing climate for Swedish horticultural production on a basis of a literature survey. Climate scenarios from the Swedish governmental inquiry about climate change, SOU 2007:60, are related to Swedish production of peas and strawberries. Plant physiological factors affected by carbon dioxide (CO_2), temperature and water availability are used to explain growing prerequisites.

The general scenario used is:

- more yield per hectare and possibilities to grow new products
- growing season will be longer
- amount of precipitation will increase in most parts of the country but in southern Sweden summers will be dry
- more insects and pathogens will be problems in production
- weeds will experience better growing circumstances
- quality of the product will be affected by pest management and growing velocity
- risk of plant nutrient leakage will increase

Future climate will affect Swedish production of peas and strawberries. To some extent the explanation for this is to be found in plant physiology, but cropping systems are too complex to give easy solutions. Increase in yield due to temperature rise and CO_2 level, predicted by SOU 2007:60, is possible but uncertain in many crops. More research is needed. Water will be limiting in southern Sweden but wet soils can be problematic in other parts. Growing another cultivar or product are good possibilities adjusting to temperature and amount of precipitation. Pea production could move further north in Sweden and more cultivars can be suitable in strawberry production.

Climate change will be fast in a historical perspective but awareness in today’s society gives good possibilities to develop cropping systems continuously when climatic conditions change.

Sammanfattning

När klimatet i Sverige förändras får det konsekvenser för svensk odling. I denna litteraturstudie används scenarion från Klimat- och sårbarhetsutredningens rapport, SOU 2007:60 för att undersöka effekt på produktionen av två trädgårdsprodukter. Produktionssystemen för gröna ärtor och jordgubbar ställs i relation till de förutspådda förändringarna. De växtfysiologiska faktorerna CO_2, temperatur och tillgänglighet av vatten används för att försöka förklara de förändringar som väntar.

Det scenario från SOU 2007:60 som används är:

- ökad skörd och möjlighet att odla nya typer av grödor
- odlingssäsongen kommer att bli längre
- nederbördsmängderna kommer att öka i hela Sverige men sommaren i Skåne blir torr
- nya insekter och sjukdomar kommer att trivas i det nya klimatet
- kvaliteten på produkterna påverkas av såväl växtskyddsåtgärder som ökad tillväxthastighet
- risken för växtnäringsläckage ökar

Både jordgubbs- och ärtproduktionen kommer med stor sannolikhet bli påverkad av nya klimatförutsättningar. Delar av de effekter som väntas går att förklara med växtfysiologi, men odlingsförhållanden är generellt för komplexa för att kunna ge ett enkelt svar. Den ökade skörden som klimat- och sårbarhetsutredningen förutspår är möjlig, men det är fortfarande ovisst för många produkter. Mer forskning behövs inom det här området. Tillgång på vatten kommer att begränsa odlingsmöjligheterna i södra Sverige medan blöta jordar kommer att ge begränsningar i andra delar av landet. I jordgubbsodlingen finns det möjlighet att anpassa produktionen med nya sorter. Ärtproduktionen kan eventuellt flytta längre norrut i Sverige och därmed ha ett mer gynnsamt klimat. Nya typer av produkter kommer också att vara möjligt.

De snabba förändringar som nu diskuteras är snabba i ett historiskt perspektiv. Det allmänna medvetandet om klimatförändringarna som finns i samhället ger oss goda förutsättningar att kontinuerligt förändra odlingssystemen.

1 Introduction

1.1 Background

This report describes the consequences of a changing climate for Swedish horticultural production. Climate change is not discussed as a variable but as a fact based on the scenarios used of the Swedish governmental inquiry Sweden facing climate change– threats and opportunities (SOU 2007:60). The climatic factors discussed are carbon dioxide (CO_2) level, temperature and precipitation.

The factors from the inquiry are described from the plant's photosynthetic perspective. The effect on parts of photosynthesis, and thereby on plant growth, that concern CO_2, temperature change and water availability is in focus. The aim of describing these factors is to understand the plant's physiological limitations and further the possibilities and challenges for crop production.

The study discusses if it is possible to explain suitability of a crop to the present climate with physiology. In what way does the crop cope with increased CO_2 level? What is the role of water and temperature in plant growth and how is the plant affected by flooding and drought? In general the study dwells into the physiological reasons for the predictions made in SOU 2007:60 and their relevance for horticultural production?

The photosynthetic response of climate change is discussed in the context of two valuable horticultural Swedish outdoor crops, peas and strawberries. The effects on yield and production are interesting for the producer. The case study is further important in putting the effect of global warming into perspective for the consumer. Quality, expressed as outer and inner quality, and timing of produce are important when discussing these crops.

1.2 Method

This report is a literature study based on research of plant responses to climatic factors.

2 Global warming – future scenarios

There is no longer any doubt that the temperature and the concentration of carbon dioxide of the world are rising. However it should be emphasized that predictions about the extent of global warming are insecure. There is consensus that there will be substantial effects even if the predictions in the debate about size and consequences deviate.

2.1 Climate scenario

2.1.1 Global perspective

The energy balance of the climate system is changed by concentration of greenhouse gases (for example carbon dioxide, methane and nitrous oxide) in the atmosphere, land-cover and solar radiation. Between 1970 and 2004 the emission of greenhouse gases made by human activity has increased by 70%. Carbon dioxide (CO_2) is the most important greenhouse gas. The emission of CO_2 rose by 80% between 1970 and 2004. Other important greenhouse gases, methane (CH_4) and nitrous oxide (N_2O) have also increased as a result of human activity. Emission of the second most important greenhouse gas, methane, comes from both human activity and wetlands (Bernstein et al. 2007, SOU 2007:60).

Atmospheric concentration of CO_2 was 379 ppm in 2005. This can be compared with 280 ppm around 1850 when human emission was low. Average temperature increase is very likely dependent on emission of greenhouse gases. It is further very likely that this has influenced biological systems. The uncertainty of the impact is due to lack of long-term studies. According to IPCC (the UN intergovernmental panel on climate change) CO_2 concentration is most likely continuing to go up but it will depend on present activities to reduce emission. Predictions are therefore insecure. The higher concentrations will most likely have larger effect in the future than seen during the 20th century. Even if emission of CO_2 is reduced, temperature increase will continue. Global warming also affects the weather with changed pattern of precipitation and winds (Bernstein et al. 2007).

2.1.2 Climate in Sweden 2080

General scenario:

CO_2 level in the atmosphere ↑

Average temperature ↑

Amount of precipitation ↑ (↓)

All predictions in this chapter (2.1.2 and 2.2) about Swedish future climate are from Sweden facing climate change– threats and opportunities, SOU 2007:60.

Predictions about the future are dependent on different scenarios concerning CO_2 concentration and what measures taken by society to reduce emission of greenhouse gases. Data from the period 1960-1990 is according to international decisions used as a reference period and compared to that period, average temperature in Sweden in 2080 will be 3-5 °C higher. Average temperature change will be larger in Sweden than the global average. Temperature rise will be unevenly spread during the year and throughout the country. It will be biggest during winter time. The total climate change will lead to a shift in climate zones further north.

Together with temperature rise, pattern for precipitation will change towards higher amounts of precipitation over the country. During winter time, precipitation in some areas will be more than the doubled, year 2080 as compared to 1960-1990. Days with heavy rain will be more common during wintertime and especially in Western parts of the country. With heavy raining, high water levels in rivers and lakes follows. Flooding will be more common in these parts.

Factors changing for specific regions:
Southern Sweden
Higher summer temperatures than today are expected in Southern Sweden and in costal areas around the Baltic Sea. In Southern Sweden precipitation will increase during fall, winter and spring, in contrast, summers will be drier. Days with extreme temperatures can be a problem and heat waves occur more often. Tropical nights will be more common. Snow will be very rare.

Northern Sweden

In Northern Eastern Sweden, average temperature will rise about 7 °C. The change is greater than average due to less snow in wintertime. Snowfall will to a large extent be replaced by rain. Amount of precipitation will be larger all year around.

Middle Sweden

For the middle of Sweden it is predicted that climate will resemble to Northern France today. Temperature during spring and fall will increase more than in the rest of the country during this season.
(SOU 2007:60).

2.2 Effects for horticulture and agriculture

General scenario:
More yield, new products ↑
Longer growing season ↑
Precipitation ↑ ↓
Problems with plant protection ↑
Problems with weeds ↑
Quality ↑ ↓
Plant nutrition leakage ↑

Compared with countries with spreading deserts or flooding the effects of climate change in Sweden will be small. According to SOU 2007:60, changes will have large effect on Swedish horticulture and agriculture. Following part will briefly present the predictions from the study on the effects on agriculture. Some of these predictions will later be discussed in relation to the case study in chapter 4.

Use of land

Sweden will probably have more competitive growing conditions. Yields per hectare will increase. Crops such as sunflower and maize may be possible in larger scale when temperature is rising. Calculations about land use are however uncertain due to difficulties in predicting demographic changes and technological advances.

Growing season

The period with temperature allowing plant growth will generally be prolonged in Sweden. Spring will be early and fall season will be longer due to higher temperature. Spring tillage will however be determined by the amount of water in the soil. Generally spring tillage will start at the beginning of March in southern Sweden, end of March in the central parts and in April in Northern Sweden. The model scenarios predict that spring sown crops will be ready for harvest three weeks earlier than today. Winter grown crops will be beneficial since growing period will start earlier than spring tillage will be possible.

Water supply

Changes in precipitation for different regions in Sweden are briefly described above. Water supply is calculated at the basis of both precipitation and other external factors, such as temperature. The total climate picture is therefore important considering water supply for the plant. There are great regional differences in predictions of precipitation. The amount of water needed by the plant is dependent on CO_2 level and temperature and will be further discussed in chapter 3.

Plant growth in Sweden will not generally be limited by water supply. In southern Sweden precipitation in summer periods is reduced and simulations show an increased future need of irrigation of field crops. In horticulture, irrigation systems are already in use, but production could be limited by the total water availability and water quality. New technique is needed to purify and stock water in order to even out seasonal variation.

Plant protection

Crop pest will be affected by changing climate. Higher temperature and prolonged growing season will benefit insects as well as some fungal plant pathogens. Insects will be favored by having a better life cycle with more generations every season. Adult insects will have better possibilities to survive the warmer Swedish winters. Increased virus damages are mainly due to the amount of insects as vectors but also due to lower plant tolerability when they are exposed to other stresses. New species of insects as well as fungi and viruses will be established in Sweden. Fungal problems may be reduced in southern parts of Sweden due to a dryer climate. More pesticides or other restricting methods will be necessary. Virus-free crops will be difficult to maintain and seed reservation areas may be necessary to protect commercial crops. The new pest and pathogen situation can be solved with cropping technology, resistant varieties and good crop rotation. These activities will be central in activity to prevent spread of diseases and as an alternative to pesticide use.

Weed

Growing conditions for weeds as well as for crops plants will be improved. With prolonged growing season more generations per year are possible. In spring, wet soils will not allow tillage at the same time as temperature is signaling growing to plants. This supports weed establishment and thereby competition with crop production will be favoured. More weed species will be found in Sweden and a warmer winter climate will allow over winter growing. Weed problems can be affected by future crop choices.

Quality

Pest management, growing velocity and effects of climate in different growing stages will affect future product quality. More severe pest problem can lead to more extensive use of chemicals in production. Favourable growing conditions can enhance growth and may reduce nutrient content in the product. Timing of harvest has to be recalculated due to changing factors.

Plant nutrition leakage

Leakage of both nitrogen and phosphorus will most likely increase with changing climate conditions. More precipitation together with a higher nutrient demand due to more rapid development and thereby higher fertilizer use can lead to a greater risk of leaking. Different scenarios claim leakage 10-70 % higher compared to today's depending on location and climate. Since reduced nutrient leakage from agricultural land is a main governmental climate goal, this will challenge crop production.

Light

The level of particles in the atmosphere has increased due to emission of sulphur and soot combustion. A higher amount of particles in the atmosphere will cool the temperature and can reduce radiation. Radiation and photoperiod is mainly due to the planets position to the sun. This is not expected to change (SOU 2007:60).

This report will not discuss the insecurity of the climate scenarios or the reasons to the changes but will use the scenarios as reference background. Complementary data are discussed in conclusions of the study.

3 Plant physiological response

CO_2, water availability and temperature are well known factors affecting photosynthesis and plant growth. If these factors are scarce there is risk of plant stress leading to reduced growth and predisposition to pathogen attack. These factors are not independent but interact with each other and also with other external factors affecting plant growth.

In this chapter physiology relevant to CO_2 concentration in air, to water availability and to temperature changes are described. The descriptions are limited to physiology concerning photosynthesis and to consequences from climate change.

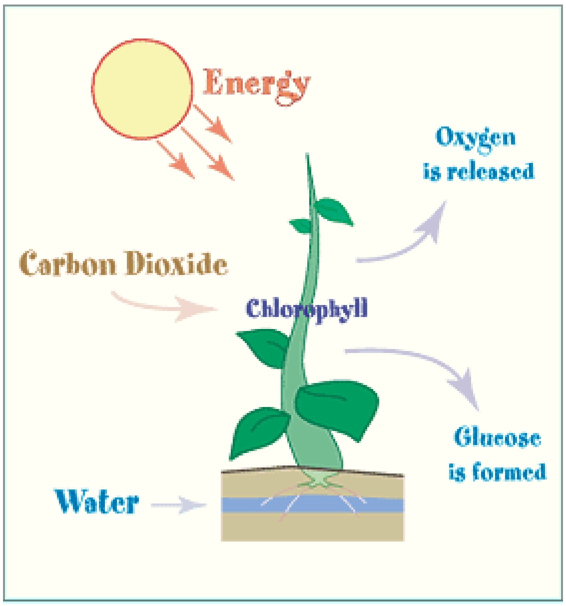


Figure 1. Basic photosynthesis (factmonster 080227)

3.1 Carbon dioxide

Carbon dioxide is a limiting factor of photosynthesis and is therefore an essential factor in plant surrounding. Function of the carbon cycle divide plants in C_3, C_4 and CAM plants depending on which mechanism the plant uses to convert CO_2 into sucrose and starch. Importance of concentration of CO_2 depends on type of mechanism. CAM plants are primarily desert plants (Larcher 1995:61-71, 95).

3.1.1 Carbon dioxide uptake – the cell level

Carbon dioxide entering plant through stomata depends on concentration gradient in the plant and in the air (Larcher 1995:95). CO_2 diffuses from stomata through intercellular air spaces with destination of the cell and chloroplasts. CO_2 move from the air into the plant and further to the carboxylation site of the enzyme rubisco trough gaseous phases, liquid phases and several membranes (Taiz & Zeiger 2002:183-184). Temperature, hydration of the protoplasm, supply of minerals, developmental stage and activity of the plant affect how efficient carbon is transformed (Larcher 1995:62). Same path used of $CO_{2,}$ is used by water traveling the opposite direction. The dilemma for the plant is to take up as much CO_2 as possible through the complex pathway without loosing too much water. This is complicated since air has much lower concentration gradient than the plant and this result in loss of water. The plant tries to solve this by regulating opening of stomata (Taiz & Zeiger 2002:183-184).

Physiology of C_3

The reduction of CO_2 to carbohydrates is common for all eukaryotes. The process for C_3 plants is called the Calvin cycle or the reductive pentose phosphate cycle.

During the *first step* of the Calvin cycle, the carboxylation, CO_2 molecules are linked to a carbon skeleton assisted by rubisco. Rubisco is also a factor in oxygenating RuBP in the process called photorespiration and is therefore a limiting factor. In the *second step*, energy from the light reactions is used in reduction of 3-phosphoglycerate to glyceraldehyde-3-phosphate that is the base for synthesis of sucrose and starch. The *last step* regenerates ribulose-1,5-bisphosphate to enable uptake of more CO_2 (Taiz & Zeiger 2002:146-152). 95% of terrestrial species are C_3 plants (Bowes 1993).

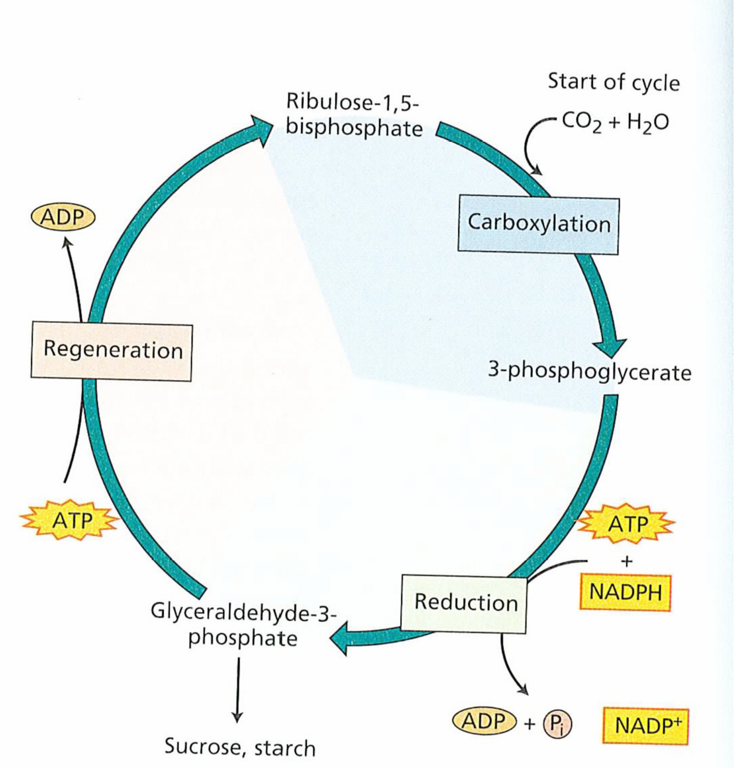


Figure 2. Calvin cycle (Taiz & Zeiger 2002:146)

Photorespiration

Photosynthesis and the reaction of photorespiration work in opposite reactions. Photorespiration occurs since rubisco is able to bind with both O_2 and CO_2 depending on concentration. The effect of photorespiration depends on external factors as air concentrations. High O_2 and low CO_2 favor photorespiration. Photosynthetic carbon fixation is estimated to be reduced from 90% to 50% by photorespiration. Photorespiration should be separated from dark respiration that occurs in all plants and animals consuming O_2 (Taiz & Zeiger 2002:152-155, Hay & Porter 2006:74).

Physiology of C_4

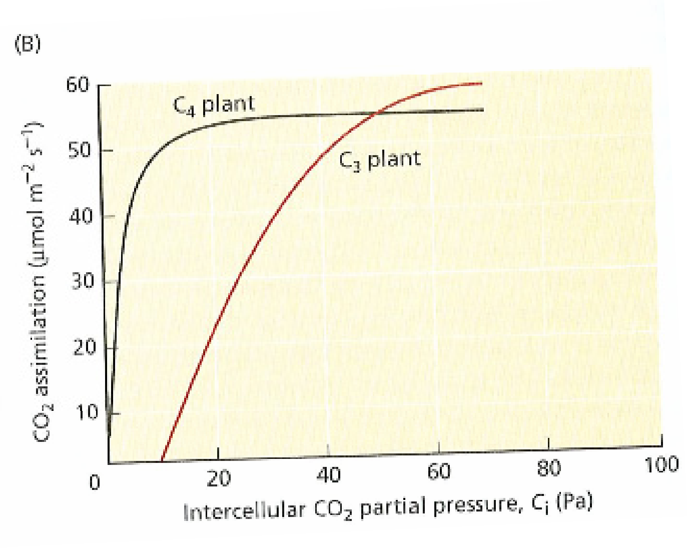
The C_4 photosynthetic carbon assimilation cycle is an "add on" to the Calvin cycle described for C_3 (Taiz & Zeiger 2002:146). The C_4 plants lack photorespiration but have normal rubisco. Differences between C_3 and C_4 become clear when examining leaf anatomy. Besides mesophyll cells with chloroplasts, C_4 plants also have bundle sheath cells. Both are necessary for carbon reactions and are interconnected by plasmodesmata. In the *first step* of the C_4 cycle, CO_2 is fixed by carboxylation of phosphoenolpyruvate in the mesophyll cells to form a four carbon (C_4) acid. In the *second step* the C_4 acids are transported to the bundle sheath cells. Reduction of CO_2 to carbohydrates occurs in the *third step* where C_4 acids are decarboxylated into CO_2. In the *last step* remaining C_3 acid is transported back to mesophyll cells to enable fixation of new CO_2.

This process results in much higher concentration of CO_2 in the bundle sheath cells than would be equilibrium with the atmosphere. When CO_2 concentration is elevated rubisco becomes occupied with CO_2 and photorespiration is reduced. C_4 plants need more energy for the carbon reactions and require therefore more light (Taiz & Zeiger 2002:156-160). 1% of terrestrial species are C_4 plants (Bowes 1993).

Saturation curves/ optimum curves

When evaluating the limitations of low concentration of CO_2, photosynthetic rate is expressed as a function of CO_2 pressure. The pressure is measured in the intercellular spaces of the leaf. Photosynthesis is limited by a very low CO_2 concentration. Respiration of the plant remains the same resulting in negative balance where the plant is producing more CO_2 than it takes up. When uptake is same as respiration rate it is called the compensation point. How plants react to higher CO_2 level than the compensation point differs between C_3 and C_4 plants. It is by this function importance of physiological differences between carbon cycles becomes clear (Taiz & Zeiger 2002:186-187).

C_3 plants have a slower increase in CO_2 assimilation when CO_2 concentration is increasing. Photosynthesis is limited at high concentrations by the third step in the Calvin cycle where ribulose-1,5-bisphosphate is generated to slow. C_4 plants reach saturation of CO_2 uptake at a much earlier stage. This is due to higher efficiency in making use of the existing CO_2. In a low concentration CO_2 environment this is favorable.



The compensation point of C_4 plants are lower than for C_3 plants since photorespiration is very low (Taiz & Zeiger 2002:186-187). How plants react to changes in environmental conditions depends on these physiological differences. Most agricultural crops are C_3 plants. Examples of C_4 plants are sugarcane, maize and sunflowers (Hay & Porter 2006).

Figure 3. CO_2 response curves (Taiz & Zeiger 2002: 186)

Other gases
Ozone (O_3) is harmful in lower atmosphere and is a result of human pollution. The molecule releases free radicals harmful for cell and organelle membranes. Even low levels of O_3 reduces yield but effect is species dependent. Elevated CO_2 level may protect against ozone when reducing stomatal conductance and could even prevent yield losses (Hay & Porter 2006:115-116).

3.1.2 Effects for plant growth – the plant level

With the atmospheric concentration of today, CO_2 is limiting photosynthesis for C_3 plants. Today's vegetation is restricted by the CO_2 concentration to only 60-70% of the photosynthetic potential (Bowes 1993).

Experiments and use of CO_2 fertilization proves that it is possible to increase yield by about three times. Increasing supply leads to faster growth and more biomass production. Stomata open less widely in the CO_2 rich environment leading to less water lost by evaporation. Negative effects can be seen when chloroplasts are overfilled with starch or leafs become hypertrophy (cells enlarge). The higher growth rate may lead to fewer flowers and smaller fruits when nitrogen uptake is slower or N supply is too small. This imbalance can lead to stress for the plant (Larcher 1995:442-443). The estimations show that despite the problems dry mass production will be favored by the higher level of CO_2 (SOU 2007:60, Larcher 1995:443).

For C_3 plants, more CO_2 in the atmosphere raises photosynthetic activity despite of the plants' own limitations. At low concentrations, efficiency of rubisco and its carboxylation activity reduces photosynthesis, while use of a higher concentration is limited by the efficiency of the Calvin cycle. The C_3 plants' strategy is to keep CO_2 uptake at a "in between" level by adjusting stomatal conductance. Higher concentrations of CO_2 keep stimulating photosynthesis (Taiz & Zeiger 2002:186-187). C_3 plants loose about 25% of CO_2 in photorespiration. This loss can be reduced by 50% when the concentration in the atmosphere is doubled. Such increase will have a very little effect on C_4 plants (Bowes 1993).

The effect of elevated CO_2 level has been studied on many crops and with the aspect of various physiological responses. In soybeans it has been shown that elevated CO_2 level gives a bigger total biomass than during normal environment. The study claims that antioxidant activity is down regulated during high CO_2. This is suggested to result in reduced capacity to handle stress situations for the plant. Lower stress capacity could be a problem in case of a pathogen infection (Pritchard *et al*. 2000).

Stress physiology

No growing site is totally free from stress and stressing factors are a natural part of the plants life. To maintain the normal functions under stress, plants must spend extra energy which otherwise would been used in dry matter production and growth. Acclimatization processes reduce time available for carbon assimilation and photosynthesis. The protective response of the plant against stress is a way to compromise between biomass formation and survival (Larcher 1995:326-331). Stress functions will be discussed in chapter 3.3.3.

3.2 Water availability

3.2.1 Water in photosynthetic reactions –the cell and plant level

Water is needed in the plant both for growth (photosynthesis) and hydration of the plant. Unlike other organisms the plant can not escape changes in the environment. The plant exists in a “soil-plant-atmosphere continuum” (Taiz & Zeiger 2002:62). Water is essential in all these parts. The movement of water surrounding the plant is depending on the physical forces: diffusion, bulk flow and osmosis. Base for function of these forces is the water potential (Taiz & Zeiger 2002:62-64). Water is essential in the plant for several processes including internal hydrostatic pressure, (turgor pressure needed for cell enlargement), nutrient uptake and transport, gas exchange in the leaf, transport in the phloem and transport across membranes (Taiz & Zeiger 2002:34).

When water reserves of the soil are declining, the plant is gradually forced to take action to prevent dehydration. Plant response to drought is reducing degree and duration of stomatal opening. When soil is drying, the plant sends a signal by abscisic acid from the roots to leaves to close stomata. When this action is made depends on habitat. In dry habitats the plants are adopted and roots grow deep in soil to find ground water. This process in enhanced by dry air in the surrounding. When water content of the plant is decreasing concentration of cell sap is increasing and the photosynthetic processes are stopped. Photosynthesis inhibition is a signal to closure of stomata (Larcher 1995:248-251).

A higher concentration of CO_2 in atmosphere results not only in reduction of inefficiency by reducing photorespiration but it also reduces water loss. Doubling CO_2 may lead to 30-60% reduction in stomatal conductance. Lower conductance improves leaf water potential and may lead to leaf expansion. Transpiration may decline but this is dependent on the temperature in the air and in the leaf (Bowes 1993).The plant needs to absorb 500 g of water by the roots to be able to form 1 g of organic matter (Taiz & Zeiger 2002:33).

The water situation for the plant is determined by absorption and transpiration. Water balance is the difference between absorption and respiration. This balance fluctuates with water availability. A negative balance narrows stomata and reduces transpiration until balance is reestablished. This balance fluctuates naturally during day and night, but when water deficit accumulates over time it leads to water stress (Larcher 1995:246-248).

Water stress - deficit and flooding

Since water stress and temperature stress are interrelated these problems will be described in following chapter.

3.3 Temperature

3.3.1 Photosynthesis – the cell level

Biochemical reactions in the plant work faster with increasing temperature. Since growth is reactions of photosynthesis, growth is dependent on temperature. However, optimal temperature is species specific and the optima vary between crops and growing stages. Temperature also effects CO_2 uptake. With very high temperatures CO_2 uptake ends (Larcher 1995).

Photosynthetic rate is highest at the optimal temperature response. After this point a higher temperature results in lower photosynthetic rate and plant experiences stress. These stress factors can be reversible or nonreversible (Taiz & Zeiger 2002:188-190).

How the plant reacts to CO_2 enrichment is dependent on temperature and optimal temperature is highly species specific (Bowes 1993).

3.3.2 Plant growth and development – the plant level

Germination of seeds is species and habitat dependent. The optimum temperature for cell division (30 °C) is very close to the maximum temperature for growth (30-40° C for herbaceous dicotyledons, cultivated plants in temperate zone). Flower formation is often regulated by temperature. Many crops require low temperatures in winter to flower the following year (vernalization). It is most often not one optimal temperature that is important for plant development, but rather the sequence of temperatures. This thermoperiod indicates the alternation between night and day temperatures and is often required for plant growth (Larcher 1995:282-286). Winter dormancy protects over wintering plants to freezing. Buds that are formed in end of the summer transform into winter buds. This prevents too early opening when weather turns warm temporarily. Other plant parts become hardened against frost and dehydration. To break this temporary interruption of growth, the plant must experience the right temperature. In many plants termination of dormancy depend on fulfillment of cold requirements such as a exposure to cold for a certain period (Larcher 1995:306-309).

Warmer temperatures may have effect on plant growth. In a Canadian modelling study temperature is studied during doubled CO_2 level. In C_4 cereal crops, sunflower and tobacco, growth is promoted and this increase could override the reducing factors such as drought and accelerated maturation. C_3 cereals together with legumes and vegetables are more sensitive to the higher temperature and suffer yield losses (Sing *et al.* 1998).

Induced termotolerance is when the plant by being exposed to brief periods of heat stress acquires tolerance to heat that would normally be lethal. Slow temperature changes lead to adaptions, acquired thermotolerance (Taiz & Zeiger 2002:602).

3.3.3 Temperature stress and water stress – heat, water deficit and flooding

Water stress can be induced in a plant by too little precipitation and in some cases high temperatures. Too much water is followed by O_2 deficit in root area and is also a stress factor.

High temperatures stressing plants is usually connected with very dry habitats with extreme temperatures. Such examples are deserts or volcano surroundings. In that context the increasing temperatures of Sweden will be moderate. (See chapter 2.) But still higher temperatures put today's crops into stressful situations. Warm dry summers with little wind may give dangerously high temperatures (Larcher 1995:344).

When the plant is exposed to harmful stress the thylakoid membranes of chloroplasts are damaged resulting in disturbance of photosystem II. Lacking energy from the photosystems carbon metabolism is reduced. Together with damage in photoinhibition processes, heat and high irradiation damage the plant. Additional stress factors such as drought reduce plant heat tolerability further (Larcher 1995:348).

Water stress

"Water deficit can be defined as any water content of a tissue or cell that is below the highest

water content exhibited at the most hydrated state" (Taiz & Zeiger 2002:592). Movement of water is regulated by water potential gradient. When the soil dries water potential increase sharply to the permanent wilting point where the plant cannot regain turgor pressure. When plants dehydrate, roots shrink and loose contact with soil particles. This is a larger problem in a sandy soil with big pores than in the more compact clay soil. An irregular precipitation with mainly rainfall during winter and spring benefits early growth and leads to large leaf areas. During late season big leaves result in fast use of available water and water deficiency. In this case, the plant experience drought during the important stages of reproduction. Some species can solve this problem with a fast reproductive cycle. If the plant can have both vegetative growth and flowering during an extended period it is called an indeterminate plant. The short period flowering plants are called determinate. In indeterminate plants drought limit leaf number by reduced growth of branches (Taiz & Zeiger 2002:592-597).

When a plant experiences drought there are quick responses in reduction of cell volume, increase of concentration of cell sap and increasing dehydration of the protoplasm. Growth processes are slowed down and protein metabolism and synthesis of amino acids are constrained (Larcher 1995:384).

As mentioned concerning thermotolerance, plants can adopt or acclimate to stressful climate. Inhibited leaf expansion, leaf abscission, enhanced root growth, and stomatal closure are examples of measures taken to acclimate to drought (Taiz & Zeiger 2002:592-593). The root signal of drought initiates stomatal closure affecting CO_2 uptake. Among other consequences, change in allocation of assimilates, root-shoot growth ratio is altered and drought may induce flowering (Larcher 1995:385).

Irrigation accumulates salt in soil since evaporation and transpiration only release pure water from the soil and solutes concentrates. Salt tolerance varies among cultures. Too much salt in the soil lowers the soil water potential. Most plants respond to salt stress in the same way as to drought (Taiz & Zeiger 2002:611-612).

3.4 Effects for crop yield – the canopy level

The studies referred to considering CO_2 level affecting growth are primarily made on cell-level, leaf level or in some cases for single plants. When discussing horticultural production it is most interesting to study the response of a canopy and later on what can be called a crop.

The efficiency of plant photosynthesis depends on the ability to use light effectively. Higher efficiency means increasing rate of photosynthesis (decrease respiration), or to develop ability to use more of available light. Since light interception in the canopy is due to plant architecture this is difficult to change. At canopy level, photosynthesis per unit of leaf area correlate poorly with crop yield. In the canopy the variation among leaves and the variation in microclimate reduce the effect of increasing photosynthetic response at cell or leaf level. Therefore it is hard to get higher yield by increase efficiency of photosynthesis. Optimal humidity, irradiation and nitrogen is species specific. In canopy level, photosynthesis does not only depend on C_3 or C_4 pathway, but mainly on growth cycle and partitioning of dry matter in the plant. Nitrogen level is less important than species for photosynthetic efficiency, but when nitrogen is limiting, efficiency is reduced (Hay & Porter 2006:96-97, 272-273).

Increase in CO_2 level, rising temperature and amount of rainfall is thereby maybe not the relevant subjects for investigation. Hay and Porter (2006:267) give two reasons for this. (i) Plants do not respond linearly to changes in growing conditions and (ii) the crop deals with a combination of stresses that all the time affects growth and development. This means that it is the combination of all factors, and the variability of those factors, that is important for plant growth in future climate. Light level, plant architecture and interception of radiation give together with photosynthetic rate the prerequisites for crop growth (Hay & Porter 2006:267).

Supporting the argumentation of Hay and Porter (2006), reports show results of lower photosynthetic rate with exposure of high CO_2 concentration. Plants are commonly acclimating to elevated CO_2. Production of more biomass resulting in higher yield may be a possibility even with reduced photosynthesis per leaf area. The higher concentration may lead to greater leaf area, leaf area index, leaf area duration, leaf thickness, branching, stem and root length, dry mass, fruit size, number of flowers and could promote maturation (Bowes 1993).

Large scale experiments and simulations covering the northern ecosystems show that plant response of photosynthesis and respiration differs between seasons. In autumn both photosynthesis and respiration will increase but respiration will increase more. In spring photosynthesis increases more than respiration does. These findings suggest that the warming of autumns may reduce the capacity of the ecosystem to fully use the elevated CO_2 in the atmosphere (Piao *et al.*, 2008).

Precipitation

The water from precipitation available for the plant is depending on density of the canopy, soil type and temperature. Water to the plant is affected by evapotranspiration, run-off and percolation through the soil. During summer, amount of water in the soil decreases. In dry regions rewatering of the soil may take weeks after a dry period. In dense plant stands, run-off but also interception allows precipitation to reach the soil and the water become available for the plant roots. The water drips from leaves and runs down the stem. Transpiration decreases in a dense stand since the microclimate restricts evaporation (Larcher 1995:264-275). Heavy rains or poor drainage can cause yield losses. When too much water fill pores of the soil the plant experience O_2 deficiency. Growth is depressed during such conditions (Taiz & Zeiger 2002:616).

Stress in canopies are most likely dependent on water deficit, lack of nutrients, too high temperature or pathogen problems. Since water can not move far in dry soil the roots must reach present water by growing. Root systems are therefore important comparing crops with regular supply of water or crops that rely on water in the soil. Shallow roots demand regular supply of water by irrigation or precipitation (Hay & Porter 2006:181).

In horticultural production it is important to ensure best possible growth premises as crops often are valuable and sensitive. As stressed by Hay and Porter (2006) adjusting leaf angle to the sun are difficult. Choice of variety is however of great importance concerning both growth pattern and drought hardiness. Cultivars differ in density of the plant and genetic variances regulates stomatal conductance even within species. The grower can influence climate in the field in a number of ways including irrigation. Humidity can also be regulated by covering soil surface to avoid evaporation. Soil structure in combination with choosing suitable crop also affects water availability. Reduction of wind by wind shields can increase water efficiency. Irrigation helps lowering temperature and soil cover can warm too cold soil. Controlling field climate is of course harder when field is larger (Hay & Porter 2006).

4 Pea and Strawberry production in a changing climate

In this chapter climate change is discussed in context of cropping systems producing two valuable and important Swedish horticultural products, peas and strawberries. Cropping systems are described briefly and crops are related to the general scenarios presented in chapter 2.

4.1 Peas

The garden pea, *Pisum sativum*, is a vining annual belonging to the family Leguminosae. Different products derive from different subspecies. The products are for example sugar snaps or green peas. The edible pod pea, sugar snaps or snow pea produces a low fiber pod with peas inside. Growth pattern of peas are similar to green beans. Many cultivars with different anatomy are available. Main photosynthetic activity takes place in the large stipules subtending each leaf (Swiader & Ware 2002:427-440). Peas are a very important crop in Sweden and export is extensive (Adelsköld 1991).

CO_2 level in the atmosphere ↑

Average temperature ↑

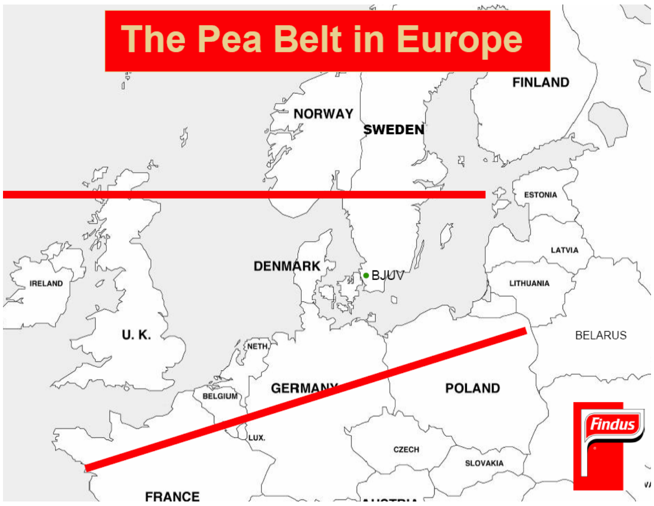


Figure 4. Map showing countries with present climate beneficial for good quality pea production (Stegmark pers. comm. 2008)

Garden peas are a cool-season crop. The temperature should be between 10 and 18 °C. Growth is inhibited at temperatures above 30 °C. Yield drops at temperatures above 24 °C. Minimum temperature is around 5-7 °C. Germination is highly dependent on temperature. A low temperature increases germination time, but a higher temperature and faster germination reduces yield. High temperature at time of maturation and harvest reduces quality (Swiader & Ware 2002:427-440).

Garden peas are a field crop and studies with elevated CO_2 level have not been found. Trials with Swedish bred pea cultivars in Spain showed good results in warmer climate but the lower temperature in Sweden gives a slower maturation rate and better quality. Future pea production may be beneficial in middle Sweden where summer drought is less severe (Stegmark pers. comm. 2008).

Growing season ↑

Peas are a sensitive crop and quality is highly dependent on harvest at the exact maturation level. This is due to the conversion of sugars to starch as the pea mature. The heat unit system is used to predict maturity. Requirements vary among cultivars and between seasons and areas. The system uses a base temperature to compare with mean day temperature recorded in field. Crop is ready for harvest with a certain number of heat units (Swiader & Ware 2002:427-440). Early planting could be a possibility with higher temperature but this depends on soil humidity (SOU 2007:60).

Precipitation ↑ ↓

Plant nutrition leakage ↑

Soil structure and drainage are essential for pea production. Wet soils delay germination and root development. Sandy soils give earlier maturation than heavier soils. Organic matter allows better aeration. The soil pH should be 5.8-6.6. *Rhizobium* in root nodules fixes atmospheric nitrogen. The need of nitrogen fertilization is therefore low but starter fertilization may be needed. Too much N can delay pod set in some cultivars. Potassium and phosphorous can be needed (Swiader & Ware 2002:427-440). With Swedish climate of today, wet soils can delay sowing. Water is a limiting factor and pea production is extra sensitive during flowering time. Presently few growers use irrigation systems but this could be of grater importance with longer dry periods. Irrigation may be more economically sustainable in case of more common drought. Controlled irrigation systems in a drier climate may be beneficial for crop development (Stegmark pers. comm. 2008).

Problems with plant protection ↑

Problems with weeds ↑

Several diseases and insects can be problematic in pea production. Aphids and vector borne virus diseases as pea mosaic, yellow bean mosaic, pea stunt, pea streak and also enation virus could be a problem. Generally more insects and especially aphids can make a more difficult pest problem in Sweden. Crop rotation and resistant cultivars is of great importance. Injuries from heavy rainfall can result in pathogen attacks and can be more common in some parts of the country (Adelsköld 1991, SOU 2007:60, Swiader & Ware 2002:439).

Yield ↑, new products ↑
Quality ↑ ↓
The pea products demand different type of handling to keep quality and yield. Cultural requirements depend on cultivar. The fresh products such as sugar snaps grow are more sensitive than the common green pea. Since the pod is part of the product sugar snaps are sensitive to maturity date and insect attacks. Both products require immediate cooling to keep quality (Swiader & Ware 2002:427-440). Less protein and more carbohydrates in peas could be an effect of faster growth with higher temperature and CO_2 level. This could also affect other nutritional levels. Such quality problems could be reduced by earlier sowing and early varieties (SOU 2007:60).

4.2 Strawberries

Strawberries, *Fragaria x Ananassa*, are grown over a large part of the world. Varieties and growing requirements alter between regions and cultivars. Strawberries are for example grown in several different regions of Europe, from the Mediterranean to the Scandinavian countries, despite the differences in climate (Hancock 1999).

Average temperature ↑
Growing season ↑
The development of strawberry plants is dependent on environmental as well as physical factors. The genotype together with light intensity, temperature and light quality/photoperiod regulates growth of leaves, crowns, roots, runners and inflorescences. In commercial growing systems there are both day neutral and short-day plants. Temperature and photoperiod requirements differ between the types. If cultivars are grown in an unfavorable climate, yield is reduced (Hancock 1999:90).

Buds are initiated during short days or at temperatures below 15° C. Flowers are induced at 8-12 h of photoperiod if temperature is above 15° C. In present Swedish climate with cold winters, flower buds are formed in late summer and autumn and bud breaks in spring. The short day cultivars developed for temperate climate can be grown in mild subtropical climate but floral development is strongly temperature dependent and bud formation can be reduced if temperatures are too high (Hancock 1999:95-96).

Very high temperature is a problem for bud formation also in day neutral plants. These cultivars produce buds three months after planting. Growth of both types continues during season until temperature falls below 0° C, but plants grown at high temperatures have smaller canopies. Generally strawberries require a cold period to optimize yield. The shorter days and cooler temperatures induce dormancy that requires chilling to break (optimal temperature around 0° C). Also in this case requirements vary with cultivars and adaption but generally production is lower without the chilling period (Hancock 1999:97-99).

Flowering in strawberries are dependent on several environmental factors. A study by Verheul *et al*. (2007) on varieties "Korona" and "Elsanta" showed that photoperiod in combination with temperature is important. Both day and night temperatures have impact on flowering. The combination of high night temperature and high day temperature reduced the number of plants with emerged flowers. Low day temperatures increase the number of flowers per inflorescence. The authors also showed that temperature requirements differ depending on plant developmental stage (Verheul *et al*. 2007).

Cropping systems have been developed as a result of the varying possible growing conditions and are regional specific. The hill system is used in areas with mild winters such as California, Florida, Italy or Spain. Matted rows are used in cold winter climate such as continental Europe or Northen North America. The cultivars used grow generally better in one of the systems but some are flexible and can be used in both. Planting date, chilling requirements, mulch, bed height, irrigation and nutrition are some of the variations included in these systems. Winter planting is for example used in regions where temperature allows all year growth whereas summer planting is used in cold winter regions (Hancock 1999:112).

Quality ↑ ↓

Temperature is one factor affecting quality as well as growth velocity and nutritional value in strawberries. Wang and Camp (2000) studied how after bloom growth depends on different temperatures. These results are from trials with the varieties "Earliglow" and "Kent" (Wang & Camp 2000). Temperatures of 30/22 inhibited plant and fruit growth and reduced fruit quality.

The authors discuss that this might be a consequence of enhanced dark respiration due to high temperature. The higher temperature may also inhibit cellular metabolism and chloroplast biogenesis, reduce chloroplast photoreductive activity and cause disruption of protein-lipid interactions and decreased photosynthetic capacity. In this study different parts of the plants do not have similar optimal temperature for growth. Leaf and petiole growth is optimized at 25/12 and root and fruit at 18/12 (Wang & Camp 2000).

The study also shows differences in quality aspects depending on temperature. The highest temperatures (30/22) were darkest in color and had significantly reduced fruit soluble solids (SSC), titratable acids (TA) and ascorbic acid content. The SSC/TA ratio was lower (Wang & Camp 2000). Low levels in those components are common in pale, less flavored fruit. Growth climate are important for quality, but post harvest handling is critical in strawberry production (Hancock 1999:131-132).

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CO_2 level in the atmosphere ↑
Yield ↑, new products ↑

Photosynthesis and CO_2 assimilation rates are well investigated in strawberries and the functions are to a large extent comparable to other fruit crops. As with other factors, optima differ between cultivars, but the main restricting factor is light. CO_2 assimilation is generally responding to higher light intensities. Since strawberries generally have a dense canopy, planting method affects how much light that reaches each leaf. Developmental stage and size of the leaf is also an important factor. Other factors influencing CO_2 assimilation rates are, temperature, nutrient availability, CO_2 concentration, but also culture and propagation methods. Optimal photosynthetic temperature differs between cultivars and there are also studies showing plant adoption to higher temperatures. CO_2 fertilization shows short term positive results in strawberry production. In some cultivars this has been shown to have a more long term effect, but adoption is common. The level of adoption can be exemplified with plants grown in tissue culture having higher CO_2 assimilation rates. Even compared with plants grown with similar canopy densities, tissue culture plants show higher assimilation. This feature declines with number of growing seasons (Hancock 1999:102-104).

Limited N supplies limits the effect of elevated CO_2 in strawberries and mainly root and fruit growth was promoted. The reduction is seen in leaf area ratio. The study indicates that CO_2 could be beneficial in fruit production of strawberries (Deng & Woodward 1998).

Precipitation ↑ ↓

Developmental stage of the strawberry plant affects the plant response to water stress. In late stages water stress may induce increased flowering, but in early stages it could lower number of flowers. Generally strawberries respond as other plants to drought stress with reduced leaf area, fewer leaves, lower stomatal conductance and lower transpiration. The tolerance of the plant to drought is species specific with anatomic factors differing between plants. More sunken stomata, longer roots and thicker leaves give in some species better tolerance against water deficit. Irrigation can be done with overhead watering or drip irrigation (Hancock 1999:104-107, 118).

Problems with plant protection ↑

Problems with weeds ↑

Mulching with straw or other materials is used to prevent weed problems. Since strawberries in Swedish production is a perennial crop weeding has do be done in the rows. Perennial weeds should be removed mechanically before planting. Several insects and fungi may reduce yield and lower quality in strawberry production. Strawberry bud weevil and Lyngus subspecies are among the most severe in Sweden. Some problems are regional and some are worldwide. Among the worldwide insects are aphids, spider mites and strawberry bud weevil. Insect attacks can be more severe with warm weather since it makes insects fly more and more generations are possible every season. The effect of the pest problems will differ with climate between different regions in Sweden. Generally problems with aphids are greater southern Europe and those problems could be expected also in Sweden. As seen with peas, more aphids lead to more virus problems. Grey mould is a problem in all Strawberry production but the problem is more severe with wet conditions and high temperatures. Excessive fertilization benefits grey mould. To prevent plant protection problems good air flow, minimizing standing water, resistant varieties and clean material are of great importance. Matted row system during several years demand good crop rotation system to prevent soil born diseases (Hancock 1999:149-176, Svensson 1997, SOU 2007:60).

Plant nutrition leakage ↑

As with other culture practices nutrition requirements vary with regional systems and cultivars. Fertilization should be applied in rows and amount needed should be based on soil analysis. Drip irrigation with fertilizer is a possibility to control application amount and rate (Svensson 1997).

5 Discussion and conclusions

Growing conditions will change
According to SOU 2007:60, there are good possibilities for increased yield and new products. This study shows nothing else, but rather emphasizes difficulties in making these predictions. Biological systems do not respond linearly and depend on many factors. Why one crop is suited for a climate can only partly be explained by physiology of the individual plant. Too many factors are involved for us to be able to make reliable predictions.

Carbon dioxide
With higher CO_2 level higher yield could be a possibility, but as seen in strawberry production, there are questions concerning level of plant adoption (Hancock 1999:102-104). The long term effect of CO_2 is still to be investigated. It seems obvious that more efficient plants are a theoretical possibility, but implementation on crop level is insecure. Hay and Porter (2006) strongly dismiss the possibility to have more effective photosynthesis on crop level. They do not consider difference in carbon assimilation (C_3 or C_4 plant) as relevant predicting yield. Increase in yield is highly dependent of temperature and water deficit not causing stress for the plant. In case of stress the increased yield may be at risk (Hay & Porter 2006).

Precipitation and temperature
Small deviations in predictions of precipitation and temperature can cause large changes in growing conditions. Basic physiology of plants can help predicting effects, but still large scale experiments are lacking. The extent of stress to our crops in today's climate remains unanswered. Since Swedish pea production keeps a good quality it can be assumed that this sensitive crop generally not is exposed to stressful conditions. The rather complex situation of plant protection of strawberries can indicate that stress is more common since plants are more sensitive if exposed to environmental stress.

Temperature is an important factor for growth and development. As seen in both strawberries and peas, today's cultures are adjusted to present climate and higher spring temperatures can lead to problems in matching temperature and developmental stage (Hancock 1999, Swiader & Ware 2002).
Earlier sowing may be a possibility in pea production but wet soils can be a big problem since

germinating peas are very sensitive to too high humidity. There are possibilities to shift pea production further north in Sweden to ensure more even summer temperature and stabilize maturation rate. Heat unit system is adjusted to local climate but big fluctuations in temperature could be a problem. Trials with Swedish cultivars in Spain show that the used cultivar can be grown in higher temperatures (Stegmark pers. comm. 2008).

Irrigation will be necessary in Southern Sweden (SOU 2007:60). In strawberry production this is already common (Hancock 1999). Irrigation will be necessary to keep quality in Southern Sweden pea production. This could however be more economically sustainable when it will be necessary in all production (Stegmark pers. comm. 2008). Weed and pathogen problem will gradually change during following decades. It will challenge growers and research to continue to develop restricting strategies without negative environmental effect (SOU 2007:60).

Changing climate challenges Swedish production and new generations find solutions

This study describes three important factors affecting growth. In theory the changes in CO_2 level, temperature and precipitation can have major impact on horticultural production. Following generation will have the answer on how the now discussed future will develop. In production it is positive that conditions develop gradually. Shift in generations helps when introducing new product or growing methods. The awareness of today’s environmental problems together with knowledge can help to make adjustments to gradual changes that will occur. Research has to continue and international experience used. New thinking will be needed to be able to make use of more favourable climate.

An interesting question at issue is if production changes in horticulture (field grown) will be easier than for traditional agricultural crops. The traditionally smaller area and sensitivity of the crop may have prepared growers to continuous development. This can however be a matter of discussion. Awareness of coming changes will probably help adjusting society. This could also be able to apply in horticulture. Generally regional differences in precipitation pattern could be used by adjusting crop choice but that is dependent on both flexibility of the producer and the consumer.

Consumer perspective

Swedish consumers are used to Swedish strawberries and peas with good quality. Predictions are difficult since eating habits change between generations but keeping quality will be important to justify to by local produce. Keeping nutritional value despite the adjustment to changing growing circumstances as well as reduce pesticide use will be important. Also in this area producers are helped by awareness in society that hopefully will open the consumers mind to new alternatives.

An early season can lead to less strawberries around midsummer and the high temperature may affect growing velocity and thereby quality aspects as color, taste, and nutritional value. Since strawberry cultivar has different growing requirements there is a big possibility to adjust to more suitable cultivars but short day plants will continue to be most common (Hancock 1999) .

Changing climate will affect Swedish horticulture and in depth studies of details of crops may give such answers.

Insecurity in predictions and future research need

The climate scenario used in his study is from SOU 2007:60 who refer to published results from IPCC. Climate change is a complex problem and new research is published continually. One example of this is Piao *et* al that have found changes in photosynthetic rate that differs from earlier recordings. Autumn warming will reduce the capacity of the northern ecosystems to bind carbon. The complex nature of climate change will probably continue to give answers that change earlier statements, question them or make complements.

SOU refers insecurity in the predictions about future effects on Swedish agriculture and horticulture to lacking long term data recording changes in the past. Today's awareness can lead to future clearer focus. Predictions are too insecure to make, but today's assignments are to identify those recordings that are needed to be able to make necessary adjustments of culture practices when climate changes.

Climate changes fast with a historical perspective, but still changes are slow for present generation of growers. Adjustments will probably be necessary, but this will not be dramatic. New research develops all the time and gives new advice about practice. This work continues.

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Personal Communication
Stegmark Rolf 2008-03-13, Findus R&D AB, SE- 26725 Bjuv, Sweden.

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