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Placed nitrogen (N) starter fertilizer for planted Iceberg lettuce (*Lactuca sativa* L.) - application method and fertilizer level.

Punktgödsling vid plantering av isbergssallat
- appliceringsmetod och gödslingsnivå

by

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Abstract

Fertilizer that does not get used in crop growth is a problem for Swedish agriculture since there are risks that nutrients leach into lakes, streams and seas. Short culture time and a nitrogen (N) demanding crop with fast development are factors that give high risk of nitrogen leakage in lettuce production. Extensive growth at time for harvest leaves fertilizer nitrogen in soil that can leach from the field.

Starter fertilizer is a method for precise fertilization. By using this method every plant gets the exact amount needed and fertilization of soil without roots is minimized. This project aimed at finding an application method and fertilizer level for N used as starter fertilizer in Swedish iceberg lettuce production. Earlier studies in the UK show good results for the use of starter fertilizer in lettuce.

The results from this study showed that a bigger amount of nitrogen tested does not give a better yield than the lower amount tested. The plants in the trial showed examples of physiological disorders but such plant damages can be related to climate difficulties rather than over fertilization. The damages make the results insecure. The recommended application method from the trial is to put fertilizer in two strains 3 cm beside the plant.

Even if the results from this study are insecure due to plant damages, further research in the area is recommended since the use of starter fertilizer is a method that can help reducing nitrogen leakage from Swedish iceberg lettuce production. By using starter fertilizer the amount of nutrient broadcasted over the field can be limited but yield can be maintained.

Sammanfattning

Svenskt jordbruk bidrar till övergödningen av sjöar, åar och hav genom att gödning som inte kommer grödan till del läcker ut från odlade fält. Eftersom isbergssallat är en gröda som kräver mycket näring och eftersom den skördas när den fortfarande är i tillväxt när det finns mycket näringsämnen kvar i jorden så är det stor risk för läckage. Kväve (N) behöver tillföras grödan i stora mängder och kväveläckaget är också stort. Ett sätt att kunna minska läckaget är att tillföra varje planta exakt den mängd kväve som den behöver vid plantering och sedan tillföra en mindre mängd som bredspritt kväve under kulturtiden. Därmed undviks att gödsla den omkringliggande jorden där inga rötter finns. Projektet som beskrivs i denna rapport hade som mål att hitta ett bra sätt för att tillföra gödning i form av NPK som startgiva samt att hitta en lämplig gödslingsnivå. Startgiva är testat med bra resultat i sallatsproduktion i exempelvis Storbritannien.

Resultaten från detta försök i klimatkammare med reglerad temperatur, luftfuktighet och ljus visar att den testade högre mängden kväve inte ger bättre skörd än den lägre mängden. Skador på plantorna gör resultaten osäkra, men dessa går till viss del förklara med klimatproblem på grund av klimatkammaren snarare än saltskador. Metoden som rekommenderas för ytterligare studier är att tillföra NPK i två strängar några cm från plantan.

Trots de fysiologiska skador som plantorna i denna studie visar tecken på, rekommenderas att fortsätta arbetet med att anpassa en startgiva för svensk isbergssallatsproduktion. Detta är en åtgärd som kan minska det totala användandet av kväve och därmed minska risken för läckage från fält.

Introduction

Iceberg lettuce (*Lactuca sativa* L.) is a nutrient demanding crop. It is common with up to three culture periods after each other every year. Nutrients are spread over the raised bed resulting in all nutrients applied is not reached by roots and are therefore easily leached from the field. Fertilizer leakage leads to environmental problems in sea, streams and lakes. With a more precise fertilization technique the individual lettuce plant could get exactly the amount of nutrients needed at each growth stage. The small iceberg lettuce plants are sensitive when planted and easily become damaged from to much salt at the same time as the need of nutrients is high. Application technique and amount of fertilizer needed are essential to ensure good growth.

The aim of this project was to find suitable application method for starter fertilizer and fertilizer level in iceberg lettuce production. The over-all aim was to minimize the risk of environmental influence from iceberg lettuce cultures.

The report contains a literature study of Swedish lettuce production, nitrogen as a nutrient, the risk of nitrogen leakage and finally a review on earlier research on starter fertilizers. The second part consists of a description of a trial growing iceberg lettuce under controlled climate conditions with NPK 11-5-18 placed close to the transplants.

Swedish field lettuce production

There are few written sources describing field lettuce production in Sweden. Praxis of today are commonly based on the growers own experience and contacts. This chapter describes lettuce production based on Swedish, Norwegian and North American literature. According to Swedish ministry of agriculture 1088 ha/ 26 200 tons of iceberg lettuce was grown in Sweden in 2006 (Jordbruksverket, 2006).

Production methods

Swedish field lettuce is mainly grown in raised beds with two rows and 25-30 cm between rows and plants. Soil requirements include good nutritional accessibility and ability to keep moist. Plant material is usually transplanted seedlings in contrast to the system used in some countries with direct drilling (Ryder 1999, Adelsköld, 1991, Balvoll, 1999). With direct drilling are often coated seed used since the seeds are small and difficult to handle. The sowing is very shallow and germination is often facilitated by irrigation the first days (Ryder, 1999). This study will further focus on describing the advantages and disadvantages for the in Sweden more commonly used transplants.

One advantage of using transplants compared to direct drilling is shorter field period which gives possibilities to more cultures in the shorter Nordic season. It is also positive that spacing of the plants is not needed which reduce work load. The crop becomes more uniform with transplants and the harvest density is higher (Ryder, 1999). Less weed problem is reported and (Balvoll, 1999, Adelsköld, 1999) development is faster and more even with transplants (Adelsköld, 1999).

One negative effect is that the tap root often is pruned in handling which promotes a shallower root system and a higher sensitivity to drought in the upper soil layer when the roots do not reach water deeper in the soil. The cost of transplants is much higher compared to direct drilling (Ryder, 1999).

A transplanted lettuce plant has a relatively large shoot and the roots are restricted to a small volume of soil. This can result in a risk that the transplanted crops suffer from an imbalance of nutrients when the demand of the plant can not be supplied by the roots. This risk is less with drilled seeds. Using starter fertilizer is one example of measures to improve nutrient status for the transplant (Costigan & Heaviside, 1988). Rahn *et al.* (1996) showed that reduced total growth for broccoli transplants treated with starter fertilizers could depend on the faster growth for the young transplant, resulting in water deficiency in the root zone in beginning of the culture. To prevent such deficiency, watering is very important when considering using starter fertilizer (Rahn *et al.,* 1996).

Since transplanted plants are active in growth, the need of fertilizer in the beginning of field period is higher than for drilled seeds. The diffusion of broadcasted nitrogen (N) may be too slow to be enough for good development. Sørensen (1996) showed that efficiency of uptake of broadcasted N is low for cauliflower transplants (Sørensen, 1996). This result is valid also for lettuce production.

Greenwood *et al.* (1989) present results suggesting that N deficiency can be a problem for young seedlings even if large amounts of fertilizers are broadcasted before drilling. The deficiency could be a result of the poorly developed root system during the seedling stage.

When applying N as a starter it is important to use the ammonium form instead of the nitrate form to prevent salt damage and reduce risk of early leakage (Greenwood *et al.,* 1989).

The pH recommended for lettuce cultures is between 7-7.5. Deviant pH may cause difficulties in nutrient uptake. The importance and effect of pH in nitrogen uptake are described in chapter “Importance of N in plant growth”. Lettuce is a nutrient demanding crop and many studies show that phosphorous (P) benefits early growth. NPK type fertilizer is commonly used in field production. Optimal average growth temperature is 13-16 °C and development is inhibited gradually above 20 °C causing large yield losses. To ensure growth, water availability is important (Ryder, 1999, Adelsköld, 1991, Balvoll, 1999). The risk of unstable growing conditions, including water deficit, is described below in the part about physical disorders.

Physiological disorders

Heavily reduced yield as a result of physiological disorders are problematic in lettuce production. Tipburn is a common physiological disorder and it often occurs near maturation time resulting in major costs for the grower when the crop is lost. The damage is first shown as brown spots close to margins of the inner leafs and is followed by necrotic areas. See figure 1. Lettuce culture in greenhouses or climate chambers may express damage in earlier stages. Tipburn shows as a result of accelerated growth. Ryder (1999) gives the following reasons for enhanced growth: “an increase of temperature, an increase in light intensity, an addition of nitrogen fertilizer, an irrigation application or other growth stimulant” (Ryder, 1999). As a result of these stimulants, growth rate in marginal tissues increase followed by expanding inner leaves. Calcium (Ca) is moving too slowly compared to the growth rate and the plant develops tipburn caused by local Ca deficiency in the leaf marginal tissue. Transpiration rate of the plant is insufficient to move calcium fast enough. To prevent tipburn the inducing factors described above should be regulated to ensure even growth. Cultivars are differently sensitive to tipburn which gives the grower a possibility to adjust production if the conditions give high risk of the disorder (Ryder, 1999).

Figure 1. Example of tipburn from the project. The picture to the left from project part one and to the right from project part two.

Other physical disorders in lettuce are discoloration of ribs by unknown cause and damage caused by toxic atmospheric gases as ozone, sulphur dioxide, nitrogen dioxide and peroxyacetyl nitrate. Such toxicity may occur if growing lettuce in a polluted area or near pollution sources such as main roads or factories (Ryder, 1999).

Plant protection

Several insects and diseases can be problematic in lettuce production causing large crop losses. In an interview 2000, organic growers stated the insect *Lygus pratensis* together with the fungus disease Sclerotinia drop (*Sclerotinia sclerotiorum*) and snails as the major problems (Ekbom *et al.,* 2001). Another insect problem includes aphids that are sucking the plants, transmitting viruses and reducing quality. Among the common aphids are the Lettuce aphid (*Nosonovia ribisnigri)*, the Potato aphid (*Mascrosiphum euphorbiae)* and the Green peach aphid (*Myzus persicae)* (Jönsson, 1992, Ryder, 1999). Since the consumer does not want any traces of insects in the product all insects close to the plant is a problem even if it is not harming the plant itself. Covering the field is effective to prevent insect damages but may cause downy mildew (*Bremia lactucae*) (Jönsson, 1992). Other insects causing damages are white flies (*Trialeurodes vapororiarum*, *Bemisia* ssp) and different larvae species from the *Lepidoptera* order. Apart from downy mildew that is one of the most serious diseases in lettuce production and the difficult Sclerotinia drop, for example powdery mildew (*Erysiphe cichoracearum*) and different rots can be problematic fungi problems during wet climate. Bacterial diseases as corky roots and several viruses can also destroy the crop (Ryder, 1999). Weeds may be highly competitive with lettuce plants and compete about light, space, water and nutrients. Weeds can also attract insects or be hosts for disease organisms (Ryder, 1999).

Nitrogen as a plant nutrient

Nitrogen in the soil

Most nonlegume crops need additional nitrogen (N) for sufficient yield. N can be supplied to the crop with different methods but availability to the plant is dependent on the form applied together with behaviour of the N in the soil. Plants can take up N as ammonium ions (NH_4^+), or nitrate ions (NO_3^-). Ammonium can be used directly by the plant but nitrate must be reduced into ammonia (NH_3) requiring energy of the plant (Havlin *et al.,* 1999).

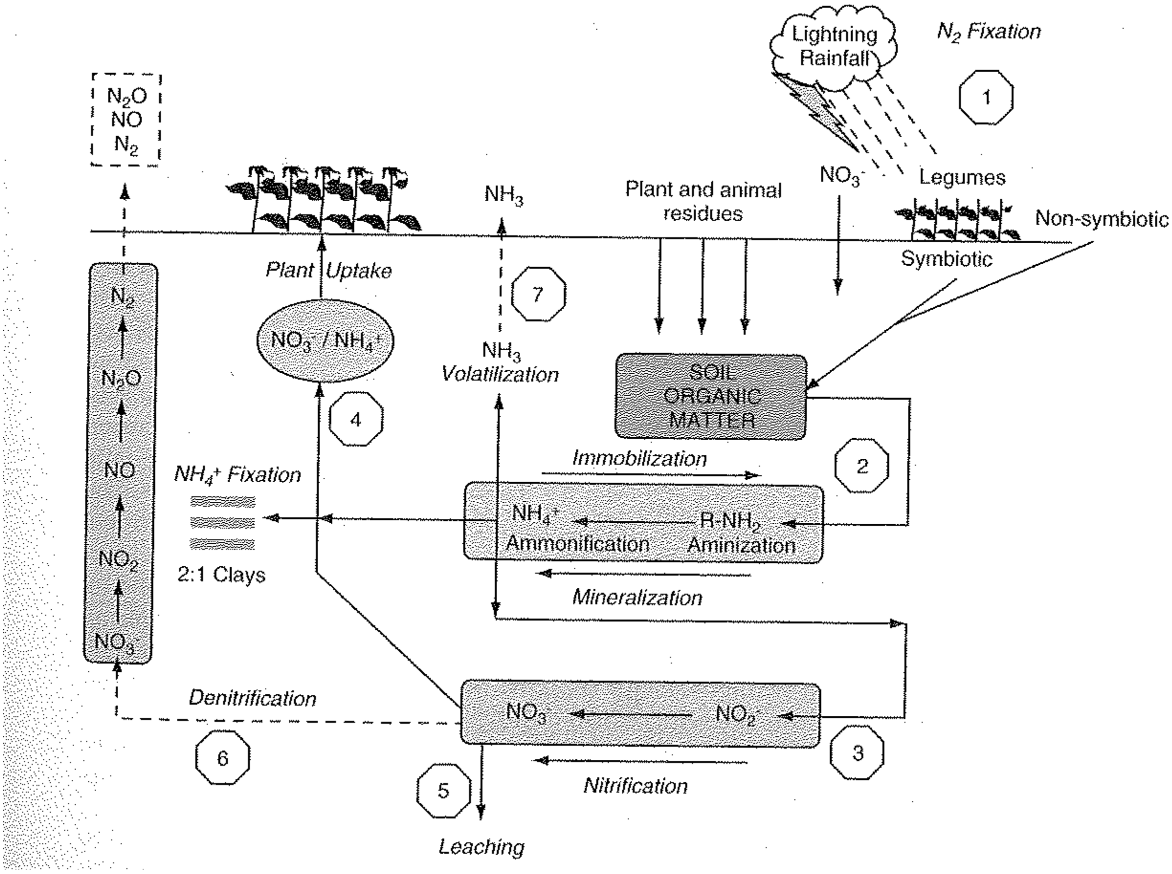

Figure 2. Several processes transform N in the soil. The different steps in the N cykle are marked with numbers (Havlin *et al.,* 1999:87).

Figure 2 describes the N cycle. The first steps (1-3) add N to the soil and make it available to the plants. In step **1** N is added to the soil as a fertilizer, bound by legumes, directly from the atmosphere or as plant and animal residues. In step **2** the organic N is mineralized with help of soil organisms to NH_4^+. Nitrifying bacteria convert NH_4^+ to NO_3^- in the **3rd** step. This process is called nitrification. Plant uptake of N as NH_4^+ or NO_3^- is possible in step **4**.

In the later steps (5-7) N is no longer available as a plant nutrient by several processes. Leaching of N to the groundwater and into nearby lakes and streams is marked with step **5**. Nitrate from step 3 is easy moveable. In step **6**, the natures own function of denitrifying NO_3^- reduces plant available N by binding N into nitrogen molecules (N_2) and nitrogen oxides that goes back into the atmosphere. NH_4^+ can be lost to the atmosphere in step **7** in the process of volatilization.

Several of the steps in the cycle in figure 2 are complex processes affected by the surrounding. Examples of such environmental conditions are amount of organic matter in the soil, temperature, moisture and O_2 availability. Both mineralization and nitrification depend on soil living organisms and bacteria making soil fauna very important. The processes are affected by addition of nitrogen to the field during crop production. This makes it important to consider suitable N source for the soil as well as for crop requirements to have an environmental and agricultural sustainable nitrogen use. One example of such consideration is fertilizing poor soils with manure that both increase soil organic matter and supply N to the crop (Havlin *et al*., 1999).

Importance of N in plant growth

Nitrogen is used in the plant for synthesis of amino acids and proteins. Nitrogen taken up as ammonium is incorporated into organic compounds in the roots. Nitrate can be stored in vacuoles of the roots, shoots or in storage organs. Both ions (NH_4^+ and NO_3^-) affect the anion-cation balance in either the plant or in root surrounding. To be able to use nitrate as a nutrient the plant has to convert it into ammonia. Whether to use ammonium or nitrate fertilizer for the crop depend on for example species, but generally the best growth is achieved by using a combination. Efficiency of ammonium use depends on root zone temperature and plant light intensity supplying the root with enough carbohydrates. NH_4^+ and NO_3^- have a strong impact on uptake of other ions by for example soil pH. Nitrate uptake may reduce soil pH and this change can severely reduce uptake of other nutrients but the effect mentioned depend on original soil factors as for example soil buffering capacity. When both nitrate and ammonium are available the plant can regulate internal pH but the optimal proportions in the soil depend on concentrations. Nitrate move more easily than ammonium in the soil and is often more available to the plant (Marchner, 1995).

The amount nitrogen required for optimal growth is between 2-5 % of plant dry weight. A higher supply of N have several effects such as delayed senescence, stimulated growth and in changed plant morphology with smaller roots and higher shoot/ root dry weight ratio. The smaller root system may be negative in case of water deficit or deficit of other nutrients. (Marchner, 1995).

Nitrogen deficiency and toxicity

Nitrogen deficiency is shown by stunted growth and yellow older leaves (chlorosis). The chlorosis is caused when nitrogen in proteins in the chloroplasts are converted to soluble N and moved to meristematic tissues. When deficiency is severe, cell death (necrosis) begins in leaf tip and progress until the entire leaf is dead (Havlin *et al.,* 1999).

Improper fertilization practices may cause toxicity as well as deficiency. Corky roots with lesions can be caused by nitrogen toxicity or *Rhizomonas* bacteria. Lettuce is sensitive to saline soils causing reduced growth, puffiness, leathery outer leaves and bitter taste. Acid soils cause mineral deficiency (Ryder, 1999).

Nitrogen fertilizers

There are many ways to apply N to the crop. As mentioned above, manure improves soil organic matter content as well as supplying long lasting fertilizer. N availability from manure depend on mineralization of the organic N. Atmospheric N can be used by growing nitrogen fixating legume crops in the crop rotation cycle. The nitrogen fixed by the crop is ploughed down into the soil where it can be decomposed, mineralized to NH_4^+ and further nitrificated into NO_3^-. By this process the fixed nitrogen become available for the next crop (Havlin *et al.,* 1999).

The most important source of N in the world is synthetic or chemical fertilizers. The fertilizers contain the forms NH_4^+, NO_3^- or both. Ammonia (NH_3) in form of urea that hydrolyses into NH_4^+ is a common fertilizer in large parts of the world (Havlin *et al.,* 1999).

The commercial company Yara supplying fertilizers describe NPK 11-5-18 as a complex fertilizer containing N, P and K and often additional micronutrients. It consists of a mix of NO_3^- (easy moveable) and NH_4^+ (slower uptake). Calcium nitrate, $Ca(NO_3)_2$, consist of easy available NO_3^- and Ca^+ and gives fast response on plant growth (Kväveformer, 2008).

Sustainable nitrogen application in lettuce

Environmental goals

Leakage of nutrients from agriculture is a serious threat to the environment. Excess nitrogen may reduce ground water quality or lead to over fertilization of seas and lakes. Many actions are taken both nationally and internationally to reduce leakage. More efficient use of applied fertilizer is one such method. Among the Swedish environmental goals are the attempt to reduce nitrogen leakage by 7 500 tons (30%) from 1995 to 2010 (Jordbruksverket, 2007).

Lettuce cultures

Short culture time, nitrogen demanding crop with fast development are factors that give high risk of nitrogen leakage in lettuce production. Extensive growth at time for harvest gives high risk of leaving fertilizer nitrogen in soil that can leach from the field (Greppa näringen, 2004).

Lettuce crop residues leave much N in the soil when incorporated. Paterson (1996) showed that consider amount N left in crop residues may reduce fertilizer needed in the second crop in the year. Paterson recommend to measure soil mineral N before planting the second crop (Paterson 1996). Nitrogen left in the field may leak trough nitrate leaching or through nitrous oxide emission to the air (Paterson & Rahn, 1996). See figure 2.

Soil analysis before planting lettuce is also recommended by Torstenson and Sandin who discuss the importance of developing easy and reliable methods for nitrogen measurements in the field. In this Swedish trial, mean amount nitrogen harvested was 90 kg ha^{-1} which was equivalent to 34% of the applied 264 kg ha^{-1} field area. In this trial 66 % of the applied N was at risk for leaching from the soil during the season or during following winter. Nitrogen leaching from the fields varied between two studied years depending on other cultures and precipitation, but with an average of 95 kg ha^{-1} year 1, and 87 kg ha^{-1} year 2. This amount of leakage may risk quality of groundwater as drinking water (Torstensson & Sandin, 2007).

Activities to reduce leakage

In addition to reduce the amount of fertilizer used in the field, Neeteson *et al.* (1999) stress three important factors for reducing nitrogen leakage.

- Placement of nitrogen fertilizer for example close to the plant or in bands.
- Splitting nitrogen fertilizer dressing and estimate the addition needed by empirical data or plant analysis.
- Reducing losses outside the growing season by growing another crop or using catch crops.

When growing season prevents catch crops, leaving the residues on the soil without ploughing until early spring is recommended. In this case risk of pathogens should be considered since this can benefit for example fungi spores (Neeteson *et al.,* 1999).

A Swedish project aiming to reduce nitrogen and phosphorus losses, "Greppa näringen" advice vegetable producers to increase nitrogen efficiency in production. These advices are similar to the measures stated above. The advices are interesting to compare in the context of starter fertilizers and nutritional demand. Some of the advices states:

- Use the amount of fertilizer needed for the expected yield. Make the predictions with reasonable expectations and do not over fertilize.
- Adjust the amount nitrogen supplied to soil N by making soil analysis.
- Fertilize in the rows at time for planting and avoid spreading fertilizer between rows.
- Split fertilizations with 50-70 % of the expected need at time for planting and the rest based on plant need during the growth period.
- Use plant rotation effects. Consider N from plant residues as well as N left in the soil at time for harvest when calculating need for the new crop.
- Irrigate to keep an even plant growth.
- Notice demand for other nutrients since other deficiencies can influence N uptake.
- Use catch crops to prevent leakage. The growth period for the catch crop should be during September in southern Sweden to ensure N uptake.

(Greppa näringen, 2004)

Using starter fertilizer is a way to reduce the amount of fertilizer supplied to the field, without risking yield. To wait with broadcasting of N to the field may reduce leaching below root depth. Starter fertilizer can supply the plant with enough P and K for the first growth period. Amount of broadcasted N later during the culture time can be reduced when the plants get enough during the first period (Costigan & Heaviside, 1988).

Starter fertilizer

Much work has been done in the UK to reduce N with maintained yield in vegetable production. Starter fertilizer is a method that gives an opportunity to reduce N. These studies are all done with liquid fertilizer injections in soil near the seed. In some cases transplants are used but the trials are mainly done on direct drilling. In early studies the starters were mainly P and K but later work includes also the effect of N in starters (Costigan & Heaviside, 1988).

Stone (2000b) showed that a higher maximum yield was obtained with starter fertilizer. Starter fertilizer (N) was supplied as an injection to seeds drilled into soil pre-treated with 100 kg P ha^{-1} and 200 kg K ha^{-1}. N was applied as ammonium phosphate or urea ammonium nitrate. There was no difference in fresh weight when comparing starter fertilizer of N with broadcasted N at 120 kg N ha^{-1} which gave the highest yield. At lower levels of applied N starter fertilizer gave a higher yield than broadcasted N. 30 kg injected N ha^{-1} gave approximately the same yield as 120 kg N ha^{-1} broadcasted. This is a reduction by ¾. Injected ammonium phosphate + broadcasted N gave a higher fresh weight that was maintained during growth period. Starter containing ammonium phosphate with 20 kg N ha^{-1} gave identical yield as 240 kg N ha^{-1} broadcast which is a huge reduction. This shows a much higher efficiency of starter fertilizer than broadcasted N. In these experiments the effect of starter application diminished during culture time (Stone, 2000b).

Stone (2000b) discuss that the variability of soils mean that starter fertilizer alone do not give enough N to the full growth period. Stone (2000a) continues with investigating a method to use starter fertilizer together with complementary N application. The results show early growth benefits from starter fertilizer. Later in the season the benefit diminishes. Burns (1996) show that lettuce plants have reduced growth during the whole growth period if exposed to N deficiency in early growth. Maturity was delayed and despite longer growing period the plants did not recover the loss compared to control. Burns conclude that controlling N is highly important when trying to reduce amounts fertilizer used but still keep satisfactory yields. Stone *et al* (1999) has earlier results on crisp lettuce showing that plants mature earlier with starter fertilizer (Stone *et al.,* 1999).

In the same study Stone *et al* (1999) also tested NPK as a starter fertilizer. Yield of both drilled and transplanted crisp lettuce increased dramatically when starter fertilizer was used on a peaty soil with good levels of nutrients present in the soil before the trials. NPK was applied as solution at sowing or at planting of the transplants. The authors discuss that these results support the use of starter fertilizer. The root zone is provided with nutrients to enable shoot growth when roots still are poorly developed (Stone *et al.,* 1999). NPK in solution was also tested by Costigan and Heaviside (1988) and it was concluded that the positive responses were mainly due to P availability in the soil.

Summary

Sweden needs to reduce leakage of nitrogen into lakes, streams and seas. Lettuce is a fast growing nutrient demanding crop that requires much fertilizer N. There is high risk of leaching from lettuce production and one way of reducing the amount of N applied to the crop may be to use placed starter fertilizer. Results from the UK show many benefits and good yields. This system could be beneficial in the Swedish system with transplants since the requirements for N is large already at planting. Starter fertilizer could be a way to reduce N leakage from lettuce production but the system has to be studied for Swedish conditions.

Material and method

Project design

The project consisted of two parts. The same cultivar was used in the two parts. Part two was based on results from part one. Climate conditions where equal. In the second part additional nitrogen was supplied after three weeks.

Plant material

Iceberg lettuce (*Lactuca sativa* L.) cultivar "Match", non chemical treated coated seeds were sown in commercial low fertilized soil. Seedlings were in the first project part grown in climate chamber (18 hours 400 µmol $^{-2}$ s^{-2} light, 70% air humidity, 20 °C day temperature and 18 °C night temperature) until 4 real leafs (15 days). In the second project part seedlings were grown for 21 days in the same climate as the trial, but had despite 6 more days approximately the same size at planting as plants in project part one.

Planting and substrate

Two types of pots were used. In the first project part the 96 pots used had a diameter of 16 cm, height of 19 cm and a volume of 3.8 liters. In the second part the 48 pots had a diameter of 30 cm and a height of 22 cm. Volume 15.5 liters. The big pot is approximately the area available at field when using raised bed system (0.5 m beds) with two rows and 27 cm between plants in the row.

The same substrate was used in both project parts. The soil was collected at a field at Alnarps Trädgårdslaboratorium. The soil was chosen to have similarities to soil used in field lettuce production and a nutrient status as beginning of the year. The soil was a clay soil that has been improved with organic matter as well as other substrates. Soil analysis result from the field soil is showed in table 1.

Table 1. Result from soil analysis of the field soil.

Analysis factor	Result	
pH 7,5		
Easy available P	9.7 (IV)	mg/100 g air
Easy available K	7.6 (II)	mg/100 g air
Easy available Mg	14	mg/100 g air
K/Mg	0.5	
Easy available Ca	630	mg/100 g air
NH_4^+	0.202	mg/100 g TS
NO_3^-	0.134	mg/100 g TS

Before moving into the climate chamber, pots in projects part one was weighed to 3.0 kg and pots in project part 2 were weighed to 14.0 kg.

Irrigation

Plants were kept with an even soil humidity. Since plant material in both project parts where reasonably equal in size during growth period, watering was done by volume with all plants given the same amount. Water was never allowed to flush trough the pots.

Climate

The plants were grown in climate chambers with 20 °C day temperature, 17 °C night temperature, permanently 70% air humidity and artificial day 16 hours per day. Light intensity was set to be 350 µmol $^{-2}$ s^{-2}. After 5 weeks in project part 2, light intensity was recorded to be 230 µmol $^{-2}$ s^{-2} and measures were taken to re-establish to 350 µmol $^{-2}$ s^{-2}. The plants were then put into day light chamber holding 70% humidity and 20 °C for 3 hours before being moved back to the climate chamber.

In second project part, pots were placed in blocks to equal climate differences between treatments within the chamber. The chamber was divided into four blocks and two plants from each treatment were placed in all blocks.

Fertilizer level and application

Project part 1

Three application methods and four levels of fertilization were tested. Complete fertilizer NPK 11:5:18 amounts were calculated by the base of N need giving P and K rates following N amount.

Application methods used were to put fertilizer directly under the plug with a thin layer of soil between (under). Fertilizer was put in two rows 3 cm from the plant (beside). The third method was to solve NPK in water for about one hour and apply over soil surface after watering (water). All fertilizer levels were applied with all methods. 8 pots in every treatment. Plants were kept in climate chamber for 19 days before harvest and analysis.

Table 2. Fertilizer level used in project part one. Plant need of N is calculated into NPK plant $^{-1}$ and further calculated into the equivalent in kg ha $^{-1}$.

Fertilizer level	N (g)	NPK (g)	N (kg ha $^{-1}$)
Extremely low	0.07	0.64	9
Very low	0.14	1.27	19
Low	0.28	2.54	38
High	0.56	5.09	76

Project part 2

After analysis application method “beside” was chosen to project part two. This method was considered to be easies to apply in Swedish production. Fertilizer level “Low” and “High” were complemented with a “in between level” (“Medium”). There were 8 pots in every treatment and the plants were kept in climate chamber for 42 days (6 weeks). 2 levels of additional fertilizer were applied as $Ca(NO_3)_2$ followed by watering after three weeks resulting in the six treatments in table 4. How starter and additive fertilizer amounts in every treatment are calculated to amount N ha $^{-1}$ is described in table 3.

Table 3. Fertilizer level used in project part two. Plant need of N is calculated into NPK plant $^{-1}$ and further calculated into the equivalent in kg ha $^{-1}$.

Fertilizer level	N (g)	NPK (g)	N (kg ha $^{-1}$)
Low	0.28	2.54	38
Medium	0.42	3.82	57
High	0.56	5.09	76

Table 4. Table shows the treatments after adding broadcasted N. The original 3 treatments (Low, Medium, and High from table 2) become 6 treatments, but the total amount is similar in two cases.

Treatments	Starter (kg N ha $^{-1}$)	Broadcasted (kg N ha $^{-1}$)	Total (kg N ha $^{-1}$)
Low, Low (LL)	38	30	68
Low, High (LH)	38	50	88
Medium, Low (ML)	57	30	87
Medium, High (MH)	57	50	107
High, Low (HL)	76	30	106
High, High (HH)	76	50	126

Table 5. Total amount of fertilizer per hectare bed area compared to praxis.

Total N (Kg ha $^{-1}$)	Compared to praxis
68	Very low
87	Low
88	Low
106	Equal to recommendations from sjv.
107	Equal to recommendations from sjv.
126	High, used by growers

Analysis

Project part 1

One plant from each treatment was used to try measuring methods resulting in 7 plants left for analysis. For analysis plants were cut at soil surface and fresh weight, number of leaves, width and length of the biggest leaf were recorded. Visual defects were noted. To measure dry weight the plants were dried in an own for 24 hours at 70 °C followed by 1 hour of 105 °C. Roots were separated from soil by putting the soil from the pot in a water bath and rinse the roots. Length and fresh weight was recorded and roots were dried and weighed as described for plants.

Project part 2

In the second project part the degree of the plant covering soil surface (graded 1-3) was noticed before plants were cut at soil surface and soil on lower leaves were removed. The plant was examined for colour differences (grading 1-3), fresh weight and finally the width and length of the biggest leaf was recorded. The plants were kept at 70 °C for 1 week before recording dry weight. The roots were left in the climate chamber for one night before taking four 3 cm soil samples from the diameter of approximately 15 cm in each pot. The soil was spread in a tray and the amount of roots from each pot was visually graded 1-3.

Statistics

The computer programme Minitab was used for statistical calculations. Differences between treatments were tested with the variance analyse Anova. When data was not normally distributed Kruskal Wallis test was used as statistical method. Significance level was 0.05.

Results

Project part 1

General appearance, colour, damages
Plants in project part one established well except for treatments high and max with placement of NPK under the plant. Plants in those treatments died in a few days and the most possible reason is too much fertilizer too close to the roots. One unexpected problem occurred when snails appeared from the soil and ate four plants. At time for harvest remaining plants showed a dark green colour and none showed any chlorosis. A little tipburn occurred the last days in a few plants in treatments low/ water, medium/ beside, medium water, max/ beside and max/ water.

Weight
Recordings of fresh weight (FW) and dry weight (DW) gave significant increase (Kruskal-Wallis test) with increasing amount of N based on placement of fertilizer (Figure 3). Both FW and DW (data not shown) decreased with amount of N for placement under the plant. For placement beside and water weight increased with fertilizer amount.

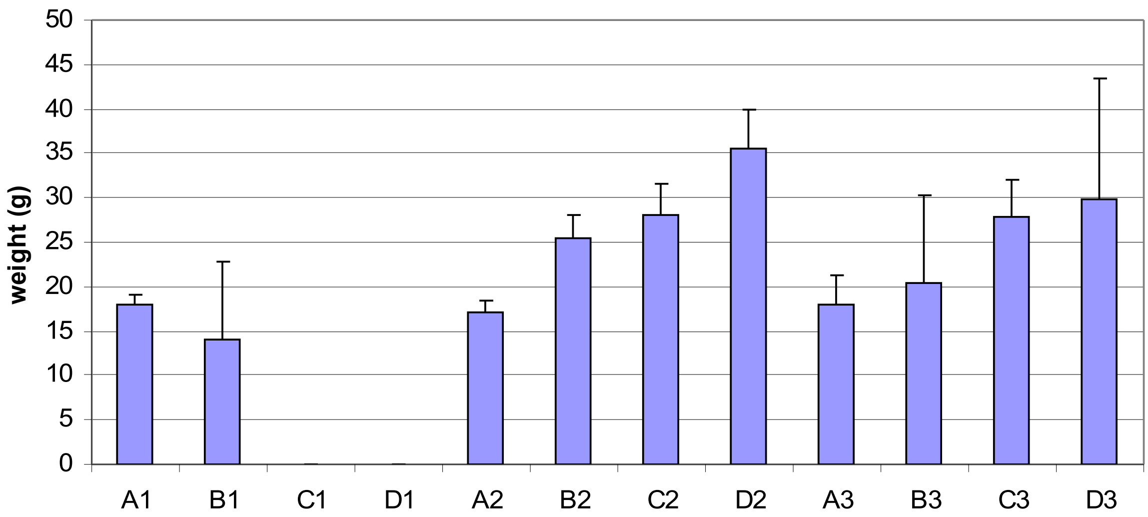

Figure 3. Graph showing difference in fresh weight between treatments. Fertilizer level is indicated with a letter (A: 9 kg ha^{-1}, B: 19 kg N $^{-1}$, C: 38 kg N ha $^{-1}$, D: 76 kg N ha $^{-1}$) and application method with the figure 1-3 (1: under, 2: beside, 3: water). Significance (0,05 level) is found between application methods. Error bars denote standard error of the mean (n= 7).

Number of leaves
Number of leaves varied between 12 and 15 leaves. It is significant difference between the treatments but no patterns can be connected with the treatments.

Leaf length and leaf width
The measurements of leaf length and leaf width gave no significant difference between the treatments.

Root measurements
The method used for root measurements was difficult and roots were lost in the process where roots were rinsed with water. Because of these difficulties the records gave no significant result.

Project part 2

General appearance, colour, damages
After two weeks all plants in all treatments developed the physiological disorder tipburn. This damage together with poor development and leathery like leaves gives a rather insecure result to make conclusions from. The last days the plant also showed chlorosis in the outer leaves. The reasons for these damages are discussed later in this chapter.

Weight
Fresh weight and dry weight differences between treatments show no significant difference (figure 4). This may indicate that the lowest fertilizer level is as good as the highest. The amounts of fertilizer are discussed further in the discussion.

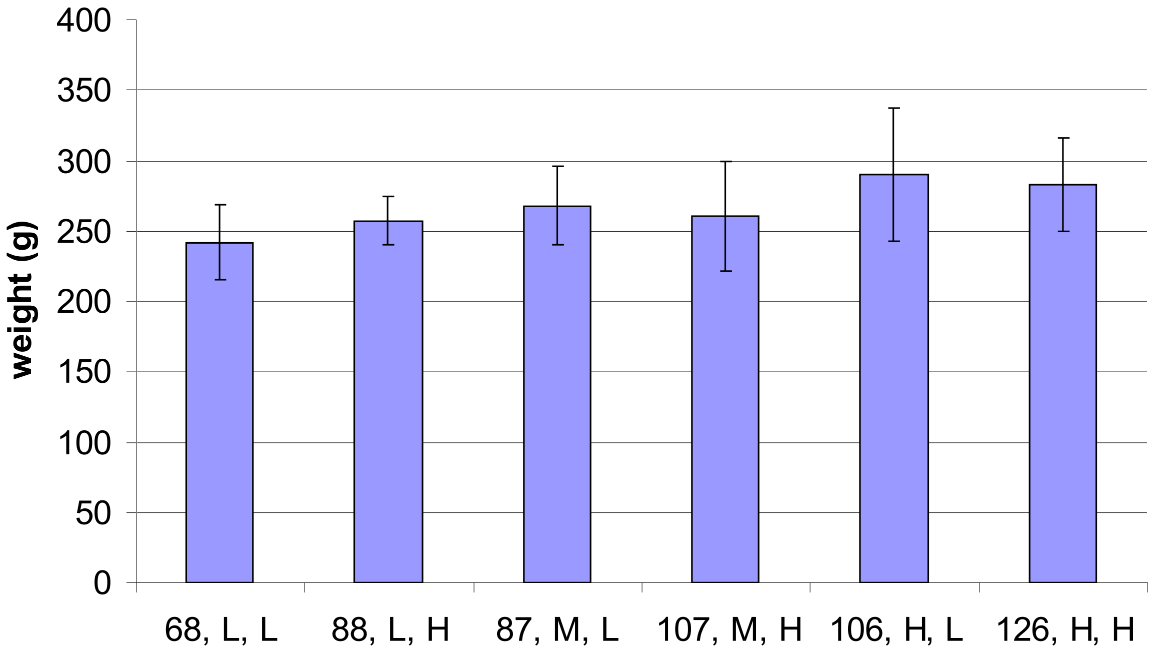

Figure 4. Fresh weight in project part 2. The treatments are named with total amount N, amount starter fertilizer (low (L), medium (M), high (H)) and amount of broadcasted N (low (L), high (H)). Error bars denote standard error of the mean (n=8). No significance is found.

Leaf length and width
The measurements of leaf length and width gave no significant difference.

Cover of the soil area
The grading of how well the plant covered the pot gave no significant difference.

Root measurements
The visual grading of presence of roots (1-3) gave significant difference between the treatments broadcasted N 30 kg ha^{-1} and 50 kg ha^{-1}. More roots were found when the plants got 50 kg ha^{-1}.

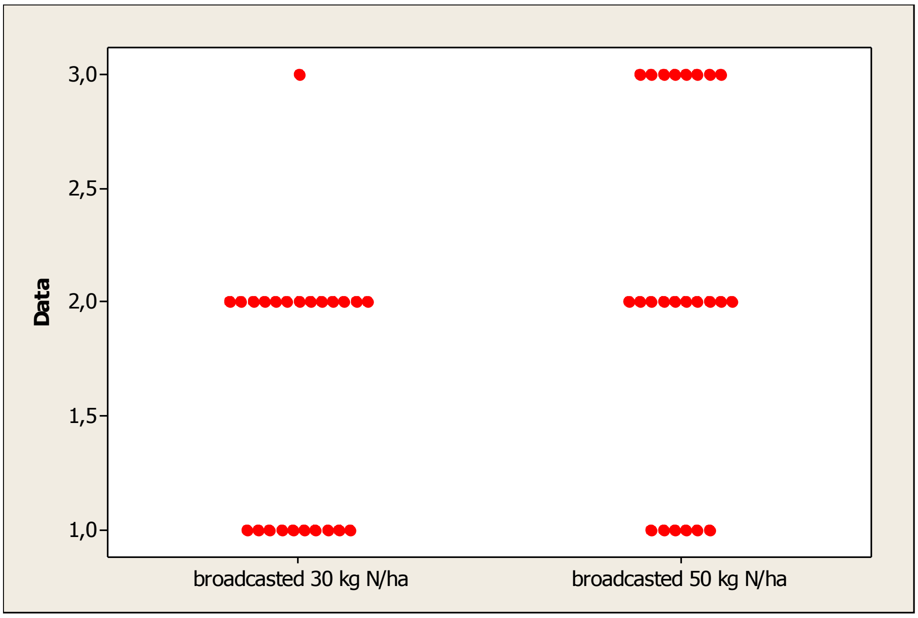

Figure 5. The amount of roots found in treatments with additive N of 50 kg ha^{-1} were significant (level 0,05) more than for plants that got 30 kg ha^{-1} additive N.

Discussion and conclusions

The fertilizer doses used in this trial are related to praxis in table 5. From this result it is interesting that the higher doses in the trial gave no significant increase in yield. Almost half as much as used by some growers gave not significant lower yield. This result indicates that the total amount used may be reduced. At time for harvest some plants developed chlorosis the last days of the test period. This may indicate that the N levels are a little too low, but since no difference were seen between treatments it could be the amount broadcasted rather than the starter level that need adjustments. As described in the results the plants showed several signs of plant damage. These damages make the results insecure since the symptoms can depend on climate conditions as well as the fertilizer level. The plant damages will be further discussed below.

Reasons for plant damage

Tipburn

The plants in project part two developed physical disorders and chlorosis. The problems with tipburn developed after two weeks, shortly before $Ca(NO_3)_2$ was added. The reasons for this disorder are complex and are not easily explained in a fertilizer trial. One reason for tipburn is too much nitrogen. Too much fertilizer in early growth should have been indicated by poor growth and week plants shortly after planting. In project part one the over-fertilized plants died within a couple of days. The result of the first weeks in project part two was good. It is more probable that the damages are a result of climate conditions in the climate chamber or maybe the climate conditions in combination with fertilizer strategy. The main reason for believing that the climate was the problem was that the damages developed at all plants in all treatments at the same time.

Another reason for tipburn may be uneven watering. Since watering have been done by hand this could have had an effect. Automatic watering could have given a more even humidity in the soil. Uneven watering may have given irregular availability to nutrients and by that fertilization could have been a part of the problem.

Leathery leaves and reduced growth

Studies show that air humidity in climate chamber influence transpiration rates. Growth is influenced by for example water potential and temperature of the leaves (Hammer *et al.,* 1978). Reduced transpiration reducing water uptake may have caused the leathery leaves in this trial. Low transpiration also makes local Ca deficiency causing that tipburn become more severe when transport is slowed down. The leathery leaves and reduced growth could also be caused by too much fertilizer. As seen in the literature study, Ryder (1999) describes leathery leaves as an effect of saline soils.

This study design was made to be as close to field conditions a Swedish summer as possible even if the work was done in a climate chamber. Of course a lot of factors deviate from field conditions. Examples are the wind in canopy level, air humidity and light level. The light level in these trials is very insecure and 5 weeks in to the second project part, it was recorded to be very low. There are no data available showing the decrease in light intensity but the measurements at beginning of project part one showed the right intensity. Light level may have been one factor leading to reduced growth and the plants leathery like leaves. The light level has not been similar to a Swedish summer day and the dark climate chamber may have caused photosynthetic problems.

Roots and over fertilization
The root measurements from project part one gave very insecure data and since the method was difficult to handle a lot of roots was lost. Another method was tested in project part two and gave significant difference. The grading is highly subjective, but the result indicates that the higher level of nitrogen gave more root growth. This result supports that the physiological damage are due to climate conditions rather than over fertilizing. Too much nitrogen should have caused fewer roots. Another reason for this result could be that a high N dose gave extensive root growth close to the plant but the roots never needed to spread throughout the pot. The sampling technique would in such a case give high presence of roots even if the total amount of roots in the pot is low. If that is the case this could indicate over-fertilization.

Results and future research need

Despite the problems in this study, the result indicate that a higher dose (126 kg N ha $^{-1}$) of N as starter fertilizer do not give a better yield than the low dose (68 kg N ha $^{-1}$). The starter fertilizer gave a good respond during the first weeks of growth in both project parts.

The use of starter fertilizers should, despite the problems, be considered as an important measure when trying to reduce the amount of nitrogen spread in iceberg lettuce production. The research must continue with field trials where climate of course may be difficult but not due to climate chamber problems. Starter fertilizer is a hopeful way and can in the future be added to the lists of N reducing measures for the grower. Minimizing the amount of N broadcasted over the field, ending up out of reach for the plant roots, is an important step when reducing nutritional leakage from iceberg lettuce production.

Growers guide

Some results from this study are relevant for the grower. The application method with two strains 3 cm from the plant gives good growth and the fact that no damages occurred during the first two weeks indicate that it can be used in production. There are restrictions in amount of fertilizer that can be placed close to the plant to prevent salt damages. This amount can be increased since these results indicate that the plants tolerate quite high doses. The starter fertilizer can be between 38 and 76 kg N ha $^{-1}$. Amount broadcasted N should probably be a little higher than 50 kg N ha $^{-1}$. All this results should be further investigated with field trials before used in commercial iceberg lettuce production.

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