Optimizing nitrogen fertilization in ley

Evaluating the usage of N-sensor and other tools for optimized nitrogen fertilization

Johan Johnsson

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Optimizing nitrogen fertilization in ley-Evaluating the usage of N-sensor and other tools for optimized nitrogen fertilization

Optimerad kvävegödsling i vall- Utvärdering av N-sensor och andra verktyg för optimerad kvävegödsling

Johan Johnsson

Supervisor:	**Karin Hamnér, SLU, Department of Soil and Environment**
Assistant supervisor:	Hugo Hjelm, Yara Sweden
Examiner:	Helena Aronsson, SLU, Department of Soil and Environment

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Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Science (NJ)
Department of Soil and Environment

Abstract

Nitrogen is an essential nutrient for plant growth. It has several functions in the plant and a lack of nitrogen can cause severe yield losses. Because of this nitrogen fertilization is important in modern agriculture, but as nitrogen prices are increasing and the fact that nitrogen leakage has a negative effect on the environment, optimizing the fertilization becomes important. Different tools can be used to optimize nitrogen fertilization. With a N-sensor the reflected light from plants is measured and based on this information the nitrogen uptake (SN value) can be calculated. Other tools for optimization are unfertilized and over optimal fertilized areas. An unfertilized area in the field can show how much nitrogen the soil can provide to the plant. An over-optimal fertilized area in the field can tell how high the plant's potential nitrogen uptake in the field is. The aim of this thesis was to study the usage of these tools in ley and suggest recommendations for field optimized nitrogen fertilization in ley. To study this, field trials with a system of 5-6 fertilization treatments without replicates were established on farms in Halland 2021 and 2022 and in Kalmar 2022. Included treatments were, 1. No added nitrogen, 2. Only slurry added, 3. Only mineral fertilizers added, 4. The farm's normal nitrogen fertilization and 5+6. Addition of nitrogen non-limiting for plant growth. The plots were measured with a Yara N-sensor and samples were cut for N-analysis at up to 4 occasions during the cropping season, with the last measurement being performed at harvest. The results showed that the Yara N-sensor overall underestimated the nitrogen uptake in ley one week before harvest and at harvest. In the unfertilized area there was a linear correlation between the SN value and the result from the N-analysis whereas in the Farm's fertilization and in the plots where nitrogen was unlimiting there were no linear correlation. This indicates that the sensor algorithm for ley need to be adjusted for Swedish leys. The nitrogen uptake at harvest in the unfertilized area differed between the regions with significant differences between Halland 2022 and Kalmar 2022. There were also differences between farms within the regions. This is in line with previous studies which have shown that the soil delivery of nitrogen can differ between fields. Another explanation for the differences in nitrogen uptake was different proportion of legumes in the leys. There was overall no significant difference between the Farm's fertilization and the treatment with extra nitrogen added for nitrogen uptake, dry matter yield or crude protein content between the regions. It was possible to see differences between farms within the regions which indicates that the potential nitrogen uptake differs at different fields. The nitrogen efficiency in the different treatments were estimated and differed, both within and between the regions. By knowing the soil delivery of nitrogen, the nitrogen efficiency of the fertilizers and how high the potential nitrogen uptake is, it could be possible to better plan for future nitrogen fertilizations in ley.

Keywords: nitrogen efficiency, optimized fertilization, SN value, unfertilized area, Yara N-sensor

Sammanfattning

Kväve är ett makronäringsämne som växter behöver för tillväxt. Kväve är en del av flera funktioner i växten och brist på kväve kan leda till stora skördeförluster. Med anledning av detta är kvävegödsling viktigt i modernt jordbruk, men med stigande gödselpriser blir det viktigt att optimera gödslingen. Det finns olika verktyg som kan användas för att optimera gödslingen. En N-sensor kan användas för att mäta reflekterat ljus hos växter och kan baserat på detta beräkna ett kväveupptag (SN-värde). Ett ogödslat område i fältet kan visa hur mycket kväve som marken kan leverera till grödan. Ett område där kväve inte är begräsande för tillväxt kan visa hur mycket kväve som grödan potentiellt kan ta upp. Målet med denna studie var att undersöka hur dessa verktyg kan användas i vall och ta fram rekommendationer för fältoptimerad kvävegödsling i vall. För att undersöka detta anlades ett fältförsök med 5-6 olika behandlingar utan upprepningar på olika gårdar i Halland-2021 och 2022 och i Kalmar- 2022. Behandlingarna var 1. Inget tillfört kväve, 2. Endast stallgödsel, 3. Endast mineralgödsel, 4. Gårdens kvävegödsling, 5+6. Kväve ej begränsande för tillväxt. Mätning med Yara N-sensor och klippning av prov för N-analys gjordes vid upp till fyra tillfällen där sista mätningen gjordes vid skörd. Resultatet visade att N-sensorn underskattade kväveupptaget en vecka innan skörd och vid skörd. I det ogödslade ledet fanns det en linjär korrelation mellan SN-värde och resultatet från N-analysen men i gårdens gödsling och ledet där kväve var obegränsat fanns ingen linjär korrelation. Detta indikerar att sensorns algoritm för vall behöver justeras för att passa svenska vallar. Kväve upptaget i det ogödslade ledet skilde sig mellan regionerna och var signifikant större i Halland 2022 än Kalmar 2022. Där fanns också skillnad mellan gårdarna inom regionerna. Detta stämmer med tidigare studier som visat att markleverans av kväve kan skilja sig mellan olika fält. En annan förklaring till skillnaden i kväveupptag var skillnader i baljväxtandelen i vallarna. Det var ingen skillnad i kväveupptag, biomassaskörd och råproteininnehåll mellan gårdens gödsling och där kväve var obegränsat. Det var möjligt att se skillnader på individuella gårdar vilket tyder på att den potentiella tillväxten skiljer sig åt mellan fält. Kväveeffektiviteten uppskattades i de olika behandlingarna och där fanns skillnader både mellan och inom regionerna. Genom att veta markleveransen av kväve, hur hög kväveeffektivitet olika gödselmedel har och hur mycket kväve växten kan ta upp är det möjligt att optimera framtida kvävegödslingar i vall.

Nyckelord: gödsling, kväve, kväveeffektivitet, nollruta, , SN-värde, , Yara N-sensor

Populärvetenskaplig sammanfattning

Kväve är ett näringsämne som jordbruksgrödor behöver för att växa. Vissa grödor kan leva i symbios med bakterier och få kväve från dem men de flesta måste gödslas med kväve. Kväve kan tillföras grödor genom gödsling med antingen organiska eller oorganiska produkter men även marken kan leverera en viss mängd kväve till grödan. Med anledning av att kvävepriset ökar och problem med näringsläckage finns ett behov av att optimera gödslingen. För att optimera gödslingen kan en N-sensor användas. En N-sensor är en ljussensor som mäter reflekterat ljus och biomassa från växter och kan baserat på det räkna ut hur mycket kväve som växten tagit upp. Baserat på kväveupptaget kan sedan en fältanpassad gödsling tas fram. Denna teknik används idag i flera av Sveriges vanligaste grödor men en gröda den skulle kunna användas mer i är vall. En vall i Sverige består ofta av olika gräs och klöverarter. Klövern kan leva i symbios med bakterier och få kväve av dem men gräset måste ta upp kväve från marken.

Syftet med detta arbete var att undersöka hur väl en N-sensor kan mäta kväveupptaget i vall, hur användning av rutor där inget kväve tillförts och rutor där kväve är obegränsat kan användas och föreslå hur kvävegödsling i vall kan förbättras. Detta genomfördes genom att försöksrutor som inte gödslats, gödslats med enbart stallgödsel eller mineralgödsel, gödslats med gårdens normala gödsling eller gödslats så att kväve var obegränsat anlades på gårdar i olika regioner och år i södra Sverige. Kväveupptaget i rutorna mättes med N-sensor och prover klipptes för labbanalys av kväveinnehåll vid olika tillfällen fram till skörd.

Resultatet visade att N-sensorn underskattade kväveupptaget i vall vid skörd och ungefär en vecka innan skörd. Det tyder på att arbete behövs för att optimera N-sensorn för att användas i svensk vall vid denna tidpunkt. Kväveupptaget i de ogödslade rutorna skiljde sig åt mellan de olika gårdarna och de olika regionerna. Det skulle kunna bero på att vädret skilde sig mellan de olika platserna eller att vallarna innehöll olika mängder baljväxter. Detta visar att kväveupptaget i ogödslad vall skiljer sig mellan olika platser och att det kan vara viktigt att känna till upptaget i sina egna fält när man planerar gödslingen. Det fanns i regionerna ingen skillnad mellan gårdens normala gödsling och rutan där kväve var obegränsat i kväveupptag, skörd eller råproteininnehåll. Det fanns dock skillnader på enskilda gårdar. Detta visade att gårdarna överlag låg på en hög nivå med sin egna gödsling och att en ruta där kväve är obegränsat skulle kunna användas för att se hur stort det potentiella kväveupptaget på fältet är. För att optimera kvävegödsling i vall i framtiden skulle dessa verktyg kunna användas. Mina resultat samt tidigare visar att upptaget i nollrutor skiljer sig mellan olika fält men, mer forskning kring användandet av nollrutor i blandvall skulle behövas då skillnader i klöverinnehållet försvårar att kunna uppskatta markens kväveleverans och mängden kväve som tas upp via fixering. Att det fanns skillnader på enskilda gårdar mellan gårdens gödsling och maxrutan vid skörd indikerar att detta kan vara ett bra sätt att kontrollera hur väl lantbrukaren har gödslat sin vall jämfört med maximalt kväveupptag. Fler studier skulle kunna göras för att se om det går att upptäcka skillnader tidigare, till exempel ungefär fyra veckor innan skörd för att kunna kombinera användande av rutor med obegränsad tillgång av kväve med delad kvävegödsling och på så sätt bättre anpassa mängden tillfört kväve. N-sensorn skulle också kunna användas vid denna tidpunkt. Om kvävegödslingen delas skulle N-sensor mätningar kunna göras fyra veckor innan skörd för att bättre kunna uppskatta mängden kväve som behöver tillföras. Det förutsätter dock att studier görs som undersöker hur väl N-sensorn mäter kväveupptaget vid denna tidpunkt då mina resultat tydde på att den underskattade upptaget vid senare tillfällen.

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0-N plot	Unfertilized area
Max-N plot	An area where nitrogen is nonlimiting for plant growth

1. Introduction

Nitrogen (N) is one of the most important plant nutrients and can often be a yield limiting factor in almost every crop. Nitrogen can be added to the plant in different forms and amounts. However, all nitrogen added to the crops is not used, as the nitrogen efficiency in the world is around 30-50% (Anas et al. 2020). The rest either stay in the soil or is lost in different ways. Because of increasing nitrogen prices and an ambition to decrease the surplus in nitrogen inputs, an optimal nitrogen fertilization can be both economically and environmentally beneficial for farmers.

A lot of studies to optimize nitrogen fertilization in wheat (*Triticum aestivum*) have been performed. One tool which has been studied a lot in winter wheat is the usage of “unfertilized areas” (0-N plot) to estimate the soil delivery. Another tool which also has been studied is the usage of “unlimited nitrogen areas” (Max-N plot) to estimate the potential nitrogen uptake. Besides knowing the potential nitrogen delivery and the potential uptake, the actual uptake can be measured. By measuring the chlorophyll content in the leaves, the nitrogen content can be estimated, as the chlorophyll content is positively correlated to the nitrogen content. A N-sensor can estimate the chlorophyll content as well as the plant matter meaning it can estimate the nitrogen uptake in above ground biomass of the plant.
By knowing the potential nitrogen uptake, the soil’s nitrogen delivery and the actual nitrogen uptake the nitrogen fertilization can be optimized. These tools have been tested and are used to a great extent in winter wheat. However, 0-N plots, Max-N plots and measuring nitrogen uptake with a N-sensor have not been tested to the same extent in another common Swedish crop, namely ley.

The purpose of this study was to evaluate the potential of 0-N plots and Max-N plot to optimize nitrogen fertilizing in ley. The study also examined the usage of the N-sensor to measure nitrogen uptake in ley for different fertilization strategies.
The objectives of the study were:

1. Evaluate how well the N-sensor can estimate nitrogen uptake in ley.
2. Study how nitrogen uptake in 0-N plots differ between farms
3. Evaluate the usage of 0-N plots and Max-N plots in ley
4. Suggest strategies for field optimized nitrogen fertilization in ley

2. Background

2.1 Nitrogen

Nitrogen is the most common element in the atmosphere and a basis for life. The atmosphere contains around 78% gaseous nitrogen and most of the world's nitrogen are stored there (Smil 1997). Besides the atmosphere, nitrogen is present in the water, in the soil and on land.

2.1.1 Nitrogen in the soil

Nitrogen can be present in the soil in organic, inorganic and gas form. There is more organic than inorganic nitrogen in the soil. Inorganic nitrogen: ammonium or nitrate, is the main source for the plant nitrogen uptake, but some organic nitrogen can also be taken up (Näsholm et al. 2000). Nitrogen gas (N_2) can be converted into ammonium (NH_4^+) ions by nitrogen fixing bacteria or react with oxygen under high energy and create nitrate (NO_3^-) ions (Yuan et al. 2013). The ammonium ion is positively charged and can attach to negatively charged particles in the soil and thus have low mobility in the soil. The nitrate ion is negatively charged and don't attach to particles in the soil to the same extent as ammonium and therefore have a higher mobility. Because of its high mobility, nitrate can follow water and leach from the soil (Di & Cameron 2002). The amount of leached nitrate differs depending on soil type and crop type. Leaching tend to decrease with a higher clay content in the soil (Johnsson & Mårtensson 2002). In general, perennial crops reduce the leaching compared to annual crops. A permanent ley can leach 5-20 kg N/ha. In Sweden, winter wheat can leach 15-45 kg N/ha (Stenberg et al. 1999).

Nitrogen in organic form is bound to carbon atoms in different structures. This nitrogen is mostly unavailable for plants. The uptake of organic nitrogen is larger among forest plants compared to agricultural, which can be due to higher mineralization rates in agricultural land which makes more inorganic nitrogen available (Näsholm et al. 2000).
Mineralization occurs when the soil's micro life decomposes the organic matter, making the nitrogen inorganic. A higher amount of organic matter in the soil give

a higher potential mineralization (Börjesson et al. 1999). During decomposition, ammonia is released which can react with hydrogen ions in the soil and create ammonium. The amount of nitrogen that can be released through mineralization varies depending on the amount of organic matter, the microbe community in the soil, the clay content and the soil moisture (Delin & Lindén 2002). Ammonium can be fixed to clay ions making it unavailable for the plant, which means that less nitrogen can be available for the plant after mineralization with an increasing clay content. The clay content also affects the soil's ability to retain water and thereby control the moisture and oxygen availability in the soil.

The factors controlling the mineralization can be affected by the cultivation history of the soil (Curtin et al. 2017). Soils where organic fertilizers such as animal manure has been used for a long time have a higher soil delivery of nitrogen than soils connected to farms without animals. Organic matter in soils increase when manure is added and decrease if no fertilizers are added (Ladha et al. 2011). The amount of organic matter can also increase if only mineral fertilizers are added, compared to if no fertilizers are used since the plant develop a bigger root biomass which increase the soil's organic matter (Singh Brar et al. 2015).

The potential nitrogen that can be released through mineralization from soils can vary between 20 and 170 kg N/ha and year in a field according to Swedish studies (Delin & Lindén 2002; Wetterlind et al. 2007). Other studies have found that 300-400 kg N/ha can be released through mineralization under optimal conditions (Börjesson et al. 1999; Curtin et al. 2017).

In parallel to mineralization, immobilization can occur. Immobilization occurs when microorganisms take up inorganic nitrogen and use it for growth to retain their C:N ratio, transforming it from inorganic to organic form (Brust 2019). Whether net mineralization or net immobilization occur depends on several factors such as soil moisture, temperature and C:N ratio of the organic matter. A high C:N ratio, when there is much carbon compared to nitrogen, usually means net immobilization. A low ratio, when there is much nitrogen compared to the carbon, usually lead to net mineralization The mineralization increase when soil moisture increase and the highest potential mineralization is at 80% of the field capacity (Wang et al. 2006; Guntiñas et al. 2012). Because of this a higher soil moisture tend to give net mineralization. However, the net mineralization depends more on temperature than moisture and increase over time with increasing temperature.

Nitrification occurs in the soil. The nitrification process is when ammonium is transformed to nitrate. The process requires oxygen and occurs in two steps, from ammonium to nitrite (NO_2^-) and from nitrite to nitrate. The first step is controlled by ammonia-oxidizing archaea and bacteria to release energy. Ammonium fertilizers can increase the activity of the bacteria but not the archaea. Bacteria have a lower optimal temperature for oxidizing (Ouyang et al. 2017). Because of this it is usually the bacteria who perform the ammonia oxidizing in agricultural soils (Ouyang et al. 2016). The second step is oxidizing nitrite to nitrate which is also performed by bacteria to produce energy (Daims et al. 2016). A high C:N ratio decreases the activity of the ammonia-oxidizing organisms (Xiao et al. 2021).

Under anaerobe soil conditions nitrate is transformed to N_2O or N_2 by denitrification bacteria in the denitrification process (Coskun et al. 2017). This can occur in agricultural soils when water content is high and thereby a low oxygen content. Because of the lack of oxygen, the bacteria use nitrate as substitute for oxygen in the oxidation process.

Gaseous nitrogen is also present in the soil. Plants cannot use this nitrogen directly. However, nitrogen fixating bacteria which can live in symbiosis with legumes can use it and convert it into NH_4^+ (Masson-Boivin et al. 2009). Legumes create nodules on the roots in which the bacteria live. The legume gives carbohydrates to the bacteria and receives NH_4^+.

2.1.2 Nitrogen in the plant

Nitrogen has many different functions in the plant. The nitrogen uptake via roots is usually active but when concentrations are high passive uptake is possible of both ammonium and nitrate (Glass 2003; Li et al. 2013). The nitrogen is transported from the roots to the shoot using transporters (Glass et al. 2001). The transporters are different for ammonium and nitrate. Ammonium is toxic for plants in high doses and because of this some of the ammonium is converted to nitrate or amino acids in the roots (Xu et al. 2012). Nitrate is not toxic and can be stored in the vacuoles (Li et al. 2013). Ammonium can be used in amino acid synthesis while nitrate needs to be transformed to ammonium before it can be used in the synthesis (Kant 2018). The nitrogen is used to create amino acids, either in the roots or the shoot which are used to build proteins which can be either soluble or insoluble. Proteins have several functions in the plant and the most common is acting as enzymes. Enzymes have many functions in the plants, for example in the first step of the Calvin cycle were RubiscCO is used in the CO_2 fixation. RubisCO is a soluble protein and is the most common protein in leaves (Xu et al. 2012). Enzymes can also act as transporters. Insoluble proteins can for example be part of different chlorophyll protein complex. Beside amino acids, nitrogen is a part of nucleotides which are used to create DNA.

Since proteins are needed both for the chlorophyll molecule and as enzymes in photosynthetic reactions, a lack of nitrogen can lead to decreased growth, pale or yellow leaves and withering (Mei & Thimann 1984). Nitrogen is mobile in the plant and can be relocated from older to younger leaves and because of that, deficiency symptoms arise on the oldest leaves first. Depending on when the nitrogen deficiency occurs, the plant is affected in different ways (Jeuffroy & Bouchard 1999). In cereals, if the deficiency occurs during tillering it will lead to fewer tillers and termination of small tillers whereas if the deficiency occurs during meosis fewer grains are created on each spike.

Nitrogen content of crops differ (Greenwood et al. 1980). Legumes are the crops with the highest nitrogen content in percentage of biomass when no nitrogen is added. When nitrogen is added other crops can have a higher nitrogen content than legumes depending on their ability to take up the nitrogen. The nitrogen content of the plants in ley mixtures depends on amount of added nitrogen, the total biomass and time of the season. Nitrogen content is higher with a higher biomass and is higher in leaves compared to stems. In percentage of biomass, the nitrogen content is higher in red clover than grasses (Huss-Danell et al. 2007). Clover has the similar nitrogen content during the entire year while the content in grasses decrease after the first harvest.

2.1.3 Nitrogen fertilization

Nitrogen is important for crops and is often a yield reducing factor. Nitrogen fertilization can be done by using different sources, both organic and inorganic. One organic source is manure. In animal manure, some nitrogen is in inorganic form, and some is part of the organic matter and can potentially be available after decomposition. The inorganic part differs depending on the kind of manure. In slurry the inorganic part is around 50-70% of the total nitrogen content while in solid manure it is around 25% (Jordbruksverket 2022b). In animal manure, around 10% of the organic nitrogen becomes inorganic during the first year (Eriksson 2004). Nitrogen in animal manure can be lost due to ammonia discharge, both before and after spreading (Mattila et al. 2003). The discharge depends on several factors such as the pH of the manure, the temperature at spreading and the spreading technique. Ammonia discharge is higher when spreading manure without injecting it into the soil (Salomon et al. 2013). The ammonia discharge also increases if the temperature is high during and after the spreading (Rodhe et al. 2015). When the pH is high the ammonia discharge increases but if the pH of the manure is lowered before spreading the discharge decrease.

Inorganic nitrogen or mineral nitrogen is also commonly used for fertilization in different crops. Inorganic nitrogen is in ammonia or nitrate form and the fertilizers can be a mix of them or only one, for example ammonium-nitrate. The products usually contain at least one more macronutrient beside nitrogen. The mineral fertilizers commonly used in Sweden are nitrogen-sulfur (NS) products, nitrogen-phosphorus-potassium (NPK) products and nitrogen-calcium (N-Ca) products (Yara 2022). The entire nitrogen content of mineral fertilizers is available for the plant the first year but the uptake efficiency can differ depending on if there are any growth limiting factors (Mengel et al. 2006).

The need of nitrogen fertilization differs between crops and is also related to the potential yield of the crop whereas a higher yield implies a higher nitrogen demand. A factor which affects if nitrogen fertilization is needed or not is if the crop can live in symbiosis with nitrogen fixating bacteria, as they receive nitrogen from the symbiosis and do not need any additional.

Quality aspects can influence nitrogen fertilization strategies. For example in wheat for flour production, the nitrogen fertilization is often divided into several applications to achieve a desired protein content and quality (Xue et al. 2016). All nitrogen can also be given at a single fertilization occasion if the quality is not as important. How efficient the nitrogen uptake is, depends on how the fertilization is performed. In general, the efficiency decreases when high amounts of nitrogen is applied at the same occasion (The et al. 2021). If the fertilization is split in smaller doses the efficiency in general increases.

To better estimate the crop nitrogen demand it is important to know nitrogen delivery from the soil the specific year. One way of estimating the soil delivery is to use of 0-N plots, which is an area where no nitrogen is added and the plants nitrogen uptake depends solely on the delivery from the soil (Wetterlind 2010). The soil's nitrogen delivery can differ both between and within fields and differs between years. The plants potential nitrogen uptake during the season can also be important to estimate to see if complementary fertilization is needed as the potential uptake can vary within fields and between years. By adding enough nitrogen to make it non limiting for crop growth a Max-N plot is created (Jordbruksverket 2022b). By measuring the difference in nitrogen uptake between the Max-N plot and the normal fertilization it is possible to see if nitrogen is limiting the plant growth and if additional nitrogen fertilization is needed (Engström & Piikki 2016).

2.2 N-sensors

2.2.1 Principles of N-sensors

Crop demand of nitrogen can differ within a field during the cropping season. To account for these differences a N-sensor can be used when spreading nitrogen fertilizers. A N-sensor measures the light reflected from a plant. The sensor can be either passive, (not sending out any light) or active (sending out light). Passive sensors cannot be used at dawn or by night while active sensors can be used at any time. Based on the reflected light, the chlorophyll content and biomass can be calculated. There is a correlation between a plant's chlorophyll content and nitrogen concentration which means the nitrogen uptake can be calculated based on the chlorophyll content and biomass of the plant. Based on the plant's nitrogen uptake and the plant's biomass a variable nitrogen fertilization can be calculated using the sensor specific algorithm (Tremblay et al. 2008).

A N-sensor measures the reflected light from the plant which is in the spectrum 400-1000nm. The sensor measures multiple wavelengths to calculate a ratio. A common reflectance ratio is one waveband in the visible area and one in the near infra-red. When an active sensor is used it can be better to use both wavelengths in the near-infra red area (>750 nm) (Reusch 2005). Chlorophyll reflects a higher amount of light in the infrared area compared to the red (Vian et al. 2018).

Yara's N-sensor calculates a normalized sensor value (SN) which is the crop's current nitrogen content in above soil biomass. The SN value is calculated based on reference material of the studied crop which is used to develop a sensor-based algorithm for the specific crop.

2.2.2 Previous studies

Several studies with different models of N-sensors have been performed. In Sweden, a study to measure the soil delivery of nitrogen and optimal nitrogen fertilization in winter wheat was performed from 2007-2009 at different locations in the west and east part of Sweden (Wetterlind 2010). The sensor used was Yara's handheld N-sensor. The study showed that both the economical optimal nitrogen fertilization and soil delivery of nitrogen differed between the years. This study also found that a N-sensor measurement in a 0-N square at the stem elongation phase could give information about the soil's nitrogen delivery, which could be used to calculate a rate for complementary nitrogen fertilization.

In one study from 1998-2000, the nitrogen uptake at DC stage 30 (before the first node is visible) in winter wheat was measured with a sensor (Lukina et al. 2001). This study found that based on the nitrogen uptake in these growth stages the potential yield and potential nitrogen need could be calculated. By using this method on an entire field, it would be possible to reallocate nitrogen from areas with low yield potential to areas with high potential.

Another study was performed in winter wheat in 2012-2014 to check the possibility of using Yara's N-sensor to estimate the future yield before complementary fertilizing (Engström & Piikki 2016). The study found that it was possible to predict the yield when measuring with the N-sensor in growth stage DC 37 (flag leaf visible) to DC 63 (flowering). According to their results, the accuracy of the yield estimation increases when sensor measuring is performed after DC45 in some individual years. However, when the results from all years were combined the accuracy of the yield estimation was higher when measuring in DC 37-42. Engström och Pikkii (2016) say that this shows that it is possible to estimate the needed complementary fertilization in DC 37-39 by using N-sensor, but they believe that more data is needed to build a better prediction model.

A study performed in 2016 examined how optimal nitrogen fertilization for grass leys can be estimated using light sensors (Berry et al. 2017). The sensor used in the study was a HandySpec MMS1 NIR enhanced handheld passive spectrometer. The study found that the spectral reflectance index had a high potential of estimating the nitrogen content of grass but that more data for calibration was needed. It was found that a strong indicator of the grass's nitrogen need was the soil nitrogen delivery and that the soil delivery could be estimated by measuring with a N-sensor before fertilization. Berry et al. (2017) argued that if the fertilization of the grass was performed on multiple occasions, the N-sensors ability to estimate variations in the soil nitrogen delivery and therefore optimal nitrogen fertilization could increase.

In a study performed in Sweden from 2003 to 2005 the possibility to divide fields into different zones based on soil mineralization was evaluated (Wetterlind et al. 2007). It was tested how to create the zones based on different methods. Zone dividing was based on organic matter and clay content, NIR reflectance from the soil and light reflectance from above soil biomass. To measure the above soil biomass a N-sensor from Yara was used. The crops tested were winter wheat and oat and sensor measuring was performed in DC 39 and DC 69. The study found that all these methods could be used to divide the field into mineralization zones. However, the study found that it was necessary to have 0-N plots to estimate the mineralization no matter what method that was used. Wetterlind et.al (2007) says that information about past years mineralization combined with 0-N plots could be used when fertilizing with a N-sensor to optimize fertilization. This would be done by achieving a healthy stand in zones with low mineralization and limit the amount of unused nitrogen in zones with high mineralization.

2.3 Ley

2.3.1 Ley in Sweden

Ley is the crop grown on the largest area in Sweden (Jordbruksverket 2022a). It is mainly used for fodder, but there are other areas of usage as well such as biogas production and green manure. Ley can be grown in the entire country and on all type of soils. A common composition of ley is a mixture of grass and legumes, but pure grass leys are also grown (Martin et al. 2020). The composition of the ley can differ depending on where it is grown and the purpose of it. Grasses which can be part of a ley mixture includes timothy (*Phleum pratense*), rye grass (*Lolium spp.*), different fescues (*Festuca spp.*) and cocksfoot (*Dactylis glomerate*). Legumes commonly used in ley mixtures are red clover (*Trifolium pratense*), white clover (*Trifolium repens*), and alfalfa (*Medicago sativa ssp. sativa*).

There are three main quality aspects in ley; the energy content, the crude protein content and the fiber content (NDF). The quality is affected by several factors including the nitrogen fertilization and the timing of the harvest. The energy and crude protein content decrease during crop development while the fibre content increase over time. The crude protein content depends on the nitrogen uptake. The dry matter amount and quality aspects of the ley is also controlled by the number of harvests. The dry matter amount for each harvest decreases with an increasing amount of harvests, as well as the total dry matter yield while the protein and energy content of the total yield increase (Gunnarsson et al. 2014). The desirable quality depends on the purpose of the ley and what animal the fodder is produced for. For high producing dairy cows, a recommended energy content is 11,5 MJ and the recommended crude protein content is 150-180 g crude protein/ kg ts (Groot et al. 2007).

2.3.2 Fertilization of ley

Fertilization of a ley can be performed in different ways. Manure is commonly used, which can be either in solid or liquid form as slurry. Besides manure, mineral nitrogen can be used for fertilization. A common strategy is to fertilize with manure to cover the demand of phosphorous and potassium and complement with a mineral nitrogen product to cover the nitrogen need.

The nitrogen need of ley depends on several factors. Some of the factors are the same as for other crops, that is expected yield and desired quality, but there are some factors that are unique. One factor is that the composition of the ley can vary. A pure grass ley has a higher demand of nitrogen input than a mixture of grass and legumes if the same yield and protein content is wanted (Halling 2022). Also, the percentage of legumes in the mixture affect the nitrogen need where a higher percentage of legumes in the mix implies a decreased nitrogen demand. The amount of legumes in a ley tends to decrease over years which increase the nitrogen need in older ley crops (Hallin 2019). However, the amount of nitrogen that the legumes receive through N-fixation can depend on the weather conditions (Mårtensson & Ljunggren 1984; Watson et al. 2015). Other factors which affect the nitrogen need are the precipitation and the temperature since they affect the growth of the ley and thus how high the potential nitrogen uptake is. Another factor which effects the nitrogen need is the number of harvests and which harvest it is. The nitrogen need is in general the highest before the first harvest because of the higher yield potential and decrease over time. Because of these factors, it can be difficult to estimate the total nitrogen need in a grass-clover ley.

There is usually more than one harvest in ley and because of that a recommendation is to fertilize before each harvest to receive similar quality in all yields. Both organic and inorganic fertilizers can be used to each harvest. When spreading slurry in the summer there is an increased risk of a high ammonia discharge due to the generally warmer weather (Rodhe 2000). Ley is usually only fertilized once in the spring before the first harvest, but studies have been made to examine the possibility to split the fertilization in two. One study was performed in 2018-2020 in grass leys in Sweden and in Norway (Bakken & Nadeau 2023). The leys were fertilized with 110 kg N/ha, either in one fertilization, or two with the second fertilization being performed two or four weeks before harvest, which was performed at ear emergence of timothy. The study found that splitting the fertilization did not affect the raw-protein content. The total yield could be lowered if the second fertilization was performed two weeks before ear emergence. However, the nitrogen remained in the soil and was taken up by the regrowth. The authors recommended to fertilize four weeks before harvest as the nitrogen uptake is weather dependent and claims that it can be beneficial with high nitrogen prices and fluctuating weather conditions.

3. Material and methods

To study the nitrogen uptake in ley, field studies on dairy farms were conducted in 2021 on 4 farms in Halland and in 2022 on 4 and 5 farms in Halland and Kalmar respectively. The nitrogen uptake was studied by N-sensor measuring and by sampling of biomass for analysis of nitrogen content. All studied fields were grown with second year ley. In Halland 2021, N-sensor measurement and ley sample collection was performed by Växa Halland. In Kalmar 2022, N-sensor measurement and ley sample collection was performed by Hushållningssällskapet Kalmar.

3.1 Experimental design

On each farm, a system of five or six different nitrogen fertilization treatments were created in the end of March and beginning of April.
The fertilization treatments were 1. “0-N”- no nitrogen added”, 2. “Only slurry”- the added nitrogen was received only from the slurry used by the farm, 3. “Only mineral N”-the added nitrogen was received only from the mineral fertilizers used by the farm 4. “The Farm’s fertilization”- the nitrogen fertilization the farm used for the field with both slurry and mineral fertilizers, 5. “Max-N” -the farms nitrogen fertilization plus additional 55 kg of nitrogen. On the fields in Kalmar there was also an additional treatment 6. “Max-Max N”-55 kg more nitrogen than in Max-N.

3.2 Fertilization

The farmer of each farm created the fertilization treatments plots. When spreading slurry in the spring, an area of roughly 12x15 meter was left unfertilized. The area was marked after spreading. Before spreading mineral fertilizers, a tarpaulin was placed which covered an area of around 4x4 meter in the part which had not received any slurry and 4x4 meter in the part which had received slurry. After the mineral fertilizer was spread the tarpaulin was removed and the area it had covered was marked. These areas resulted in the “0-N” and the “Only slurry” plots. An area of 4x4 meter was marked next to the 0-N plot in the part which hadn’t received any slurry but had received mineral fertilizers, this was the “Only mineral N” plot. Adjacent to the “Only slurry” plot two areas of 4mx4m meters were marked in the part which had received both slurry and mineral fertilizers. The first was “The Farm’s fertilization” plot and to the second area extra mineral fertilizers, was added to create the “Max-N” plot. The “Max-Max-N” plot was created in the part which had received both slurry and mineral fertilizers by adding double the amount of extra mineral nitrogen compared to the Max-N plot.

The nitrogen effect from the slurry was based on the ammonium nitrogen content according to the last performed nutrient analysis of the slurry. It was assumed that no losses occurred when spreading.

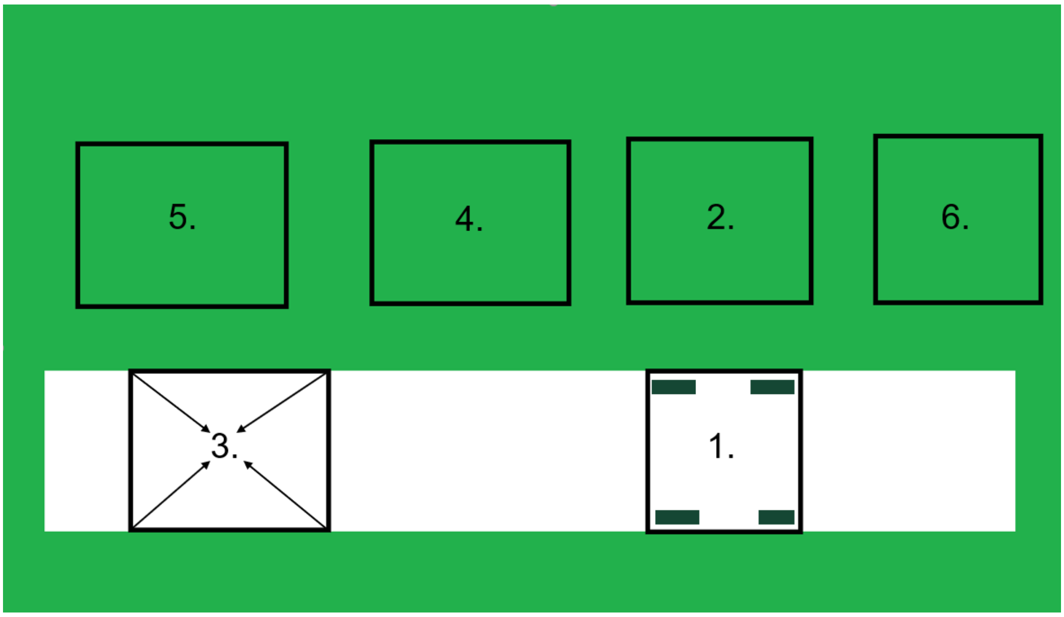

Figure 1 Schematic picture of the different fertilization plots 1. 0-N, 2. Only slurry, 3. Only mineral nitrogen 4. The Farm’s fertilization, 5. Max-N, 6. Max-Max-N, Arrows in plot 3.: How N-sensor measuring was performed, Black squares in plot 1.: Areas cut for N analysis, White area: Area which have not received any slurry, based on (Hjelm 2021)

Table 1 Location of the farms and nitrogen fertilization in the different treatments in Halland 2021, Halland 2022 and Kalmar 2022

Farm	Location	1. 0-N (kg N/ha)	2. Only slurry (kg N/ha)	3. Only mineral N (kg N/ha)	4. Farm's fertilization (kg N/ha)	5. Max-N (kg N/ha)	6. Max-Max-N (kg N/ha)
A	Getinge	0 (+3)[1.]	27(+3)	65 (+3)	95	149	-
B	Getinge	0 (+5)	32(+5)	69 (+5)	106	160	-
C	Sibbarp	0	38	60	98	152	-
D	Vessingebro	0	53	48	101	155	-
E	Getinge	0 (+5)	38 (+5)	64 (+5)	107	161	-
F	Getinge	0 (+5)	37 (+5)	65 (+5)	102	156	-
G	Vessingebro	0	61	48	109	163	-
H	Vinberg	0 (+5)	61 (+5)	38 (+5)	99	153	-
I	Öland	0	25	100	125	180	235
J	Kalmar	0	50	27	77	135	187
K	Kalmar	0	35	100	135	190	245
L	Öland	0	28	19	47	101	157
M	Öland	0	35	100	135	190	245

1. Number in parentheses= Estimated effect from slurry spread in the autumn 2021

3.2.1 Halland 2021

The fertilization areas were created in the spring of 2021 on farms A-D. Two of the farms spread slurry in the autumn and it was assumed it would contribute with 3 or 5 kg N/ha in the spring, depending on the amount of slurry spread. The effect from the autumn spread slurry was added to the fertilization in each treatment on these farms, including the 0-N treatment (Table 1).

Fertilization in the spring was performed in the end of March and in the beginning of April. All farms spread slurry in the spring with a corresponding N-rate of 27-53 kg N/ha. All farms also spread mineral fertilizers with a rate of 48- 69 kg N/ha. This resulted in a “Farm’s fertilization” of around 100 kg N/ha. For the Max-N plot an additional 54 kg N/ha was added making the amount of nitrogen around 150 kg.

3.2.2 Halland 2022

In the region Halland in 2022, three farms spread slurry in the autumn. For these farms, this fertilization was assumed to correspond to 5 kg N/ha and this amount was added when documenting the N-rate in all treatments, including the 0-N treatment.

Farms E-H in Halland 2022 fertilized with slurry and mineral fertilizers in the end of March and in the beginning of April. The added nitrogen from slurry spread in the spring was between 32 and 61 kg N/ha (Table 1). Added nitrogen from mineral fertilizers was between 38 and 65 kg N/ha. The N-rate of the “Farm´s fertilization” was around 100 kg N/ha. Two farms had slurry as the major nitrogen source and two farms had mineral nitrogen as the major nitrogen source. To create the Max-N treatment, an additional 54 kg N/ha was added making the total nitrogen fertilization 150-160 kg N/ha.

3.2.3 Kalmar 2022

On the farms I-M in Kalmar 2022, fertilization was performed in the end of March and in the beginning of April. The amount of nitrogen added from slurry was between 25-50 kg N/ha (Table 1). Added nitrogen from mineral fertilizers was 19-100 kg N/ha. The “Farm’s fertilization” was 47-135 kg N/ha. To the Max-N and Max-max-N treatment an additional N-rate of around 55 or 110 kg N/ha was applied and these treatments received in total 101-190 or 157-245 kg N/ha, respectively.

3.3 Data collection

Data collection was performed by measurements with a N-sensor and by cutting aboveground biomass samples for analysis of nitrogen content.

All plots were measured with a HandySpec MMS1 NIR enhanced handheld passive spectrometer (Yara’s handheld N-sensor) to estimate the nitrogen uptake. The spectrometer measures the reflectance spectra in the visible and near infrared spectral. Four measurements were performed, one in each corner of the fertilization plot to avoid shadowing or influence from the suns positioning. For each measurement, the N-sensor was directed towards the middle of the plot and an average value was calculated for each plot. From the measurements, a SN value was received. The SN value was calculated by Yara based on the sensor-based algorithm developed for ley with reference material from mostly pure grass leys in Germany and the Netherlands. The SN value was presented in kg N accumulated in aboveground biomass per hectare. Measurements were performed on 3-4 occasions on every site where the last measurement was representing the nitrogen content at harvest.

Ley samples were cut for determination of biomass and nitrogen content. Samples were cut when the ley was deemed high enough to receive a representative sample of the plot. The sample area was 0,5 m^2, except in Kalmar 2022, where the total area was 0,25 m^2 in some plots. The samples were collected by cutting an area of 0,5x0,25m (0,25mx0,25m in some plots in Kalmar) in every corner of the plot with 5 cm stubble. Cutting was made in the corners to avoid disturbance on future N-sensor measurements. Starting on the same day as collection, the samples were dried in 60 degrees for 48 hours and weighed. The samples from Halland 2022 and Kalmar 2022 were sorted in grass and legume fractions and weighed separately. After sorting, all samples were sent to Yara's lab in Germany, grinded and analyzed for nitrogen content.

The nitrogen uptake in kg N/ha was calculated by multiplying the nitrogen concentration from the N-analysis with the dry weight of the cut biomass and adjust it depending on the cut area in each plot. Only the samples where there was a defined area of cutting were used. The nitrogen uptake based on the result from the N-analysis was then used to calculate the crude protein content. The crude protein content was calculated by multiplying the nitrogen uptake with 6,25 and divided with the biomass weight.

3.3.1 Halland 2021

Measurements with N-sensor and cutting of ley samples were performed at 10, 17 and 24 May (Table 2). Ley samples were cut from every plot at every date but only the cutting on the 24 May was made from a defined area of 0,5 m^2.

Table 2 Dates with performed measurements with N-sensor and biomass cutting in the different farms and treatments in Halland 2021

Farm	10 May		17 May		24 May	
	N-sensor	Cutting[2.]	N-sensor	Cutting[2.]	N-sensor	Cutting
A	1-5[1.]	-	1-5	-	1-5	1-5
B	1-5	-	1-5	-	1-5	1-5
C	1-5	-	1-5	-	1-5	1-5
D	1-5	-	1-5	-	1-5	1-5

1. 1=0-N, 2=Only slurry, 3= Only mineral fertilizer, 4= Farm's fertilization 5= Max-N
2. An unknown area was cut for N-analysis

3.3.2 Halland 2022

N-sensor measurement was performed on three occasions 28 April, 15 May and 25 May (Table 3). On farm G the Max-N plot was created on 28 April and therefore no measurement was performed in Max-N treatment at farm H on 28 April.

No ley samples were collected for nitrogen analysis at the 28 April since there was too little biomass to receive a representative sample.
Ley samples from every treatment were collected on the 14 or 15 May. On the 25 May, ley samples from the 0-N, Max-N and the Farm's fertilization treatments were collected.

Table 3 Dates with performed measurements with N-sensor and biomass cutting in the different farms and treatments in Halland 2022

Farm	28 April		15 May		25 May	
	N-sensor	Cutting	N-sensor	Cutting	N-sensor	Cutting
E	1-5[1.]	-	1-5	1-5	1-5	1,4,5
F	1-5	-	1-5	1-5	1-5	1,4,5
G	1-4[2.]	-	1-5	1-5	1-5	1,4,5
H	1-5	-	1-5	1-5	1-5	1,4,5

1. 1=0-N, 2=Only slurry, 3= Only mineral fertilizers, 4= Farm's fertilization 5= Max-N
2. Max-N treatment (5) was created on 28 April, no N-sensor measuring performed at G in that treatment on 28 April

3.3.3 Kalmar 2022

Measurement with the N-sensor was performed on four occasions at every site (Table 4). The first measuring was performed 27-28 April. No ley samples were collected as the ley had to little biomass to receive a representative sample. The second measurement was performed on 5 May and ley samples were collected from treatment 1 and 4 on two of the farms (J and K). The third measurement was performed 12-13 May. Ley samples were collected from treatment 1 and 4 on all farms. On farm M samples were collected from all treatments. The last N-sensor measurement was performed 18-20 May ley samples were collected from every treatment on every farm. In treatment 1 and 4 the sample was always collected from an 0,5 m^2 area. In the other treatments, the area was 0,25 m^2.

Table 4 Dates with performed measurements with N-sensor and biomass cutting in the different farms and treatments in Kalmar 2022

Farm	27-28 April		5 May		12-13 May		18-20 May	
	N-sensor	Cutting	N-sensor	Cutting	N-sensor	Cutting	N-sensor	Cutting
I	1-6[1.]	-	1-6	-	1-6	1,4	1-6	1-6
J	1-6	-	1-6	1,4	1-6	1,4	1-6	1-6
K	1-6	-	1-6	1,4	1-6	1,4	1-6	1-6
L	1-6	-	1-6	-	1-6	1,4	1-6	1-6
M	1-6	-	1-6	-	1-6	1-6	1-6	1-6

1. 1=0-N, 2=Only slurry, 3= Only mineral fertilizers, 4= Farm’s fertilization 5= Max-N, 6= Max-max-N

3.4 Weather data

Data from weather stations located close to the farms were used to document precipitation and temperatures (Table 5). There can be differences between the weather at the weather station and the site of the trial.

The precipitation in 2022 on the weather station Kalmar D located west of Kalmar from 1 April to 20 May was 25 mm which was below the average precipitation for the region (SMHI 2022a). On the weather station Eftra D in Halland, located between Getinge and Falkenberg the precipitation in 2021 from 1 April to 24 May was 123 mm which was above the average precipitation of the region (SMHI 2022b). On Eftra D in 2022 from 1 April to 26 May the precipitation was 77 mm which was below the average precipitation of the region.

Accumulated temperature sum for Halland 2022 was 209 °C from 1 April to 25 May (SMHI 2022b). This was slightly warmer than average temperature sum of the region. In Halland 2021 the temperature sum was 159 °C from April 1 to 24 May which was slightly colder than the average temperature sum of the region. In Kalmar 2022 the temperature sum from April 1 to 20 May was 141 °C (SMHI 2022a). This was slightly colder than average temperature sum of the region. The base temperature when calculating the accumulated temperature sum was 5 C.

Table 5 Weather data at the different sites from April 1 to last measurement (SMHI 2022a, SMHI 2022b)

Site	Weather station	Accumulated temperature sum (°C)	Precipitation (mm)
Halland 2021	Eftra D	159	123
Halland 2022	Eftra D	209	77
Kalmar 2022	Kalmar D	141	25

3.5 Statistical analysis

All statistical tests were performed in JMP Pro (SAS Institute) and limit for statistical significance was set to p=0,05.

The sites were grouped based on the location of the farm and year in three groups: Halland 2021, Halland 2022 and Kalmar 2022. The farms were grouped based on regions and year as it was estimated that the precipitation and temperature on farms from the same region was similar, resulting in similar growth conditions.

The N-sensor value was correlated with the corresponding nitrogen uptake according to the N-analysis in a scatter plot and a linear regression analysis was performed. There were several analyses done which included different sub-sets of the data: 1) All treatments grouped together, 2) only the 0-N treatment and 3) Max-N, Farm's fertilization and Max-Max-N together were tested. The sampling time used was 12-15 May and 18-25 May since there were both N-sensor measurements and N-analysis values at these dates.

To determine if there were statistical differences between regions and treatments for yield, nitrogen uptake and crude protein content, one-way ANOVA analyses were performed, and standard deviation was calculated to illustrate variation within treatments. Treatments tested were 0-N, Farm's fertilization and Max-N.

To calculate the nitrogen efficiency at harvest the result from the N-analysis was used. The nitrogen uptake in the 0-N plot was removed from the nitrogen uptake in the fertilized plot and the result was divided with the amount of added nitrogen.

$$N\ efficency = \frac{N\ uptake\ in\ fertilized\ plot - N\ uptake\ in\ 0N}{Added\ nitrogen}$$

The treatments from the same region were grouped together and an average efficiency was calculated.

4. Results

4.1 Accuracy in N-sensor measurement

Only results from occasions and locations where N-sensor measurements were performed together with cut biomass samples are presented. All SN values are shown in Appendix 1.

When SN values and the result from the nitrogen analysis from both the 12-15 May and 18-25 May measurement from all fertilization treatments are compared, the SN value from the N-sensor was overall lower than the nitrogen uptake, according to the nitrogen analysis. The formula of the SN value was 0,2838x+22,088 where x is the nitrogen content according to the N-analysis and the R^2 value was 0,40 ($p<0,001$; Figure 2).

For the 0-N plots, there was a positive linear correlation between the SN value and the result from the N-analysis on the 12-15 May measurement with a R^2 value of 0,89 ($p=0,001$; Figure 3). There was also a linear correlation between the SN value and the nitrogen uptake at harvest (18-25 May measurement) with a R^2 value of 0,79 ($p<0,001$; Figure 4). The SN value is lower than the actual nitrogen uptake on both occasions. When including only “Max-N”, “Max-Max-N” and the “Farm’s fertilization” treatments, there was no linear correlation between the SN value and the result from the N-analysis at neither occasion (12-15 May, $p=0,1572$; 18-25 May, $p=0,611$; Figure 5 and 6).

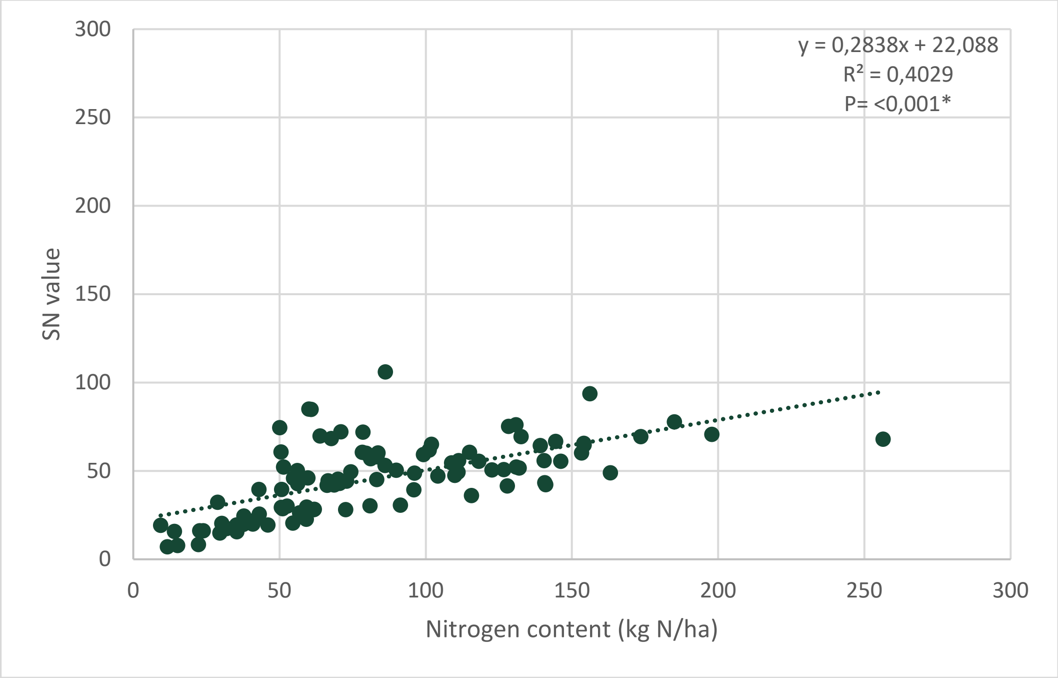

Figure 2 Linear regression between SN value and nitrogen content according to N-analysis in cut biomass samples from 12-15 May and at harvest (18-25 May). Measurement from all fertilization plots are included N=99

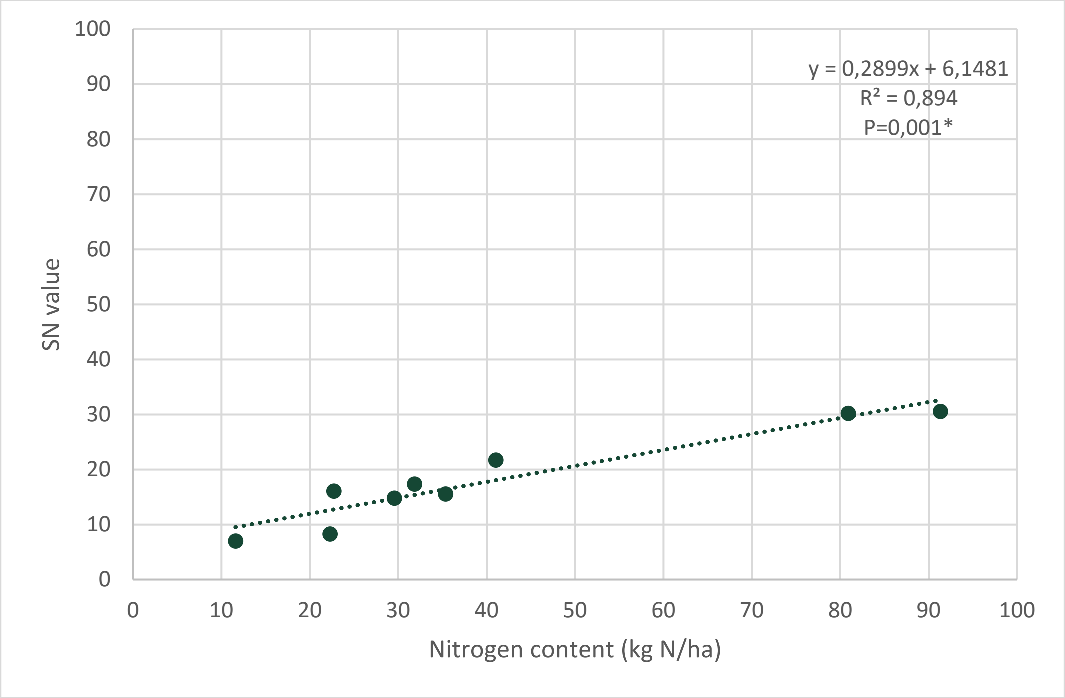

Figure 3 Linear regression between SN value and nitrogen content according to N-analysis in cut biomass samples in 0-N plot 12-15 May N=9

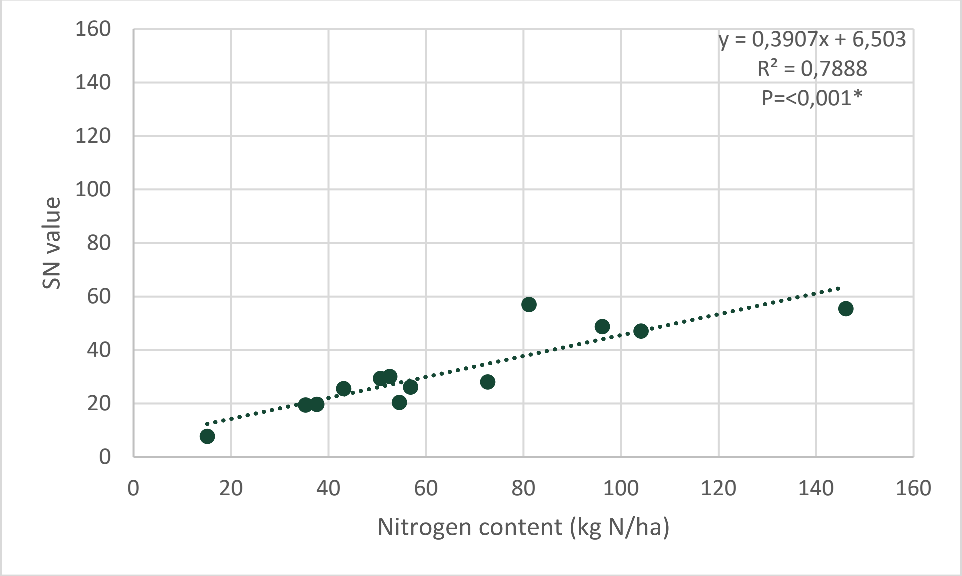

Figure 4 Linear regression between SN value and nitrogen content according to N-analysis in cut biomass samples in 0-N plot before harvest (18-25 May) N=13

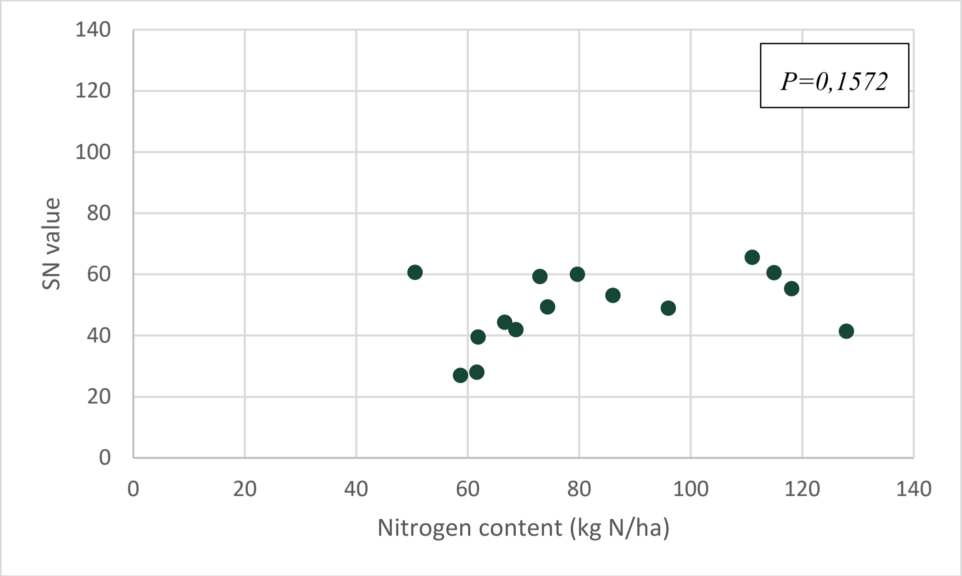

Figure 5 SN value and nitrogen content according to N-analysis in cut biomass samples in the Max-N, Max-Max-N and the Farm's fertilization plot 12-15 May, N=15

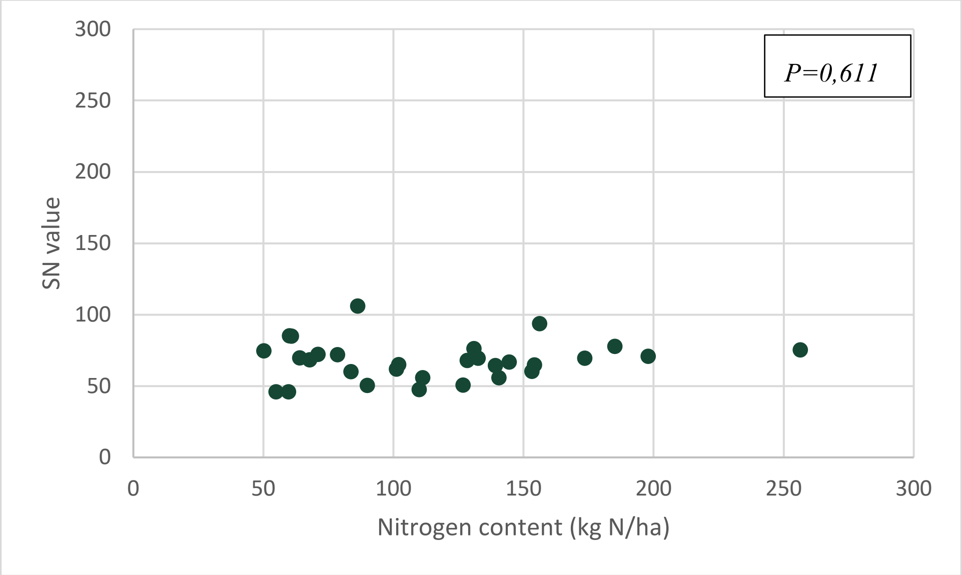

Figure 6 SN value and nitrogen content according to N-analysis in cut biomass samples in the Max-N, the Farm's fertilization, and Max-Max-N plot at harvest (18-25 May) N=30

4.2 Nitrogen uptake in unfertilized plots

In the unfertilized plots, there was a significant difference in nitrogen uptake in aboveground biomass between the farms in Halland 2022 and Kalmar 2022 at the last measurement (94 and 36 kg/ha respectively; Figure 7). The farms in Halland 2021 had an average uptake of 71 kg N/ha which did not differ significantly from either Halland 2022 or Kalmar 2022.

In Kalmar 2022, the nitrogen uptake varied from 15 to 50 kg N/ha for the individual farms in the region (Figure 8). In Halland 2022 the uptake varied from 55 to 145 kg N/ha and in Halland 2021 between 50 and 95 kg N/ha.
The average proportion of legumes in the 0-N plot at harvest was significantly higher in Halland 2022 compared to Kalmar 2022 (Figure 9). For Halland 2021, no data was available.

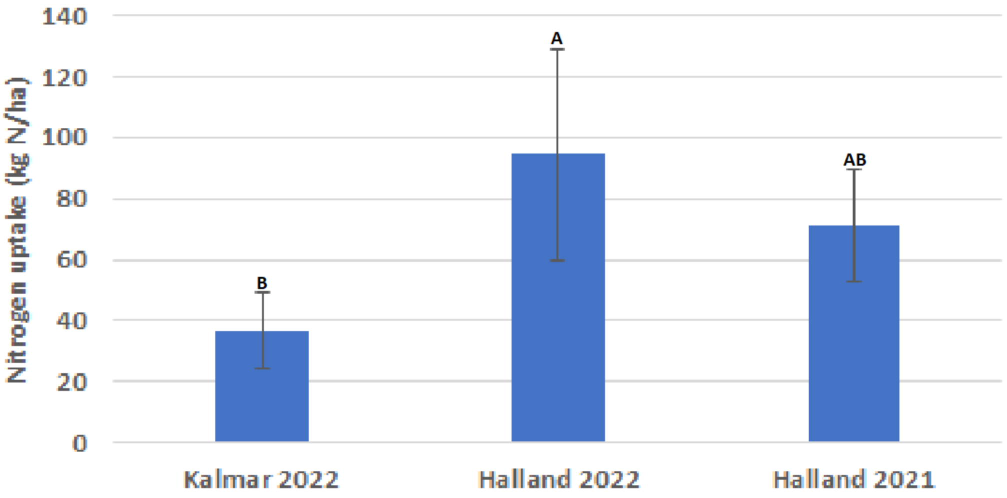

Figure 7 Nitrogen uptake in aboveground biomass in the 0-N plot at harvest, $N_{Halland}$=4, N_{Kalmar}=5. Error bars indicate standard deviation and different letters indicate significant differences between treatments.

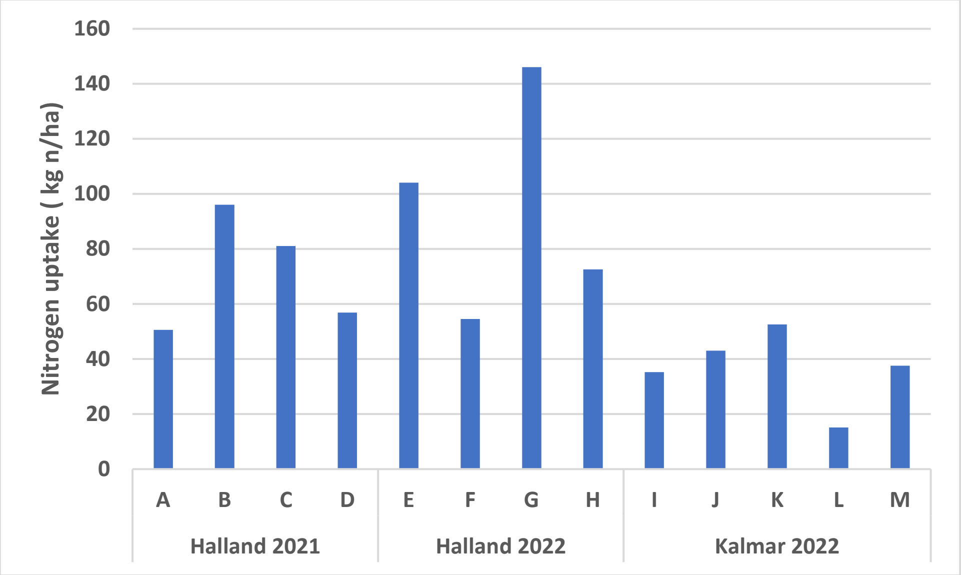

Figure 8 Nitrogen uptake in the aboveground biomass in the 0-N plots of the individual farms at harvest (18-25 May)

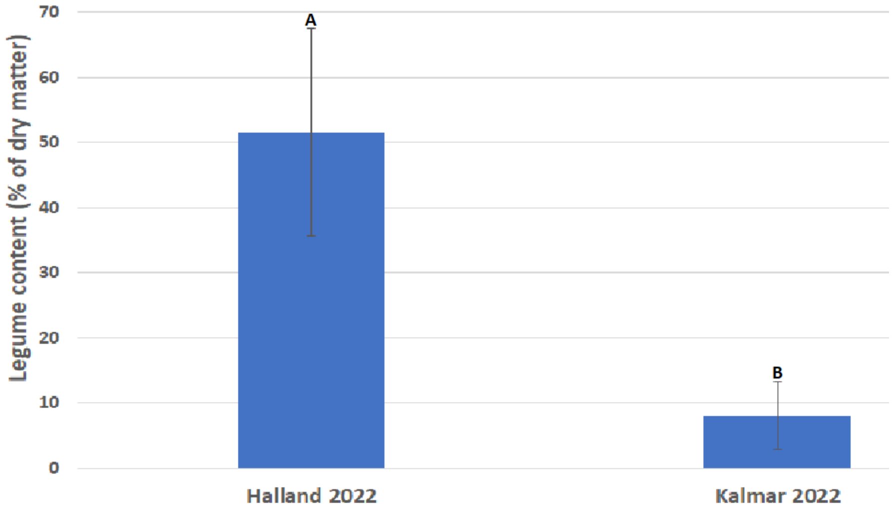

Figure 9 Average legume content in % of the dry matter yield in the 0-N plot in Halland 2022 and Kalmar 2022 at harvest $N_{Kalmar}=5$*,* $N_{Halland}=4$*. Error bars indicate standard deviation and different letters indicate significant differences between treatments*

4.3 Differences in nitrogen uptake, yield and crude protein content in the Farm's fertilization plot and the Max-N plot

There was no significant difference between the Max-N plot and the Farm's fertilization for any region or year for nitrogen uptake, dry matter yield or crude protein content (Figure 10, 12, 14).

For the Max-N plots, there was on average no significant difference in nitrogen uptake, biomass yield or crude protein content between the different regions or years. There was a difference in the Farm's fertilization plot between the locations as the nitrogen uptake in Kalmar 2022 was significantly lower than Halland 2021 and Halland 2022. The dry matter yield was significantly lower in Kalmar 2022 compared to Halland 2022.

At individual farms there were differences between the Max-N plot and the Farm's fertilization plot for the studied traits (Figure 11, 13, 15). However, this could not be tested statistically since there was only one replicate on each farm. The highest nitrogen uptake in aboveground biomass was at farm H in Halland 2022 with >250 and 130 kg N/ha in the "Max-N" plot and "Farm´s fertilization" plot, respectively. The biomass yield in the Max-N plot on farm H was also the overall highest whereas the crude protein content was higher in the Max-N plots on farms E and F. At some farms the nitrogen uptake, dry matter yield and crude protein content was higher in the Farm's fertilization than in the Max-N plot.

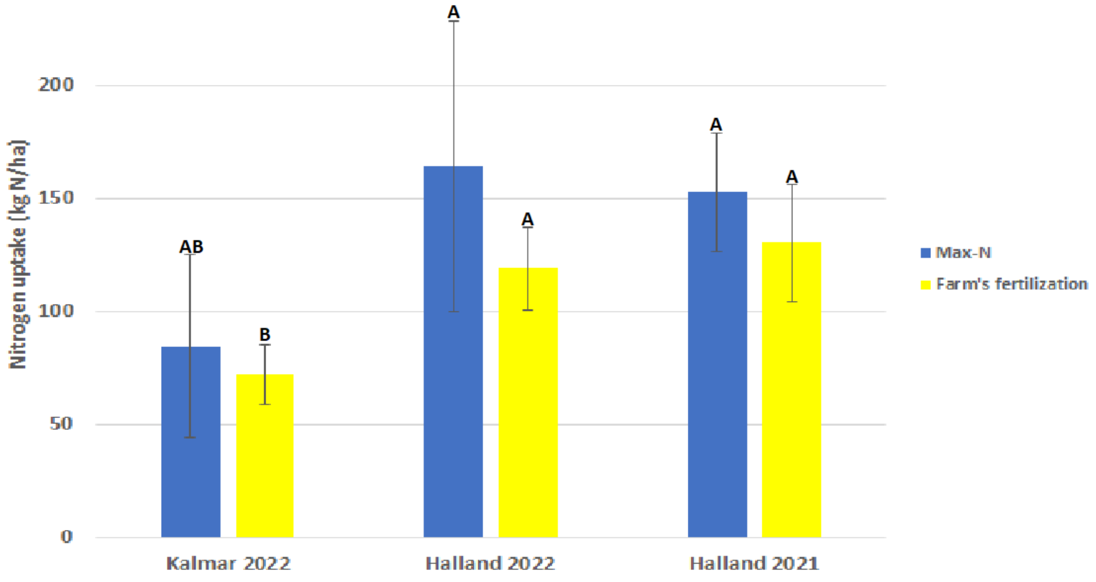

Figure 10 Average nitrogen uptake in the aboveground biomass in the Max-N plot and the Farm's fertilization plot at harvest (18-25 May) N=4. Error bars indicate standard deviation and different letters indicate significant differences between treatments.

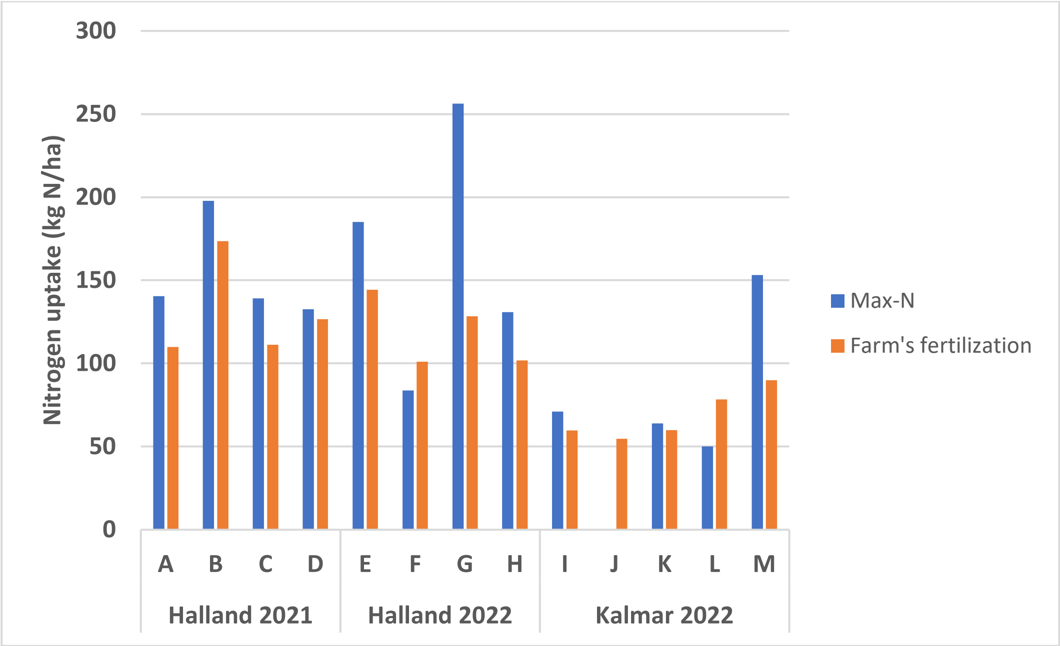

Figure 11 Nitrogen uptake in the aboveground biomass in the Max-N plot and the Farm's fertilization plot at the individual farms at harvest (18-25 May)

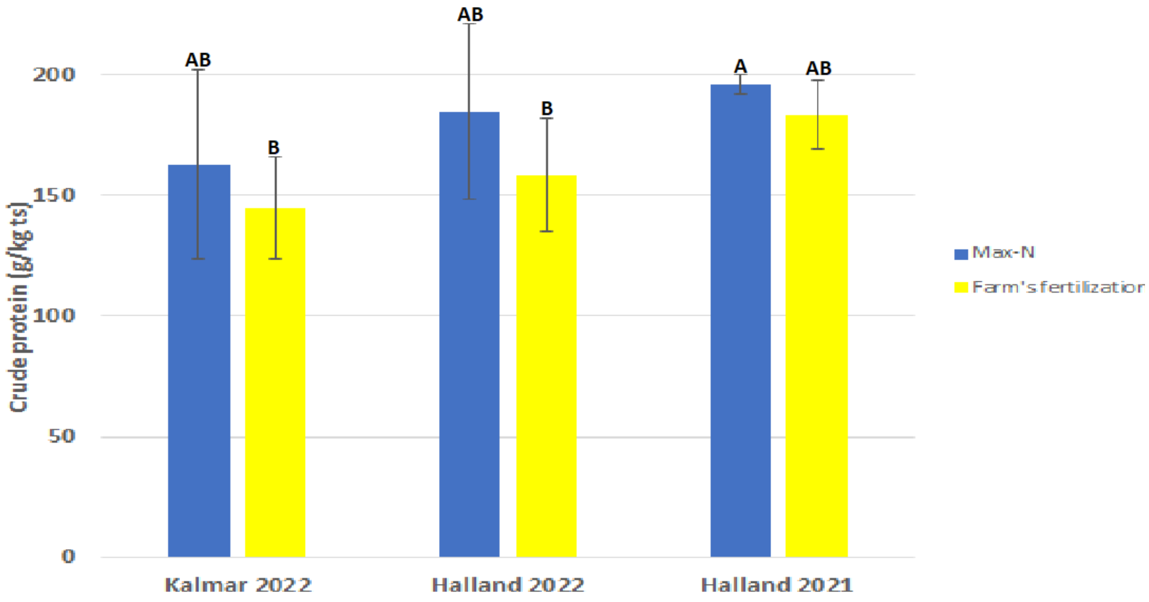

Figure 12 Average crude protein content in the Max-N plot and the Farm's fertilization plot at harvest (18-25 May) N=4. Error bars indicate standard deviation and different letters indicate significant differences between treatments

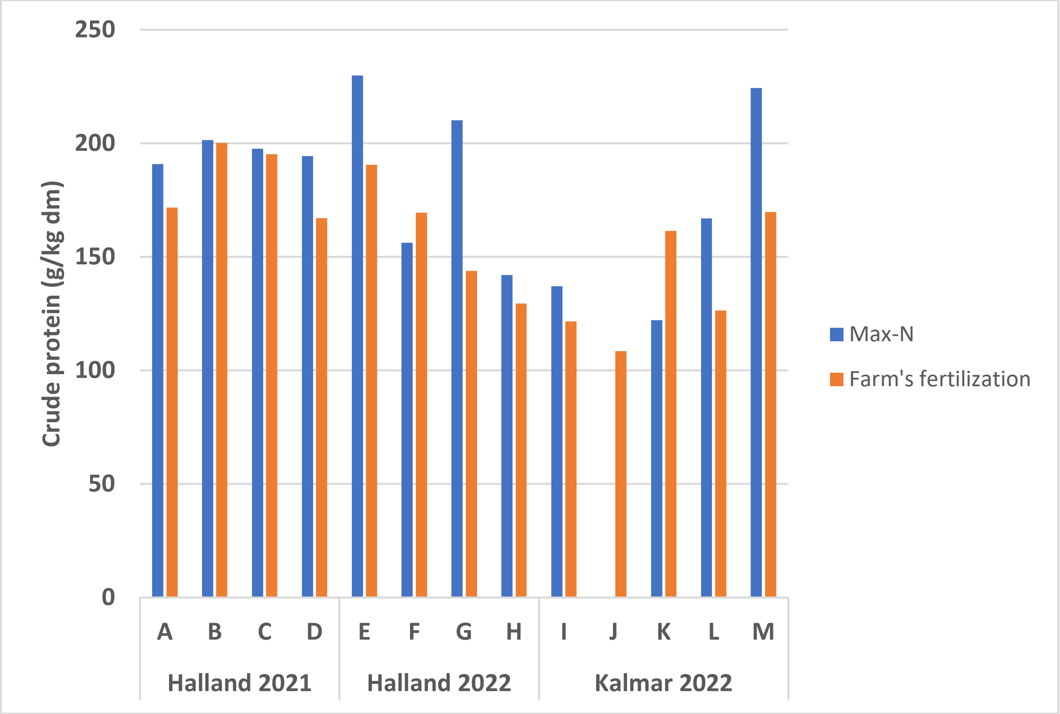

Figure 13 Crude protein content in the Max-N plot and Farm's fertilization plot at the individual farms at harvest (18-25 May)

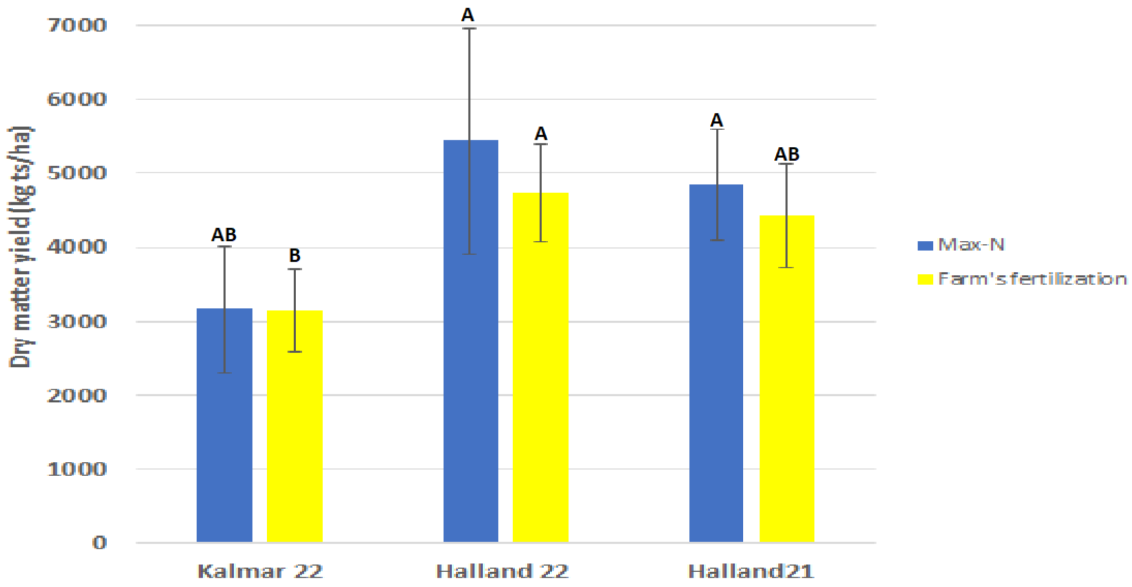

Figure 14 Average dry matter yield in the Max-N plot and the Farm's fertilization plot at harvest (18-25 May) N=4. Error bars indicate standard deviation and different letters indicate significant differences between treatments

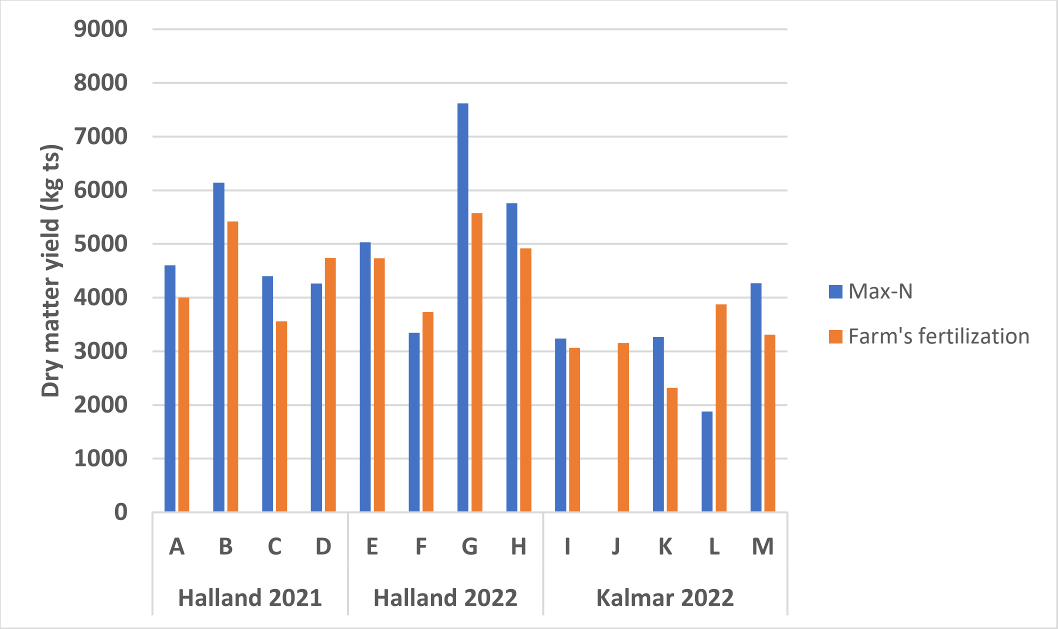

Figure 15 Dry matter yield in the Max-N plot and the Farm's fertilization plot at the individual farms at harvest (18-25 May)

4.4 Estimated nitrogen efficiency in the different treatments

The calculated nitrogen efficiency differed both within and between regions (Table 6). In Kalmar, the only mineral fertilizer plot resulted in the highest N-efficiency in with on average 74 % and the lowest in the only slurry plot with 6% efficiency. In Halland 2021 the efficiency was highest in the Farm's fertilization plot with on average 59% and the lowest in the only slurry plot with 29 %. In Halland 2022 the efficiency was higher in the Max-N plot than the Farm's fertilization plot; 44% compared to 24%. The highest average efficiency in the Farm's fertilization plot was in Halland 2021 and the lowest was in Halland 2022.

In some plots at individual farms the nitrogen uptake was higher in the 0-N plot than in the fertilized plot giving a negative nitrogen efficiency. The lowest calculated efficiency was in Kalmar and was -30%. At some farms, the nitrogen efficiency in treatments was over 100%. The highest efficiency was on a farm in Kalmar which had a nitrogen efficiency of over 200% in the only mineral fertilizer plot.

Table 6 Average, highest, and lowest nitrogen efficiency in the different fertilization treatments and locations at harvest (18-25 May) calculated as % nitrogen taken up out of fertilized, with nitrogen from soil and fixation (0-N) removed

Location	Number of farms	Treatment[2.]	Average Efficiency (%)	Highest Efficiency (%)	Lowest Efficiency (%)
Kalmar	5[1.]				
2022		2	6	61	-27
		3	74	268	-30
		4	42	134	5
		5	30	60	5
		6	31	51	3
Halland	4				
2021		2	28	94	-29
		3	42	48	28
		4	58	73	30
		5	52	63	38
Halland	4				
2022		4	24	45	-16
		5	43	67	18

1. Results from four farms were used to calculate average nitrogen efficiency in treatment 5

2. 2= Only Slurry, 3= Only mineral fertilizers, 4=Farm's fertilization, 5= Max-N, 6=Max-Max-N

5. Discussion

5.1 Accuracy of N-sensor measurements in ley

The SN-value from the N-sensor had a rather weak correlation with the calculated N-uptake from cut biomass samples (R^2=0,40) when all measurements were used (Figure 2). This correlation is lower compared to studies in wheat where a higher precision has been observed for N-sensor measurements for estimation of nitrogen uptake (Lukina et al. 2001; Stettmer et al. 2022). According to Stettmer et al. (2022) it is possible to achieve an accuracy of ±15% of actual nitrogen uptake in winter wheat with a N-sensor which is a higher accuracy than the results in the present study indicate. This could be explained by the fact that the formula used by the N-sensor is based on reference material of pure grass leys. The leys in the present study included clover or alfalfa and this could have affected the SN value, as legumes usually have a higher nitrogen content than grass. Another reason that the correlation was rather low could be that the N-sensor's primary purpose is to register variation in nitrogen uptake in a field, to create a field optimized nitrogen fertilization and not to measure the actual nitrogen uptake.

A previous study in Sweden which used a handheld N-sensor to estimate the nitrogen uptake in ley indicated a higher accuracy than the results in the present study (Zhou et al. 2019). Based on the results of Zhou et al. (2019) it should be possible to obtain a high linear correlation between actual nitrogen uptake and N-sensor measurements with an R^2 value close to 0,90. In their results there was a mean absolute error of the measured nitrogen uptake on 17 or 9,2 kg N/ha depending on method used. However, in their study, they created their own sensor algorithm with reference material from Swedish ley instead of foreign. This indicates that a change in the algorithm is needed to obtain a more accurate SN value, and to develop an algorithm based on ley mixtures grown in Sweden.

In the 0-N plot there was a high correlation between the SN value and the nitrogen uptake measured from the biomass cuttings (Figure 3,4). This indicates that the sensor can be used to measure the nitrogen uptake when N-uptake in ley is low but that the algorithm behind the calculation still needs to be adjusted. If the sensor can be used to estimate nitrogen uptake in 0-N plots it could be possible to use this to better optimize future fertilizations. However, as only a small number of measurements were performed in this study, no conclusions on how the formula should be altered can be made. Results also indicated that the sensor could estimate the N-uptake in a better way early in the growing season. This could also be seen in Zhou et al. (2019) study where a higher accuracy in N-sensor's measurements in ley could be seen early in the season compared to at harvest. However, fewer 0-N plots in my study were measured at early stages compared to at harvest which makes the result from the early measurements more uncertain. A reason for the higher accuracy earlier in the season could perhaps be the lower biomass of the ley which could mean that light from more plants are reflected.

In the "Farm's fertilization" and "Max-N" plots there was no correlation between the SN value and the actual nitrogen uptake at any of the occasions of measurements (Figure 5,6). The reason for this could be that the biomass was larger in these plots, making the leaves shade each other. This could imply that less light was reflected to the sensor, which results in an underestimation of the nitrogen uptake.
A current recommendation is that measurements with the N-sensor in winter wheat should be made no later than the heading stage (Walsh et al. 2023). Since the last measurement in this trial was performed before heading, the developmental stage should not have had a negative effect on the results. However, one difference between wheat and ley is that a wheat field is usually developed evenly, and the plants have a strong straw, whereas a highly fertilized ley can fall over due to the weak stem of the grass. If the ley lies down, it can become unevenly developed and the plants at the top will reflect light but not the plants in the bottom. Again, this will result in an underestimation of N-uptake and a lower SN value.

To get a correct measurement with the N-sensor, there is a need of background data. To establish a good background material for ley can be difficult as the composition of ley can differ a lot between locations and fields. To achieve this, there is a need of more studies with N-sensor measurements in ley, both at different growth stages and with different species and compositions.

5.2 Potential usage of unfertilized and extra fertilized plots in ley

The nitrogen uptake in the 0-N plots differed between the regions and between the farms, which was expected as previous studies have obtained similar results (Delin & Lindén 2002; Wetterlind et al. 2007). It is expected that farms that use organic fertilizers would have a high mineralization as they add organic matter to the soil

(Börjesson et al. 1999; Maitlo et al. 2022). Because of this it would be expected to have a high mineralization on all locations that were included in this study. Wetterlind et al. (2007) showed that nitrogen uptake in unfertilized cereals could be on average 50-100 kg N/ha at DC 91. This is similar nitrogen content as in the plots from Halland but higher than the plots from Kalmar. However, the nitrogen uptake in Wetterlind et al. (2007) study occurred under a longer time period compared to the nitrogen uptake in the 0-N plots in my study indicating a higher mineralization in my fields.

A lower nitrogen uptake in the 0-N plots in Kalmar compared to Halland could be due to less rainfall during the measuring period since mineralization rate depends on the amount of available water in soil. Alternatively, it could be that water was the growth-limiting factor in Kalmar and not nitrogen. However, as the fertilized plots in Kalmar had a higher nitrogen uptake than the 0-N plot this is not likely. Another reason for the lower nitrogen uptake in the 0-N plot in Kalmar could be the lower temperature in this region. This would be in line of results from Guntiñas et al. (2012), who say that a higher temperature leads to a higher mineralization.

As every farm had legumes in the ley, this likely resulted in a relatively higher nitrogen uptake in the 0-N plots than if it would have been pure grass leys as the legumes are not negatively affected by the lack of nitrogen. Moreover, the lack of nitrogen could also have favoured the legumes as the grass becomes less competitive, meaning that the legumes could grow bigger and subsequently have a higher nitrogen uptake (Boller & Nösberger 1987). According to Boller & Nösberger (1987), the total amount of fixed nitrogen in a ley mixture is heavily dependent on the total amount of legumes in the mixture. Because of this, it could be expected that fields witha larger proportion of legumes in the leys also results in a higher nitrogen uptake in the 0-N plot. This matches my results as the farms in Kalmar 2022 had a significantly lower proportion of legumes in their leys compared to the farms in Halland 2022 and a significantly lower nitrogen uptake.
This issue can make the implementation of 0-N plots in ley crops a bit problematic as the legumes will have less competition when the grass is unfertilized, meaning that the fixation may become higher in this plot than in the rest of the field, which is fertilized. This could make it difficult for the farmer to use the results from the N-uptake in the unfertilized plots when planning for the fertilization.

On average, there was no significant difference between the Max-N plot and the Farm's fertilization plot in Halland 2021, Halland 2022 or Kalmar 2022. This indicates that at the N-rate of the fertilization used at the farms, nitrogen was not a limiting factor for plant growth since the input of more nitrogen had no significant effect on dry matter yield or crude protein content. However, at some individual farms it was possible to see that the Max-N plot resulted in a higher nitrogen uptake, yield as well as crude protein content. This indicates that at some farms, nitrogen was a limiting factor for plant growth. However, even though adding more nitrogen could increase yield, it does not have to mean that it is economically motivated. The economical optimal nitrogen fertilization rate depends on the price of nitrogen and the value of the ley and can differ between years (Baker et al. 2004; Valkama et al. 2016). If the price of nitrogen is low and the value of the ley is high, it is economical motivated to add more nitrogen and if the nitrogen price is high and the value of the ley is low it is motivated to add less nitrogen.

A higher crude protein content is not necessarily something positive. A recommended value for crude protein content is 150-180 g/kg dm for dairy cows (Groot et al. 2007). At some farms, the Max-N plots had values higher than this indicating that if the farms would harvest at the time of the measurements, the crude protein content would above optimum. This could be avoided by a later harvest as the crude protein content decrease with time. However, protein content is not the only quality parameter in ley. The energy content also decreases over time and is connected to the developmental stage of the ley. This means that a later harvest may cause the energy content to become too low. On the opposite, the NDF value (fiber content) increases with a later harvest and may become too high, meaning that the silage will not be suitable for dairy cows.

The Max-N plot could perhaps be useful early in the season to see if there is a lack of nitrogen in the fertilization strategy on a farm. For example, according to Bakken & Nadeau (2023), adding additional nitrogen four weeks before harvest had the same effect as adding the entire nitrogen fertilization early in the spring. By measuring the nitrogen uptake in a Max-N plot four weeks before harvest it could be possible to see if additional nitrogen is required or if nitrogen is a non-limiting factor. If the Max-N plot shows a higher nitrogen uptake it indicates that there is a higher growth potential in the ley than expected. It would then be possible to add extra nitrogen but under the risk of receiving a too high protein content as previously stated.

5.3 Nitrogen efficiency in the different treatments

The nitrogen efficiency was on average lower in plots receiving only slurry compared to plots where only mineral fertilizer was added (Table 6). This was expected since inorganic fertilizers tend to result in a higher efficiency than organic fertilizers due to ammonia discharge (Mattila et al. 2003). More nitrogen was overall added in the only mineral plot compared to the only slurry plot. Increasing the amount of added nitrogen usually lead to a lower nitrogen efficiency

(Fernández-Escobar et al. 2014). However, as the added amount of nitrogen in the only mineral plot never was higher than 100 kg N/ha it is possible that the added nitrogen was not enough to see a decrease in efficiency.
Based on results from Fernández-Escobar et al. (2014), increasing the amount of added nitrogen should lead to a lower nitrogen efficiency, this could be seen on two locations (Halland 2021 and Kalmar 2022) but not in Halland 2022. That this was not seen in Halland 2022 is unexpected and no clear explanation have been found.

The results from the study show that in some plots there were a lower nitrogen uptake when nitrogen was added compared to the 0-N plot, resulting in a negative nitrogen efficiency. This was only seen in some plots on some farms indicating that the sample collection was not representative of these plots.

The nitrogen uptake depends on available nitrogen and amount of nitrogen needed for growth (Eckersten et al. 2007). It could be possible that something other than nitrogen was the limiting factor in the 0-N plots and not nitrogen as assumed.
That would mean that the potential soil delivery of nitrogen was in fact larger than assumed which could explain why some treatments have a nitrogen efficiency of over 100%. Another problem with estimating the nitrogen efficiency based on the nitrogen uptake in the 0-N plot is that the proportion of legumes can differ. As seen in Appendix 2, there is a difference in the percentage of the dry weight composed of legumes in the 0-N plot compared to the different fertilization treatments, especially in farms F-I. The fact that the amount of legumes differ means that the amount of nitrogen received through fixation can differ (Boller & Nösberger 1987). This likely affected the calculated nitrogen efficiency as it is assumed that the soil delivered nitrogen plus nitrogen received through fixation is the same in every treatment. If the leys had consisted of only grass, this method for estimating nitrogen efficiency could perhaps have shown more accurate results as the nitrogen uptake in the 0-N plot would then only depend on soil delivered nitrogen.

There were differences in the nitrogen efficiency for the same treatment within regions. This indicates that local differences can affect the nitrogen efficiency and that it could be an idea to study the nitrogen efficiency of specific fields to gain a better understanding of it. These local differences could be weather dependent as the weather could differ within the region. It was assumed that the weather from the weather stations was representable for the different sites, but it is possible to have local deviation. Another reason could be due to differences in the ley mixtures. The farms could use different mixtures and as different grass species has a different development and nitrogen need, the nitrogen uptake over time could differ (Bradshaw et al. 1964).

To know the nitrogen efficiency at a specific field could be very important to better estimate how much nitrogen to add and to have an idea of how much nitrogen is left in the soil. As the nitrogen efficiency of slurry is very weather dependent, using a 0-N plot and a plot which only have received slurry could be a way to understand how much of the nitrogen in the slurry that is being used by the plant. This could then improve the planning for future fertilizations during the cropping season. It would also have been interesting to study how much nitrogen the roots contained to see if the remaining part of the added nitrogen is located there or if it has leached or accumulated in the soil.

5.4 Optimizing nitrogen fertilization in ley

By knowing the delivery of nitrogen from soil, how high the nitrogen efficiency is and by having an area in the field where nitrogen is unlimited, it could be possible to better optimize nitrogen fertilization. By using different varieties of plots, both without any nitrogen or with only slurry/only mineral fertilizers over time, it could be possible to gain an understanding on the nitrogen efficiency of the fertilization products in fields. This knowledge could be used to achieve field adapted nitrogen fertilization strategies as it could be possible to better estimate how much of different products which should be used. Preferably this should be performed in leys which do not contain any legumes since as previously stated the share of legumes in fertilized and unfertilized plots differs meaning that the amount of nitrogen received from fixation differs, affecting the estimated efficiency. More research is needed to investigate the possibilities of using this method for optimizing nitrogen fertilization.

By the usage of a Max-N plot it would be possible to see if nitrogen is a limiting factor or not. According to my results, nitrogen was a non-limiting factor on average, but if farms would decide to lower their nitrogen fertilization a Max-N plot could be a tool to avoid fertilization below optimum. The Max-N plot could also be a tool to see if the fertilization is currently too high. If there are no differences between the Max-N plot and the normal fertilization it could be an indicator that the current nitrogen fertilization is too high and could be lowered.

A potential usage for a Max-N plot in the future could be to combine it with split fertilization. According to Bakken & Nadeau (2023) it was possible to split the nitrogen fertilization and perform a second fertilization four weeks before harvest. If it is possible to see differences between the Max-N plot and the rest of the field at four weeks before harvest, it could perhaps be possible to better estimate how much nitrogen to add and thus perhaps reduce the amount of unnecessarily added nitrogen. However, studies are needed to be performed to see if it is possible to see differences between the Max-N plot and normal fertilization at that point in time as this study do not cover that. The N-sensor could perhaps be used at this time to measure how much nitrogen the Max-N plot and the normally fertilized plot has taken up. However, since the N-sensor underestimated the nitrogen uptake at later measurements, studies should be performed to see if it can estimate the nitrogen uptake at this time.

As these fertilization plots are time consuming to establish, it might only be justified to create one or two plots each year. If only one is to be created, one alternative is to establish an "Only slurry" plot, granted that the nitrogen uptake from a 0-N plot is known from previous years. By establishing a "Only slurry" plot, it would be possible to see the actual nitrogen effect of the organic fertilizer and thus it might become easier to better estimate the amount of extra nitrogen that is motivated to add by mineral fertilizers. By doing this, the amount of mineral fertilizers can potentially be better adopted to crop demand and the added amount can be decreased.

5.5 Limitations and error sources

One limitation in this study was that there was only one replicate of the treatments at every farm. The reason that there was only one replication on every field was because of that the fertilization treatments were created by the farmers and since they are time consuming to establish only one set of plots were created per farm. Because of that there only is one replicate of every fertilization treatment on every farm, any possible errors in the creations of the fertilization treatments would heavily affect the results. The lack of replicates also makes it difficult to assess if the differences depend on the fertilization or some other factor. If several replicates on each field were performed it could be possible to see if any farms had a place specific factor, for example an unusually high soil delivery of nitrogen and thus being able to assess if differences in the result are because of the fertilization treatment or some other factor. To get a more accurate result, more replicates of the treatments would be beneficial in future studies. The study could be performed with randomized plot trials on every farm.

One source of error was that different persons have made the N-sensor measuring and ley sample collections at the different sites. The N-sensor values should not be affected by this as there are instructions on how to measure and the sensor should not be affected by who is measuring. The sample collection which are used to estimate the actual nitrogen uptake is more sensitive. Different persons can cut differently or have different opinions on what is a representative sample from a test plot. However, this only affects when comparing between regions as the same person has made all collections within a region. Another error source with the sample collection is that the area cut is not the same everywhere. In Halland it was 0,50 m^2 in every plot, but in Kalmar it was 0,25 m^2 in some plots and 0,50 m^2 in some. As it can be difficult to get a representative sample with a smaller cut area this can affect the estimation of the nitrogen uptake as well as the dry matter yield and crude protein content. To get a more robust result, one person should have performed all data collection, and all cut areas should have had the same size.

Due to lack of time no estimation of the soil parameters such as soil organic matter, clay content and soil moisture was performed. This would have been interesting to know as these parameters affects soil nitrogen delivery and could perhaps have helped to explain why there were differences within and between the regions. Furthermore, the composition of the ley in terms of grasses or legume species in the mixtures was not determined. As ley mixtures can consist of different species it is likely that the leys did not look the same and knowing the species could perhaps help explain differences between the sites.

5.6 Conclusion

The N-sensor in general underestimated the nitrogen uptake in ley, compared to the result from the N-analysis. For the sensor to work properly in Swedish ley, more reference material is needed and the algorithm need to be adjusted to estimate a more accurate nitrogen uptake in ley at harvest or a week before harvest. The uptake in the 0-N plots differed between the sites and reasons for this could be the differences in weather and proportion of legumes in the ley mixture. Another potential reason for this could be differences in soil parameters such as soil organic matter but soil parameters were not measured at the different sites. There was on average no significant difference in nitrogen uptake, dry matter yield or crude protein content when extra nitrogen was added compared to the farm’s normal fertilization. This indicates that the farmer’s nitrogen fertilization is on a high level close to the field’s potential uptake.

To field-optimize nitrogen fertilization in ley, implementation of 0-N plots as well as only slurry/mineral fertilization plots to calculate the nitrogen efficiency of fertilizing products could be a possibility. Although it could be problematic in ley’s with legumes due to differences in legume shares between plots. By knowing how much nitrogen the soil can deliver, how much nitrogen the fertilizing products deliver and the potential nitrogen uptake of the ley, it could be possible to optimize the amount of added nitrogen to the ley.

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Appendix 1

1. SN value from every measuring at all sites 1=0-N, 2=Only slurry, 3=Max-N, 4= Farm’s fertilization 5= Only mineral fertilizers, 6= Max-max-N

Farm	Treatment	27-28 April	5-10 May	12-18 May	18-25 May
A	1	9,34	8,43	8,29	19,44
	2	9,12	9,18	17,47	32,14
	3	19,50	22,69	40,71	72,09
	4	18,70	16,65	26,94	45,94
	5	22,86	22,38	25,56	50,18
	6	29,09	35,06	57,71	93,71
B	1	16,32	16,07	17,37	25,57
	2	21,16	24,13	31,32	42,80
	3	29,37	41,01	51,00	81,22
	4	22,77	24,39	28,01	45,80
	5	18,80	17,81	22,95	36,08
	6	32,33	43,82	66,59	106,00
C	1	13,83	19,32	21,70	30,04
	2	20,83	25,78	31,28	39,43
	3	34,69	37,83	49,10	69,71
	4	32,05	52,12	60,64	85,02
	5	26,56	28,09	41,50	60,48
	6	31,00	37,16	55,33	84,81
D	1	6,56	6,58	6,99	7,76
	2	11,15	10,34	12,71	15,74
	3	31,68	41,09	49,71	74,49
	4	33,46	34,39	44,37	71,84
	5	16,63	18,67	16,33	19,19
	6	28,50	40,75	39,92	68,24
E	1	12,22	13,22	16,11	19,68
	2	14,99	16,33	20,28	22,61
	3	21,93	35,99	60,50	60,21

	4	20,76	31,81	49,39	50,28
	5	15,93	28,21	41,80	50,52
	6	19,18	34,72	55,36	64,66
F	1	43,00	-	30,23	47,09
	2	50,00	-	43,21	55,88
	3	55,00	-	48,92	77,78
	4	47,00	-	41,44	66,75
	5	45,00	-	39,22	65,42
G	1	37,00	-	14,82	20,45
	2	51,00	-	29,50	34,36
	3	55,00	-	39,51	60,08
	4	57,00	-	41,96	61,74
	5	50,00	-	28,32	55,79
H	1	18,87	-	30,57	55,50
	2	30,40	-	42,13	64,08
	3		-	65,56	75,18
	4	40,60	-	60,00	67,93
	5	31,77	-	49,33	62,48
I	1	22,81	-	15,54	28,10
	2	27,74	-	19,97	30,63
	3	41,84	-	59,26	76,15
	4	42,20	-	53,08	64,97
	5	38,40	-	44,26	63,43
J	1	-	22,00	37,72	29,38
	2	-	26,00	34,57	28,52
	3	-	55,00	58,98	55,86
	4	-	48,00	50,75	47,50
	5	-	50,00	59,44	57,94
K	1	-	35,00	41,72	48,72
	2	-	45,00	51,14	52,15
	3	-	61,00	68,38	70,67
	4	-	56,00	64,81	69,40
	5	-	58,00	62,83	51,63
L	1	-	29,00	38,15	56,96
	2	-	36,00	40,07	45,23
	3	-	66,00	86,72	64,35
	4	-	55,00	72,02	55,87
	5	-	39,00	52,19	54,56
M	1	-	28,94	34,21	26,21
	2	-	41,24	45,11	45,05
	3	-	61,14	36,64	69,40

4	-	56,27	68,76	50,62
5	-	37,24	81,77	42,83

Appendix 2

Legume and grass distribution in fertilization treatments at harvest in Kalmar 2022 and Halland 2022, 1=0-N, 2=Only slurry, 3=Max-N, 4= Farm's fertilization 5= Only mineral fertilizers, 6= Max-max-N

Farm	Treatment	Grass %	Legume %
A	1	95,40441	4,595588
	2	100	0
	3	97,4042	2,595797
	4	96,80157	3,198433
	5	100	0
	6	98,94459	1,055409
B	1	91,44635	8,553655
	2	95,95449	4,045512
	3	-	-
	4	95,37096	4,629042
	5	86,14994	13,85006
	6	97,02735	2,972652
C	1	98,82698	1,173021
	2	100	0
	3	100	0
	4	97,93282	2,067183
	5	100	0
	6	100	0
D	1	83,25581	16,74419
	2	71,84211	28,15789
	3	88,59275	11,40725
	4	91,23259	8,767406
	5	69,95708	30,04292
	6	86,69145	13,30855
E	1	90,92543	9,074573
	2	90,42408	9,575923
	3	94,00187	5,998126

	4	87,19033	12,80967
	5	97,69504	2,304965
	6	95,72799	4,272014
F	1	26,29985	73,70015
	3	68,54871	31,45129
	4	55,80904	44,19096
G	1	51,30435	48,69565
	3	79,0795	20,9205
	4	64,89818	35,10182
H	1	44,98705	55,01295
	3	75,59696	24,40304
	4	84,8637	15,1363
I	1	71,03708	28,96292
	3	98,22855	1,771448
	4	94,95935	5,04065

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