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Soil carbon, pH and yield development in a long-term humus balance trial

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Abstract

Agriculture has to be performed in a sustainable way in order to sustain high yields and to support a globally growing population. Functional soil properties are fundamental for high yields and in order to achieve good soil conditions sustainable management is a key. Loss of soil organic material and increased soil acidity are problems associated with degradation of soils and hence less sustainable agriculture. In this thesis, the effect of different agricultural systems on soil organic matter, pH and yield was examined. The systems examined are a cereal system with straw removal or returning and a ley system, all with different nitrogen levels. In order to compare the results and to get a wider understanding of the subjects a literature review has been performed. The systems are located in Sweden on four different sites from South to North; Lönnstorp, Lanna, Säby and Röbäcksdalen.

Assumptions were that the ley system should give more carbon to the soil then the cereal system and if straw was removed carbon content should decrease more. Further, the systems with nitrogen fertilizer should result in higher soil carbon. As for pH there was an assumption that ley should be more acidifying than cereals and that non fertilized ley system should be more acidifying than the system which received fertilizer.

The results showed that soil C contents decreased less when nitrogen was applied to the cereal treatments as compared to the no N treatment. Further straw management, return vs removal, gave different effects on soil C contents. The cereal system reduced soil carbon more than the ley system. In unfertilized leys, pH decrease was more pronounced compared to fertilized ones indicating the acidifying effect of biological nitrogen fixation. The main conclusion from the yield results showed that application of N fertilizer increases yield. Nitrogen fixation in the legumes did not compensate for an application of 150 kg N/ha in the ley systems. No correlation between yield development and soil C content was found as suggested by literature. Initial carbon content has a greater influence than management over an increase or decrease in soil carbon content.

Sammanfattning

För att kunna försörja en växande population måste jordbruket skötas på ett hållbart sätt för att bibehålla höga skördar. Höga skördar i sin tur är beroende av att markens bördighet bevaras och detta sker genom att jorden brukas på ett hållbart sätt. Problem som associeras med ett ohållbart jordbruk är en minskad bördighet genom förlust av markens organiska material och försurning. I den här rapporten kommer olika jordbrukssystems effekt på markens organiska material, pH och skördar undersökas. Systemen som undersöks är spannmål där halmen har åter- eller bortförts och vall, alla med olika kvävenivåer. För att kunna jämföra resultaten och sätta det i ett större sammanhang har även en litteratur undersökning gjorts. Systemen ligger på fyra olika platser i Sverige från söder till norr; Lönnstorp, Lanna, Säby och Röbäcksdalen.

De antaganden som har gjorts är att vallsystemen ger ett högre innehåll av kol i marken än spannmålen och om halmen bortförs så blir det mindre mark kol än om den skulle återföras igen. De system som har blivit gödslade med kväve borde ge mer mark kol än de system som inte fått något kväve. Vad det gäller pH så antas det att vallen borde vara mer försurande än spannmålen och att de vallsystem som inte har fått något kväve borde vara mer försurande än de som har fått kväve.

Resultaten visade att mark kolet minskade mindre när kväve tillfördes till spannmålssystemen än när det inte tillstattes något kväve. Halmhanteringen inverkan skilde sig mellan platser med både mark kol och pH. Vidare gav vallsystemen på de platser där mark kolet från början varit lågt en ökning i kolhalt, tillskillnad från spannmålssystemen. Det initiala kol innehållet verkar ha större påverkan än brukningssätt vid en jämförelse av det initial kol innehållet och de olika systems utveckling. I de ogödslade vallsystemen sänktes pH mer än i de som hade fått kväve tillfört. Skillnaden i skörden mellan de olika vallsystemen visade att baljväxternas kvävefixering inte kompenserade för en kvävegiva på 150 kg/ha till vallen. Ingen korrelation mellan skördeutveckling och markens kolinnehåll kunde hittas.

Populärvetenskaplig text

Med bakgrund av att vi blir fler på jorden som behöver mat är det av stor vikt att skördenivåerna fortsättningsvis också är höga. För att få höga skördar under en längre tid behöver vi sköta jordbruket på ett hållbart sätt som inte utarmar markens bördighet. Dagens brukningsmetoder med ensidiga växtföljder och plöjning riskerar att minska markens bördighet. Mullhalten är en av de viktigaste faktorerna bakom markens bördighet och därför har förändringen av mullhalt i olika jordbrukssystem undersökts i ett examensarbete vid SLU. Förutom mullhalten undersöktes också skördeutvecklingen i en ensidig växtföljd samt utvecklingen av pH mellan olika jordbrukssystem då dessa också är viktiga delar i ett hållbart jordbrukssystem. De undersökta systemen var vall eller spannmål där halmen antigen bortfördes eller återfördes till skiftet. Alla de olika systemen har brukats med fyra olika kvävenivåer men endast två har undersökts: 0 kg N/ha eller den högsta 120 kg N/ha till spannmålen eller 150kg N/ha till vallen.

Att odla mycket vall med baljväxter kan innebära en försurning av marken, då de kvävefixerande bakterierna som hämtar hem gratis kväve från atmosfären också under processen försurar marken. Förutom de kvävefixarande bakterierna så blir (förhoppningsvis!) vallskördarna höga vilket leder till att man för bort mycket positiva joner och det kan i det långa loppet leda till en försurning av marken om de inte ersätts i tillräcklig mängd. Så med tanke på det borde vallodling leda till en större försurning av marken än vad spannmålsodling gör, dessutom borde den vallodlingen som inte fått något kväve leda till ytterligare försurning eftersom de har en högre andel kvävefixerare. Så vad visade resultaten, jo att i två av de tre försöken minskade pH mer när inget kväve hade tillförts till vallen och att pH minskade mer i vallodlingen än i spannmålsodlingen. Nu ska man inte dra slutsatsen att vallodling inte är uthålligt för att vid jämförelsen av mullutvecklingen i de olika systemen ökade mullhalten där vall odlats i två av försöken medan den minskade spannmålsodlingen. I det försök där mullhalten minskade med vallodlingen var den ursprungliga mullhalten relativt hög och därför kan slutsatsen dras att vid höga mullhalter kommer inte odlingssystemet ha så stor påverkan mullhalts utvecklingen men att vid lite lägre mullhalter så påverkar odlingssystemen mer. Att mullen ökar i vallodlingen beror på att den ligger orörd under en längre tid än spannmålen, om inte vildsvin varit framme, och detta minskar mineraliseringen av mullen. Dessutom kan vallen ha ett större rotsystem som bidrar med mer kol och den tar bort mer vatten från jorden vilket gör att mikroorganismerna inte kan bryta ned lika mycket material. Att kvävegödsling ökar skördarna är välkänt och eftersom det ökar skördarna så borde också rotbiomassan öka vilket i förlängningen innebär att mullhalten i marken borde öka när mer kväve tillsätts en spannmålsodling än om det är ogödslat. I undersökningen av dessa försök visade det sig att kolhalten minskade mindre när kväve tillsats jämfört mot de ogödslade rutorna.

Det finns en trend inom jordbruket att man säljer halmen från spannmålen vilket kan ge en inkomst det året men under en längre tid kan det vara en dålig affär då man säljer en del av det material som hade kunnat bli mull och på så sätt minska den långsiktiga bördigheten. Därför undersöktes också vad som händer när halmen bortförs i en spannmålsodling men det visade ingen skillnad i mullhalt eller pH där halmen bortförts eller återförts.

Tidigare försök har visat att det finns en koppling mellan ett lågt pH och en ökad mullhalt, då mullen blir mindre tillgänglig för nedbrytning vid ett lågt pH. Men i detta försöket kunde inga sådana trender ses. Mullhalten och pH är viktigt för bördigheten men i slutändan så är det ju ändå skörden som ger en direkt inkomst och vid höga vetepriser kan det ju vara lockande att odla det ofta men det kan uppföröka sjukdomar och minska skördarna över tiden. Försöken visade inga klara trender då i två av försöken minskade spannmålsskörden över tiden medan den var ökande eller oförändrad i två av försöken när det odlats spannmål oavbrutet i 30 eller 40 år, dock med olika arter. I den ogödslade vallen var det mer baljväxter än i den gödslade och vid jämförelsen om dessa kunde kompensera för en kvävegiva på 150 kg N/ha visade det sig att de inte gjorde det.

Så slutsatsen blir att vallodling är mer hållbart för att bibehålla markens bördighet än vad spannmålsodling är.

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1 Literature review

1.1 Background

Agriculture has to be performed in a sustainable way in order to sustain high yields and to support a globally growing population. Functional soil properties are fundamental for high yields and in order to achieve good soil conditions sustainable management is a key. Loss of soil organic material and increased soil acidity are problems associated with degradation of soils and hence less sustainable agriculture. The loss of organic matter can accelerate with modern farm practices such as ploughing and removing of crop residues. High organic soil content will give more stable yield levels and also a higher yield potential, thus producing more organic matter (Bot & Benites, 2005). Govaerts et al. (2009) concluded that in order to achieve food security and sustainable agriculture, carbon content and hence organic matter have to be maintained and governed not to decrease. In this thesis, the effect of different agricultural systems on soil organic matter, pH and yield was examined and also the question if there are treatments that are more sustainable than others. The systems examined are a cereal system with straw removal or returning and a ley system, all with different nitrogen levels. In order to compare the results and to get a wider understanding of the subjects a literature review has been performed.

1.2 Acidifying processes in soil

Soil pH is an important parameter affecting biological, chemical and physical properties. Soil pH determines plant nutrient availability, mobility of pollutants and microorganisms' activity. Aggregate structure in clay soils is affected by soil pH conditions through dispersion and stabilization of soil particles. At low pH, fungi dominate soil ecosystem and they generally have a stabilizing effect on aggregates (Brady & Weil, 2002). Problems associated with soil acidity are aluminum toxicity and low phosphorus- and molybdenum availability. Soil acidification is a process occurring naturally in soils, however, through intensified agriculture acidification accelerates (Troeh and Thompson, 2005). In regions where precipitation is larger than evaporation, humid areas, acidification is a major problem as nutrients may be leached out of the soil profile. Acidified soils are one of the major constrain for crop growth in humid regions. pH conditions depend on the relationship between processes which produce hydrogen (H+) ions and on the reactions consuming them (Brady & Weil, 2002).

Soil pH conditions are determined by the proportion of acid and non- acid cations on soil particle surfaces (Brady & Weil, 2002). Cations can be released to the soil through weathering, but this process can sometimes be very slow and therefore lost cations do not get replaced in sufficient extent (Troeh and Thompson, 2005). Leaching of cations is also a factor contributing to soil acidification. Root respiration and decomposition of organic matter (OM) produces carbon dioxide (CO2) which reacts and forms a weak acid, carbonic acid, and depending on amount and type of OM this can be a contributing factor to soil acidification. Plants have a higher cation than anion uptake which results in acidification. However, if plants are not removed, the ions will be returned to the soil as the plant residues decompose (Havlin et al, 2005). One of the end product of decomposed OM are organic acids and some of which are strong acids and thus reduce pH (Eriksson et al, 2005). Organic matter accumulation can reduce pH as it contains acid functional groups which can dissociate H+.

Biological reactions can also have an acidifying effect. Ammonium (NH4+) in soils can become nitrified by the nitrification process, NH4+ is oxidized into nitrate (NO3-) and two H + ions are released to the soil. Also reduced sulfur compounds can acidify the soil. When S is oxidized from its reduced form, sulfuric acid is produced. In addition, precipitation of acidifying compounds can contribute to the acidification of soils. Since the start of burning coal and other fossils fuels, considerable amounts of nitric and sulfuric acids have been released to the atmosphere and these reacts with rain to form acids rains. Today, gases are desulfurized and acid emissions are kept at minimum. According to Kirk et al. (2010), soil pH values have increased since 1990 mostly due to the less acidity in rains. In England and Wales, pH values have increased with 0.04 units per year for all kinds of land use.

Legumes have the ability to form nodules with N-fixing bacteria, using atmospheric dinitrogen gas (N2) to be transferred into ammonia (NH3), by reducing N2. However, these bacteria also affect the soil through acidification. As shown in a trial by Marschner and Römheld (1983) examining the difference in pH values between pots where white clover had been growing with NO3- fertilizer or with N-fixation as the N source. Results from the trial showed that pots with N-fixation decreased pH to 4,5 and NO3- increased pH to 6,5 in the rhizosphere. The original soil pH was 6.

Ley crops have a greater acidifying effect in soil than cereals partly due to higher withdrawal of cations especially calcium (Ca) and potassium but also because ley plant residues have a high N content which will lead to nitrification as N decomposed. Results from a Swedish long- term field trial on four locations comparing a ley and cereal system with a low N fertilizer rate showed that pH in general decreased over 20 years for both systems on all locations and a more accentuated decrease where found in the ley system (Mattsson, 1996). Straw removal means withdrawal of more cations and can thus induce a decrease in soil pH. However, Hazarika et al. (2009) measured soil pH values in a 20 year old trial continuously grown with winter wheat where straw has been removed or returned and found no significant difference in pH between the two treatments.

1.3 Organic matter and soil properties

Soils consist of mineral- and organic fractions, the mineral fraction is derived from weathering and the organic fraction from microorganisms, plant- and animal residues. The main source of soil organic matter (SOM) is plants residues. Furthermore, the organic matter can be divided into two fractions, an active fraction which is the living parts of soils as plant roots, animals and microorganisms and a second fraction, 60-80%, which is stable and called humus (Bot & Benites, 2005). The dominating element in OM is carbon which is sequestered from the atmosphere (Brady & Weil, 2002) through photosynthesis.

When plant residues decompose, the major portion of C will leave the soil as CO2 to the atmosphere as a part of the C cycling. Another way that C can be lost from the soil is as dissolved organic C (DOC), which can be leached throughout the profile. Leaching of DOC is more common on forest soil than on agriculture land. Some C will remain in soil as decomposed soil organic matter. Accumulated SOM will act as a C sink and since the C content in soil is two times higher than of the C content in the vegetation and the atmosphere combined, the amount of SOM and its destiny will have a great effect on the atmospheric composition (Brady & Weil, 2002).

SOM is in steady state when addition is equivalent to the rate of decomposition. These conditions are to a large extent affected by vegetation, climate, microorganisms and soil type (Troeh & Thompson, 2005; Bot & Benites, 2005). Soil texture is another factor that will affect the quantity of SOM stabilized in soil. In addition, temperature and precipitation determines the rate of decomposition and a high temperature with moderate rainfall will enhance the breakdown. When decomposition is slower than SOM formed from plant residues, e.g. if plant production is very high, SOM will accumulate. The equilibrium of SOM differs between systems and climatic conditions and in arable fields SOM is lower compared to fields with permanent grass grown under the same climatic conditions (Johnston et al., 2009).

Even though SOM is only a small part of the soil, it is one of the major components for determining soils properties. Both amount and quality of SOM affects the physical properties as SOM can bind soil particles to aggregates, which is of great importance especially for sandy and silty soils (Eriksson et al., 2005). Furthermore, SOM affects the water holding capacity in soils, in particular plant available water (Johnston et al., 2009). Gregory et al. (2009) found that, when examine soils resilience to physical and biological stresses, soils with higher SOM content had a greater resilience.

Soil organic matter constitutes of several plant nutrients which are released during SOM decomposition (Brady & Weil, 2002) such as N, phosphorus (P), H, oxygen (O) and S (Johnston et al., 2009). As these elements are important for plant growth, they can potentially be taken up by plant roots when released to the soil solution as soluble ions. However, not only plants will utilize nutrients from SOM but also soil microorganism. The quality of SOM e.g. the C/N ratio will determine if there is immobilization of N or mineralization. If the amount of N is scarce in the soil solution, this may indicate immobilization or a slow decomposition rate of SOM. However, normally soils contain enough N for microbial activity and there will be decomposition (Brady & Weil, 2002). It is mainly the active soil organic matter fraction which is involved in nutrient cycling and the stable fraction is affecting CEC and water holding capacity (Bot & Benites, 2005).

SOM contents normally range from 1 to 3% (Johnston et al., 2009) and in Swedish mineral soils, the average organic carbon (C) content is 4.1% in the topsoil (0-20 cm), 1.4% in the upper subsoil (20-40 cm) and 0.6% in the lower subsoil (40-60 cm) (Eriksson et al., 2010).

1.4 Effect of different agricultural systems on SOM

Farming practices affect the amount of and type of crops produced and thereby the amount of residues added to the soil (Johnston et al., 2009). Comparing agriculture land with corresponding natural land, the latter will contain more SOM. The underlying reason is that plant residues are removed in agricultural system and a portion of organic matter produced is not returned to the soil. Ploughing mixes the soil and is often followed by more aeration which can enhance decomposition. One practice that can reduce the decomposition of SOM is minimum or no-tillage where plant residues are left on the soil surface. Returning crop residues and applying manure will increase of SOM as compared to removal without manure application (Brady & Weil, 2002). However, there is an economical aspect of returning crop residues. A high price of straw will lead to more sell-off instead of leaving it on fields (Reicosky et al., 1995).

In a waterlogged soil, decomposition will be slow due to scarce O_2 access for microorganisms also root growth can be affected resulting in a lower biomass production. Therefore, drainage can increase the decomposition rate of SOM and enhance crop growth (Bot & Benites, 2005).

Mattsson (2002) estimated the C decomposition rate in soils with different fertilizer levels and removal and return of straw in a cereal system as compared to a ley cropping system. It was found that the decomposition rate of organic matter was faster when a low N fertilizer dose was applied as compared to an ample rate. However, in all cereal systems a decline of SOM was measured meaning that decomposition was larger than formation of new SOM. The ley system showed both increasing and decreasing trends of SOM depending on location, i.e., initial SOM at start and climatic conditions.

An increase of the total amount of crops, hence production of more field biomass, will also lead to more addition of organic matter (OM) to the soil through more crop residues and a larger root biomass (Brady & Weil, 2002). This can be achieved by adding more N fertilizer as this will increase the crop biomass. The long-term Broadbalk winter wheat trial at Rothamsted (England) showed this clearly, where some plots were fertilized with 144 kg N/ha and some plots were not fertilized with N at all. After about 100 years, SOC contents had stabilized and were 1.12 and 0.93 %, respectively, with the higher C content in plots with the higher N level. Since 1985, additional treatments were introduced to the trial, plots fertilized with 240 kg N/ha and 288 kg N/ha. The SOC contents have increased with 16% in the plots with the higher N level. Moreover, when examining SOC contents in another long-term field experiment at Rothamsted, the Hoosefield experiment, where spring wheat has been grown since the 1850´s, fertilized plots contained in general 10% more SOC than the unfertilized plots after 100 years and no change thereafter. This indicates that an equilibrium has been reached in these soils (Johnston et al., 2009). Blair et al. (2006) found similar results in the winter wheat trial at Rothemsted where higher N fertilized plots had higher SOC contents compared to those with the low N fertilizer rate.

In a long time field trial at Morrow (USA), previously unfertilized plots received fertilizer and lime since 1955. Results from this trial also showed that SOC contents increased in fertilized plots and this was also explained by higher yield and hence more crop residues added to the soil. Furthermore, N fertilizer increased the N levels (part of SOM) in the soil (Brady & Weil, 2002).

In a long time field trial in Germany, where three different levels of N have been applied to either a winter wheat- or a rye rotation, Raupp (2001) found that an increasing fertilizer rate did not give a higher organic matter content in the soil and that equilibrium was reached although there was a minor change during the last 10 years. During a six year period, changes in SOC contents were examined when applying only chemical fertilizer and chemical fertilizer together with manure to soils with two different initial levels of SOC. Soil organic carbon content decreased on plots fertilized with only mineral fertilizer and to a larger extent on those plots where there was a higher initial C content (van Fassen et al., 1993). Barre et al. (2010) have made a compilation of results from six long-term fallow trials in different countries within Europe, where no vegetation has been grown for at least 25 years and no OM has been added. The results showed that SOC content declined at all sites.

Long-term field trials at Rothamsted and Woburn (England) where straw has been returned and incorporated to the soil at two different depths showed after 16 years differing results between the two sites. At Rothamsted no increase in SOC was measured but at Woburn SOC contents increased. The trials at Rothamsted and Woburn have ended but the treatments were continued in the Broadbalk winter wheat experiment (Johnston et al, 2009). A long-term field trial in South West England with only winter wheat growing since 1982 no difference was found between treatments with different straw management (Hazarika et al. 2009). Yet, when comparing soil C contents in different soil types under varying land use and rainfall conditions, only the initial SOC had a significant impact (Bellamy et al., 2005).

1.5 Impact of pH on soil C

Soil pH and SOM are closely related and they affect each other in several ways. Low pH will increase the amount of positively charged groups on humus and make it less water soluble. Low pH followed by a lower solubility of SOC will therefore decrease the ability of microbes to utilize energy and nutrients of SOC. Decomposition will decrease but also biomass production can decrease. When pH decreases, H^+ ions will bind to COO^- sites of humus and thus reduce the cation exchange capacity (Bot & Benites, 2005).

Persson et al. (1989) added either lime or an acid to a forest soil in order to examine the effects on humus when changing pH. In the samples where lime was added, CO_2 emissions increased but in soils samples acidified, the CO_2 emissions were smaller than compared to the control. An investigation about soil development in England and Wales over 25 years showed that when soil pH decreased the C content increased (Kirk et al., 2010). When a previously non-limed soils where limed CO_2 emissions increased per unit of soil organic carbon (SOC) content. This was explained by the mechanism of lower water solubility and microbial availability mentioned above (Adams &Adams, 1983). In a study from Canada, the relationship between soil pH and SOM was examined and it was found that raising pH increased decomposition initially by 2-3 times and over 100 days, CO_2 emissions were 37% and 64% higher as compared to untreated soils (Curtin et al., 1998). Kemmitt et al. (2005) also observed more SOC in fields in England with lower pH as compared to those treated with lime. In an experiment in Sweden, soils treated with lime showed higher concentrations of dissolved organic carbon (DOC) as compared to the control (Andersson et al., 2009). However, on the contrary to the above mentioned results, raising pH from 4 to 4.5 increased SOC at the Hoosefield acid strip treatment in England (Rousk et al., 2009).

Relationships between soil pH and SOM are not always pointing in one direction and depending on the type of material used to increase pH, reactions can differ. Adding lime to a soil means that Ca^{2+} will bind to negative charges on soil particles and humus, stabilize it and thus make it less susceptible for degradation. Results from a study where either NaCl or $CaCl_2$ was added in order to change pH showed that NaCl increased the concentration of dissolved organic carbon, DOC, but adding $CaCl_2$ did not affect the DOC level. This was most likely considered to be a result of the Ca^{2+} ions which were forming stable complexes with the humus and thus making it less available (Römkens et al., 1996) and probably also from the somewhat lower pH caused by $CaCl^2$.

1.6 Yield development over time

When growing crops, many factors determine yields such as climatic conditions, crop varieties, soil type and crop rotations. Some factors are possible to control e.g. variety and type of crop rotation. Crop rotations have a positive effect on yields through efficient plant nutrient utilization, improvement of soil structure, and weed and plant pest suppression. In many cases, crop yields are lower if the same crop is on the field grown the year before (Fogelfors, 2001). Over time, the yield potential has increased as fungicides have been introduced and more N has been applied (Johnston et al., 2009).

Plants fixate CO^2 from the atmosphere and incorporate it into their tissues. Carbon dioxide is one of the major greenhouse gases and before the industrial period when fossil fuel combustion became abundant, the concentration in the atmosphere was 280 ppm (Rosenweig & Hillel, 1998). Today, the level is 396.11 ppm and 1980 the concentration was 338.62 (NOAA). Plants have a trade between fixing CO^2 and releasing water. Hence an increase in CO^2 concentration could increase amounts of CO^2 fixed and thus increase yields provided that other environmental conditions are not limiting growth. According to several trials were CO^2 concentrations have been doubled, biomass production responded positively in most cases (Rosenweig & Hillel, 1998).

Legumes have a symbiotic relationship with Rhizobia bacteria which can form nodules on legume roots. Inside the nodules, Rhizobium fix N from the atmosphere and a portion of the N will end up in the legumes. Hence, growing legumes will add additional N to the system. The amount normally fixed by clover ranges between 100-150 kg N/ha/year (Brady & Weil, 2002). However, growth of legumes depending mainly on N-fixation may also become limited due to insufficient N-supply for photosynthesis and vice versa. Furthermore, when fertilizing with N, the amount of fixed N may decrease due to suppression of nitrogenase activity, the enzyme that fixate N in the nodules. Also the amount of nodules formed may decrease and a higher senesces may be the consequence. (Whitehead, 1995). Plants are supplying Rhizobium with produced carbohydrates and when N is available to legumes without the need to supply Rhizobium with carbohydrates, legumes save energy (Brady & Weil, 2002). The total amount of N fixed varies greatly between crop types and depend on several factors such as temperature, water supply but also P supply being essential for energy-supply in the fixation process. Furthermore, when legumes are grown with grass, it can suffer from competition and may therefore not reach its potential growth. However, N- fixation per unit weight of legume can be higher if there is competition (Whitehead, 1995).

Yield development when growing the same kind of crops continuously over a long time period has resulted in different trends. Carlgren and Mattsson (2001) examined yield development from long-term fertilizer trials in Sweden with different crop rotations, situated on eight locations from north to south. They found that forage harvest increased, on average, with increased fertilizer supply in the South of Sweden. Results from cereals treatments in the same experiment also showed that NPK fertilizer increased harvests and yields decreased without fertilizer addition. In a trial at Hoosfield (England), the maximum yield remained at the same level when comparing different fertilizer levels since the 1970´s. However, on soils containing more SOM, yields increased. A similar yield trend was observed at the Broadbalk continuous wheat trial where yields of wheat have remained at the same level since 1843 (Johnston et al., 2009).

At Rothaemsted, a continuously ley trial started in 1843 with 3 plots left unfertilized and two plots fertilized with 134 kg N/ha and year were examined. The yield in the unfertilized plot did not show any significant change since the start of the experiment. On the contrary, the fertilized plots showed both a yield increase in one and a non-significant decrease in the other plot. Between 1960 –1992, both fertilized plots showed a yield decrease. When matching yield development to annual wheather conditions no significant impact of temperature and precipitation were showed (Jenkinsson et al,. 1993). A trial in Sweden (1973-1979) comparing the effect of barley, wheat and oats grown in monocultures and in different crop rotations showed that cereal yields in monoculture were lower than in crop rotation each year and there were declining barley yield trend over time (Wallgren, 1980).

1.7 The aim of this study

Objectives and general information

The main objective of this study was to evaluate different agricultural systems and management effect on soil parameters and yield development. In this thesis changes in pH, soil organic carbon and yield development were evaluated using data from long-term field trials from different locations in Sweden. The parameters evaluated can be regarded as isolated ones but also as related as they are dependent on each other.

The trials analyzed consist of a ley respectively cereal system with different nitrogen levels. In the cereal system straw was returned or removed from the plots. The trial has been ongoing for 30 and 40 years, respectively. The objective of the trials was to study humus changes within different agricultural cropping systems. Data from the trials were compiled in graphs and statistically analyzed.

Additionally, a profile description from the Lönnstorp location was made.
The questions outlined below are based on earlier results and provide the basis for the hypotheses.

- Does the yield level change over time when only ley or cereals are grown on the same location for several years?
- Does soil C content change when ley is grown compared to cereals?
- Does the N fertilizer level affect of organic matter contents in soil?
- Does a high level of N fertilizer in a ley system result in higher soil organic matter contents compared to systems with cereals?
- How does a ley or cereal system affect soil pH?
- Is soil organic matter affected by removal or return of straw in cereal systems with different N supply?

1.8 Hypothesis

Based on the questions addressed above, some specific hypotheses were tested:

- Yields of cereals will stay constant or increase over time due to improved varieties, pesticide use, more effective soil cultivation and a higher nutrient use efficiency.

- Soil organic material will increase in ley systems compared to the cereal system as ley has a larger root biomass. In addition, soils under ley will be drier due to more water uptake, which will decrease the biological activity compared to cereal systems.

- Ley systems remove a large quantity of cations and will lead to more acidification than cereal systems. Low pH values make humus more stable and less available for microorganisms to decompose.

- Clover roots fixate considerable amounts of N and the net effect of fixed N on soil organic content will be the same as if fertilized N was applied.

- The highest level of N fertilizer will also result in the highest increase of SOM due to higher yields.

2 Materials and methods

2.1 Locations and initial conditions

The trials are located in four different areas in Sweden from north to south, hence climatic conditions differs between the sites**.** The sites are Säby, Röbäcksdalen, Lönnstorp and Lanna. In general, there are higher content of humus in the soils in western Sweden, where Lanna is located than in southern parts. In Skåne, where Lönnstorp is located, humus content is generally lower. An investigation over the status of the Swedish arable land showed that the organic C content has been quite stable during the period 2001- 2007 (Eriksson et al., 2010). Mattsson (2002) has made estimations for C decomposition rates at the different locations and he found differences between locations. At Säby decomposition did not exceed addition of C but at Röbäcksdalen decomposition was higher than replacement through organic matter input for all N levels. At Lanna both a positive and negative soil organic matter trend was found.

2.1.1 Säby

The trial in Säby, Uppsala (59º49`; 17º38`) started in 1970. Annual mean temperature is 5.5º C and the area has an annual mean rainfall of 528 mm. An examined soil in the area consists of 36% clay on average and according to Kirchman (1985) clay content increases with depth. The opposite applies for SOC which decreases with depth. During some parts of the year the B- horizon is water saturated. The A- horizon is between 0- 28 cm depth, horizon texture is silt loam and according to FAO soil system the soil is classified as an Eutric Gleysol by Kirchman (1985). Säby has an elevation of 10 m. The fertilizer applied in 1971 was calcium ammonium nitrate. However, the N fertilizer applied has shifted over time. Between

1996- 2003 ammonium nitrate (N28) was used and after that NS 27-4 (Axan) was used.

2.1.2 Röbäcksdalen

The trial at Röbäcksdalen, Umeå (63º49`; 17º38`) was established in 1980. Mean annual temperature is 2.8ºC and mean rainfall is 582 mm per year. Clay content at Röbäcksdalen is 10% and the altitude is 7 meters. The A-horizon is between 0-30 cm depth and the texture is silt loam. The soil has shown evidence for being water saturated during some parts of the year and it is classified as a Haplic Gleysol by Bolinder et al. (2010). The trial was limed 1984 with agricultural lime (CaO) 7.5 ton/ ha. An NPK fertilizer from the company Supra was used between 1980 -84 and since 1994 calcium ammonium nitrate (N28) was used.

2.1.3 Lönnstorp

In the south of Sweden, the trial at Lönnstorp, Alnarp (55º39`; 13º5`) was started in the year 1980. Mean annual temperature is 7.7º C and the mean annual precipitation is 569 mm. The top horizon has a sandy clay loam texture and beneath that horizon there is a hard pan at 28- 44 cm depth. Clay content of the Lönnstorp soil is 25%. N28 Calcium ammonium nitrate (N 28) has been used as N fertilizer either single or in combination with P and K since 1988.

2.1.4 Lanna

A fourth trial of this series was started was at Lanna, Skara (58º20´; 13º7´) in 1981. At Lanna mean annual temperature is 6.1ºC and mean annual rainfall is 558 mm. Soils in the close area are classified as Inceptisols and the clay content is 36%. The nitrogen fertilizer used in the trial has shifted, 1981-82 it was calcium nitrate and since 1994 calcium ammonium nitrate (N28) was used

2.2 Experimental design

Two kinds of cropping system are used in the trials one with only cereals and one with three year of leys and barley during the fourth year. Almost every year two cuts are taken from the ley. In the cereal system straw is either removed or returned to the field and four different levels of nitrogen are applied 0, 40, 80 and 120 kg N /ha. Comparable N levels are higher in the ley system 0, 50, 100, 150 kg N /ha.

Cereals → straw removed or returned
→ 0, 40, 80 or 120 kg N/ha
Ley → 0, 50, 100 or 150 kg N/ ha

All in all there are 12 different treatments which have been the same since the start, which was 1980 at three- and 1971at one location. The cereal system plots are organized as randomized split- plot design with straw as main plots and N fertilizer rate on subplots. The ley system is designed as randomized blocks. All treatments are replicated four times.

Phosphorus and potassium are added every second year are given in amounts replacing removal. Soil samples are collected every fourth year including pH, P-Al, K-AL, total C and N Carbon measurement equipment has changed over time. Initially Walkley-Black was applied followed by determination with Ströhlein C-Mat 500 and later LECO CN- 2000 equipment was used. Ley yield data are given in dry matter (DM) and cereal yield with a15% water content. Varieties used in the cereal system have changed since the start of the trial. The plots are weeded and pesticides are used when needed.

2.2.1 Treatments and data selected for this study

Of the four different levels of N added to the plots as treatments, only 0 kg N/ha and the highest N dose was used for evaluation in this thesis. Unfertilized plots were used as a control and plots with the highest N dose to get most pronounced results. Values shown in graphs are average values from four replicate plots with the same treatment at each location.
In the ley system, only data from years when two harvests were taken and when ley was not under- sown by barley. Yield values in the cereal system is only selected those years when the dominating crop, barley, is grown in order to get as even values as possible. Some pH values were not considered due to unrealistic values, 1980 at Säby and 1983 at Lanna. The trial at Röbäcksdalen was limed initially. Soil pH values were not included in the results, since the lime effect overshadowed the effect of the treatments on soil pH. Data from the data base at the division of plant nutrition/soil biology were used for this thesis, which were processed and compiled in graphs and tables and treated statistically. Excel was used for making graphs.

For the soil parameters some data are missing or not measured during some years at Lönnstorp. Therefore there are big gaps in the graphs and the data was searched for in the reported paper form but could neither be found there.

2.3 Statistical tests

The statistical analysis software (SAS) program was used for making the statics and procedure used in SAS was a two way variance analysis. No values from Röbäcksdalen were included in the statistics due to the different management (lime addition). Since no individual plot values are recorded, mean values from four plots were used. Regarding soil parameters, the three different locations had to be regarded as replicates in order to do any statistics. However, in the graphs all places are examined individually and therefore the treatment effect on soil parameters could be examined individually for each location. Harvest values were also regarded as replicates for all locations so that on each location treatment effect on harvest could be evaluated. The value used in the statistics is the last value on each location in average for all the locations. The running of statistical values was performed by Thomas Kättrer.

2.4 Soil profile description

A soil profile description was performed at Lönstorp as it was the only place of the four trial sites were no earlier description had been done. The soil profile description was performed according to FAO (1990). The site chosen for the profile description was located just between the ley and the cereal plots. The profile was digged by hand and it was considered that 80 cm depth was enough to perform a profile description.

3 Results

3.1 Yields

3.1.1 Barley grain

Barley yield was notable higher when N fertilizer was applied but there were only minor yield differences when straw was returned or removed from the plots at all sites. Yield levels differed between the sites, Röbäcksdalen had the lowest mean yield (1786 kg/ha) for all treatments while Lönnstorp had the highest yield levels (mean 4152 kg/ha) for all treatments. However, yield levels have changed during the trial and developed differently. At Röbäcksdalen and Lönnstorp yields have increased but at Lanna and Säby the trend was the opposite (Figure 1). There were no significant differences in barley yields between fertilizer levels or straw management using data from the year 2008. Yet, yields of the non N fertilized treatment decreased significantly over time compared to N fertilized yields. Furthermore, straw management, return or removal, did not give any significant results regarding yield development over time neither at high N nor at no N fertilization (Table 1 & 2).

3.1.2 Ley dry matter

At all locations, ley yields were higher when 150kg N/ha was applied compared to when no N fertilizer was applied. However, yield differences between fertilized and unfertilized treatments differed between the sites. At Lönnstorp, yield differences were smaller (1402 kg/ha) compared to Röbäcksdalen (2863 kg/ha). Also yield development differed between sites. At Säby and Röbäcksdalen, yields have increased with time while at Lönnstorp yields have decreased and at Lanna yields remained quite stable since the start of the trial (Figure 2). Ley yields after 30 or 40 years were significantly lower when no N was applied but when comparing the development over time, no significant effect of fertilization was found (Table 1 & 2).

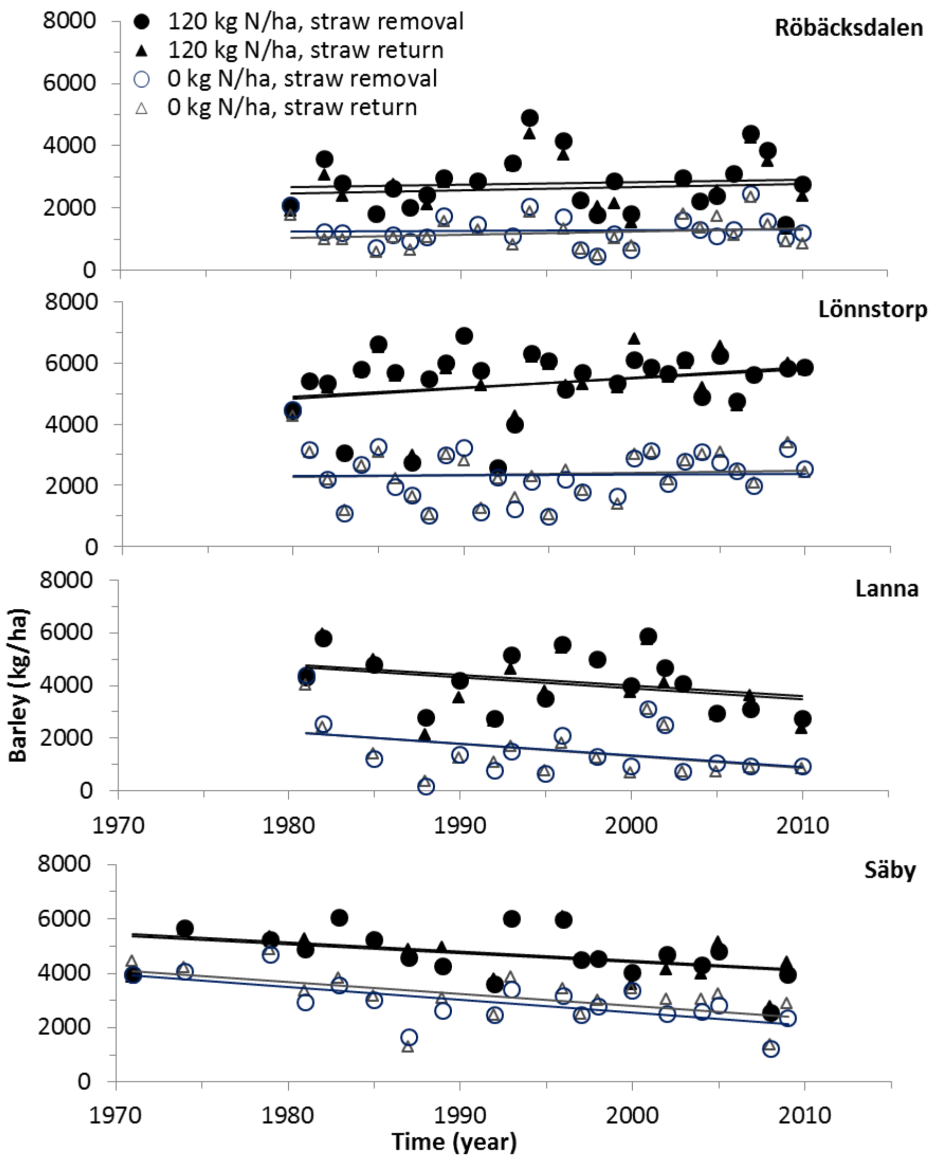


Figure 1. Barley yield development (kg/ha) at the different locations.

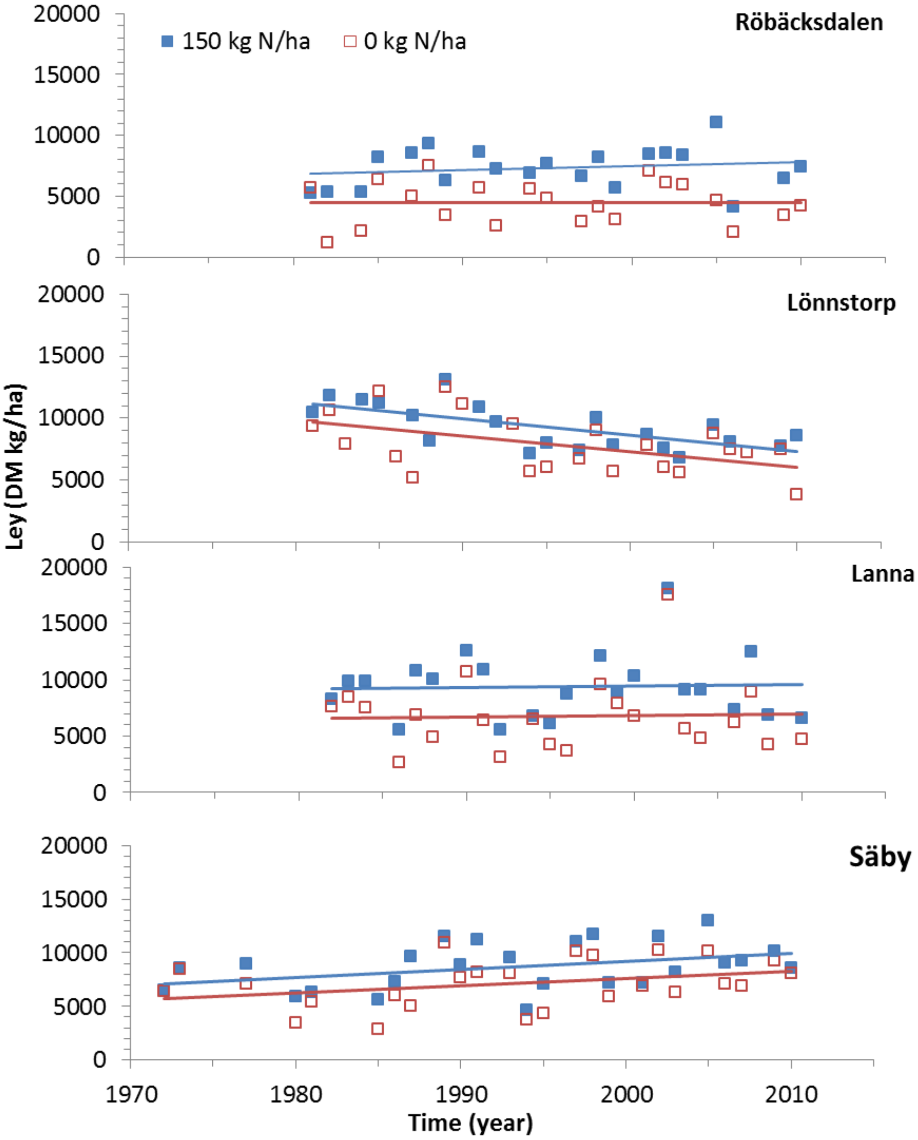


Figure 2. Ley dry matter yield development at the different sites over time

3.2 Soil carbon development over

3.2.1 Site Lönnstorp

There was a decline in the content of soil C for all cereal treatments (mean decline 0,25 % soil C) and the strongest decline (0,38 % soil C), was when straw was returned and the plots were unfertilized. Conversely, soil organic C contents increased when growing ley, both with and without N fertilization (mean figure 0,24 % soil C). Further, the largest increase was found when ley was fertilized compared to the unfertilized (Figure 3).

3.2.2 Site Lanna

Soil organic C was declining in all cereal treatments (mean decline was 0,16 % soil C). The decline was largest when plots were unfertilized and straw was returned. Since the start (1981), soil C declined by 0,25 %. Opposite to the cereal system, contents of organic C increased in the ley system (average was 0,28 % soil C). This was most pronounced in the fertilized ley where C increased by 0,36 % soil C (Figure 4).

3.2.3 Site Säby

At Säby, there has been a steady decline of soil organic C contents in all treatments (average decline was 0,54 % soil C) since the start of the trial and the largest decrease was found in cereal systems when no fertilizer was applied (0,95 % soil C) . Furthermore, the decline was least in the ley systems on average 0,18 % soil C (Figure 5).

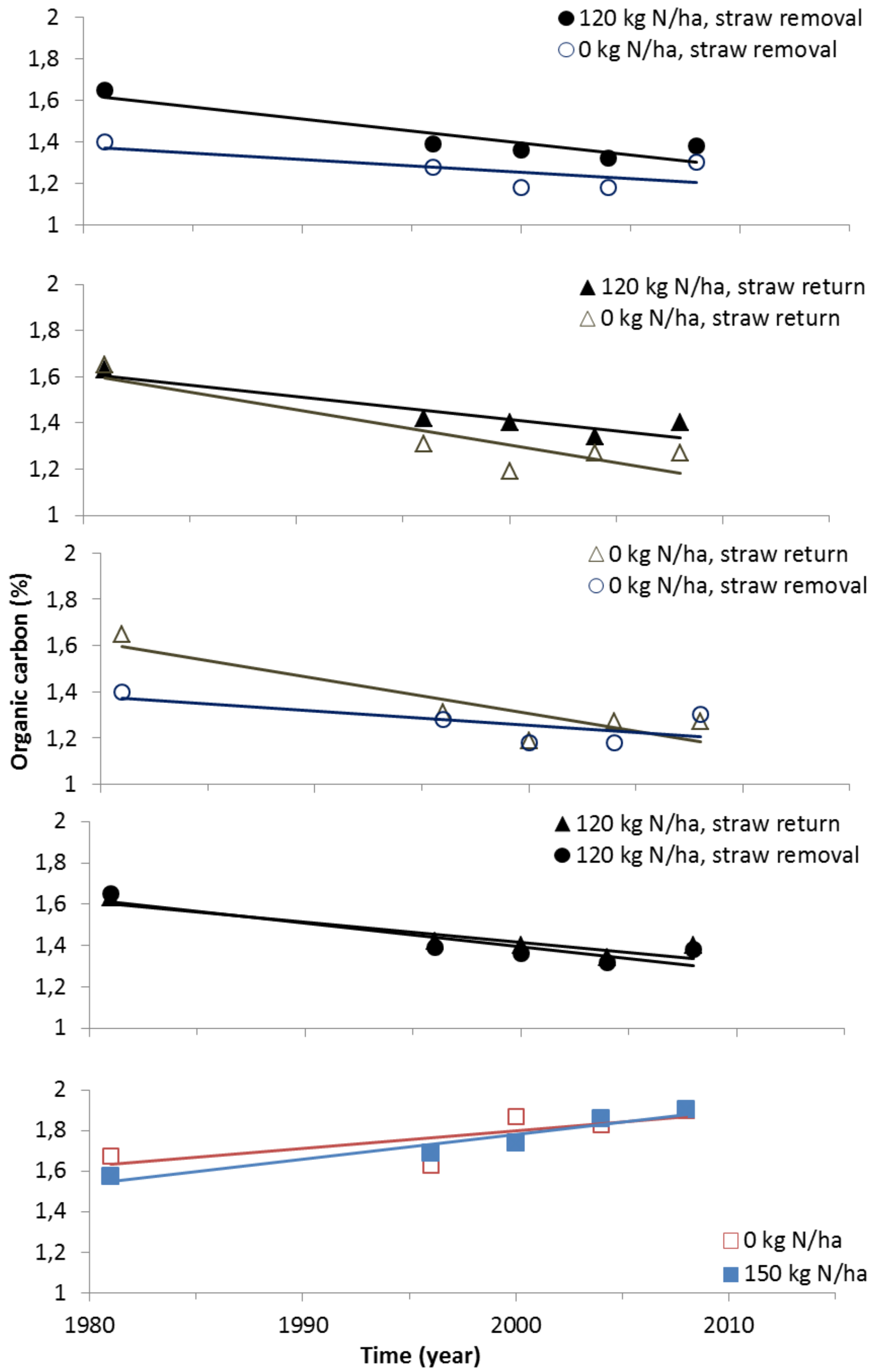


Figure 3. Soil carbon development over time at Lönnstorp in the different treatments.

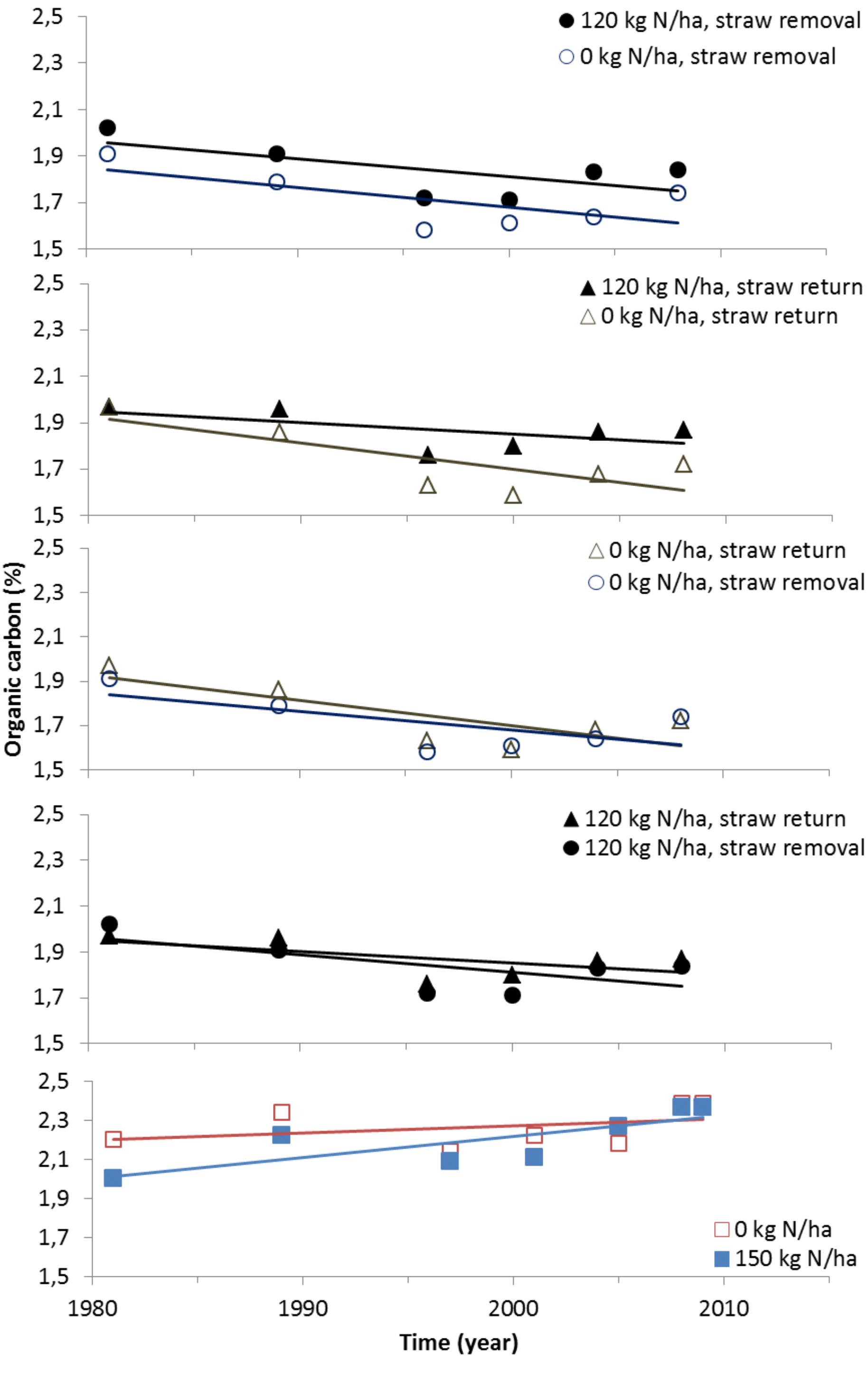


Figure 4. Soil carbon development over time at Lanna in the different treatments.

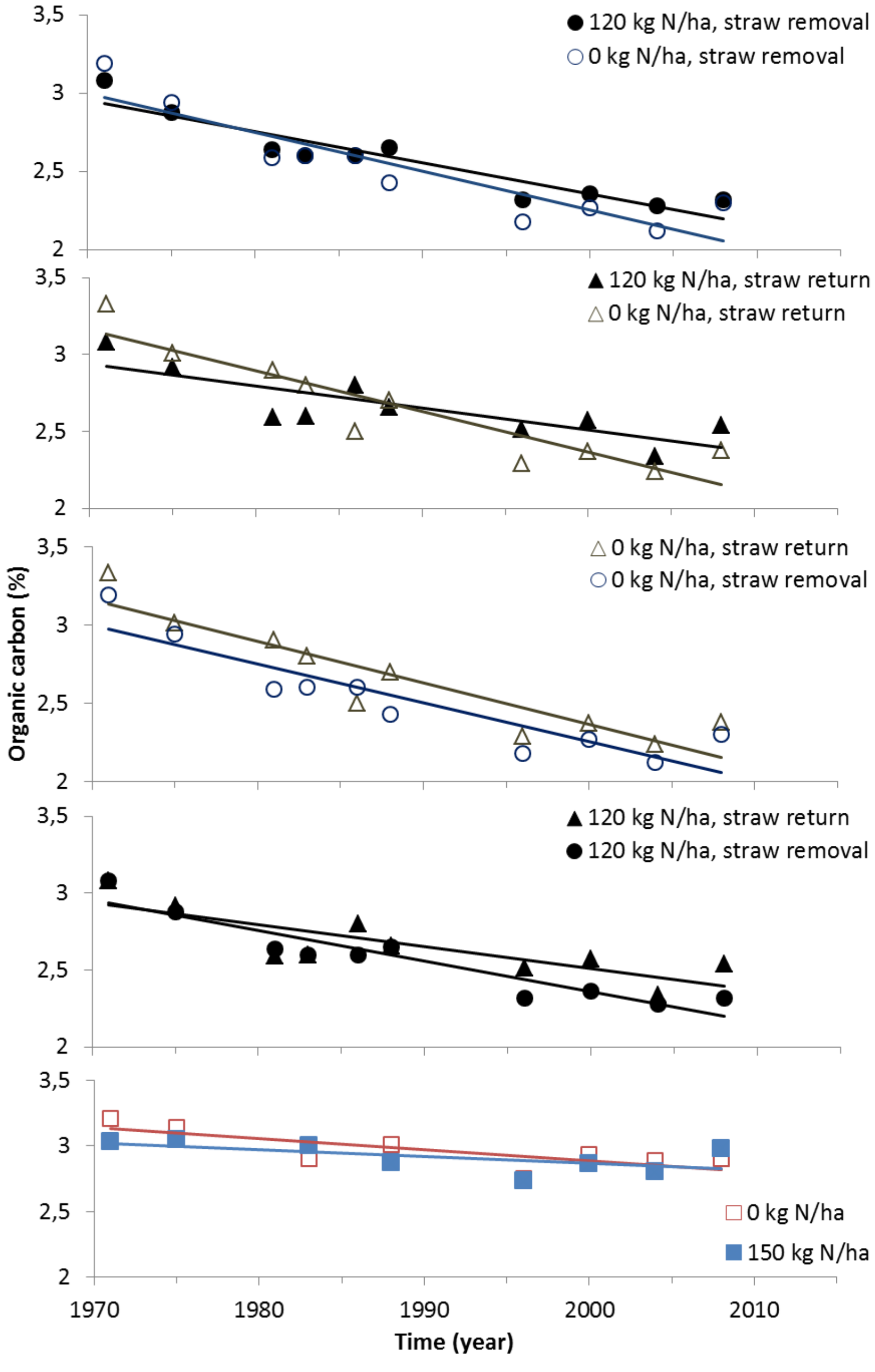


Figure 5. Soil carbon development at Säby in the different treatments.

3.3 Soil pH development over time

3.3.1 Site Lönnstorp

Soil pH values decreased in all treatments (on average 0,53 units) and the largest decline was in fertilized leys (0,58 units) and cereals (0,6 units) when straw was returned. In the cereal system, pH decreased by 0.55 units when 120 kg N/ha was applied and 0.5 units in unfertilized plots (Figure 6).

3.3.2 Site Lanna

In the cereal systems, pH values remained stable over time, in all treatments and in the unfertilized treatments when straw was removed it pH increased by 0,1 units. Yet in the ley systems, pH values decreased for all treatments and from 6,7 units to 5,6 in in the non-fertilized system (Figure 7).

3.3.3 Site Säby

Soil pH values decreased in all treatments, but largest reduction was in the fertilized ley (0,46 units). In the cereal system, fertilization with 120 kg N/ha and straw removal and the no N treatment combined with straw return resulted in the largest reduction in pH, from 6,2 to 5,8 units (Figure8).

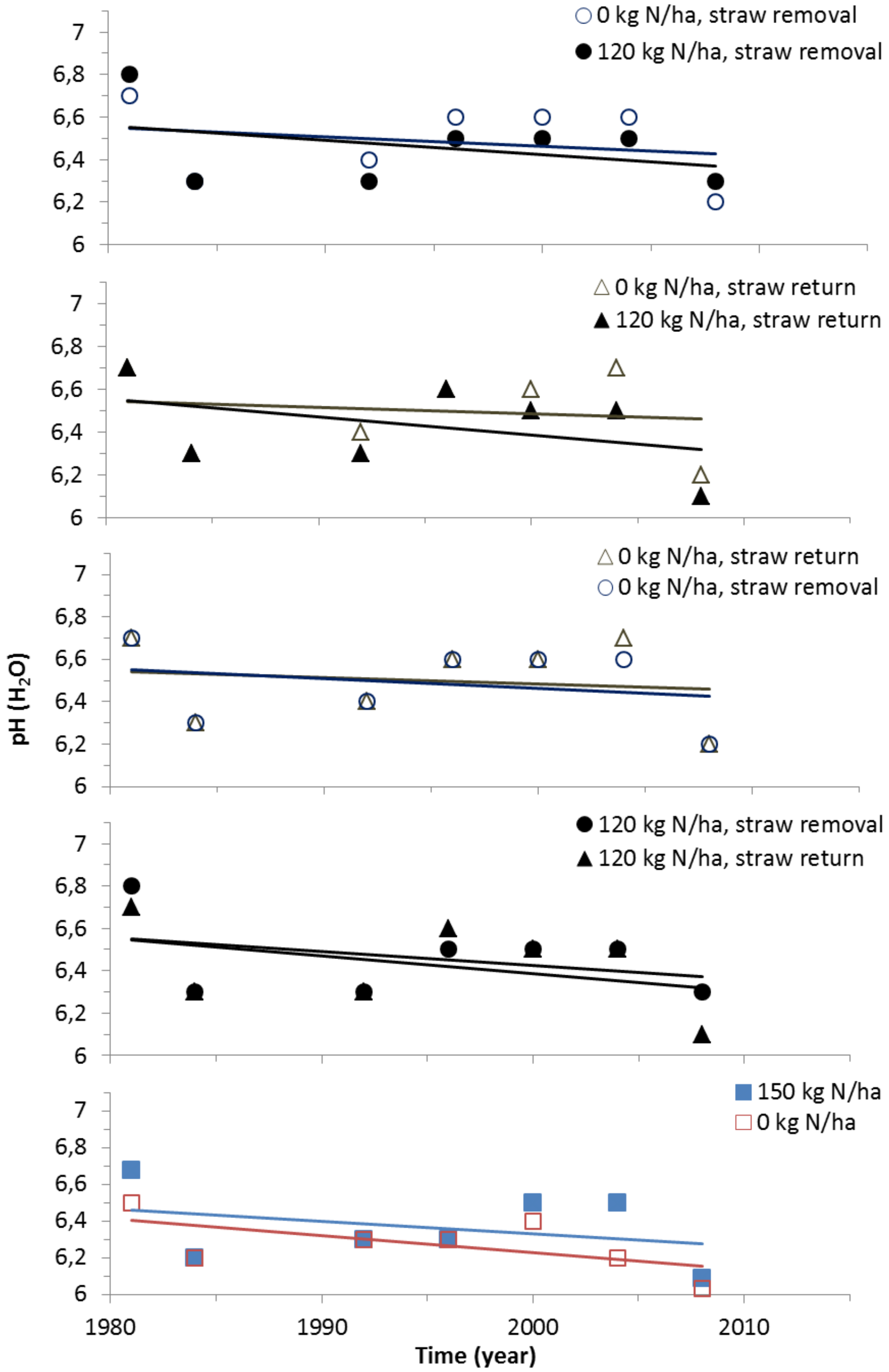


Figure 7. Soil pH development at Lönnstorp in the different treatments.

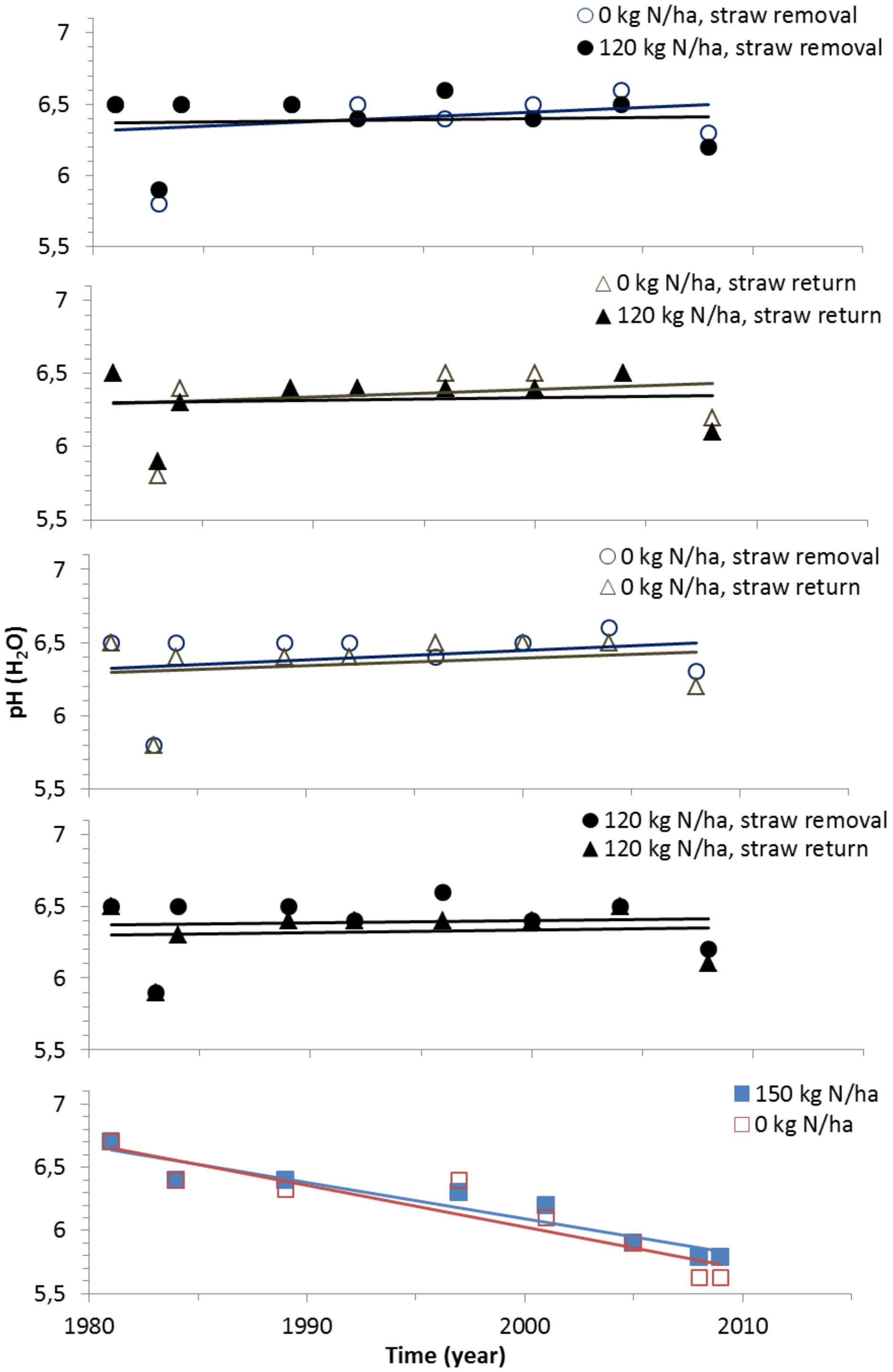


Figure 8. Soil pH development at Lanna in the different treatments.

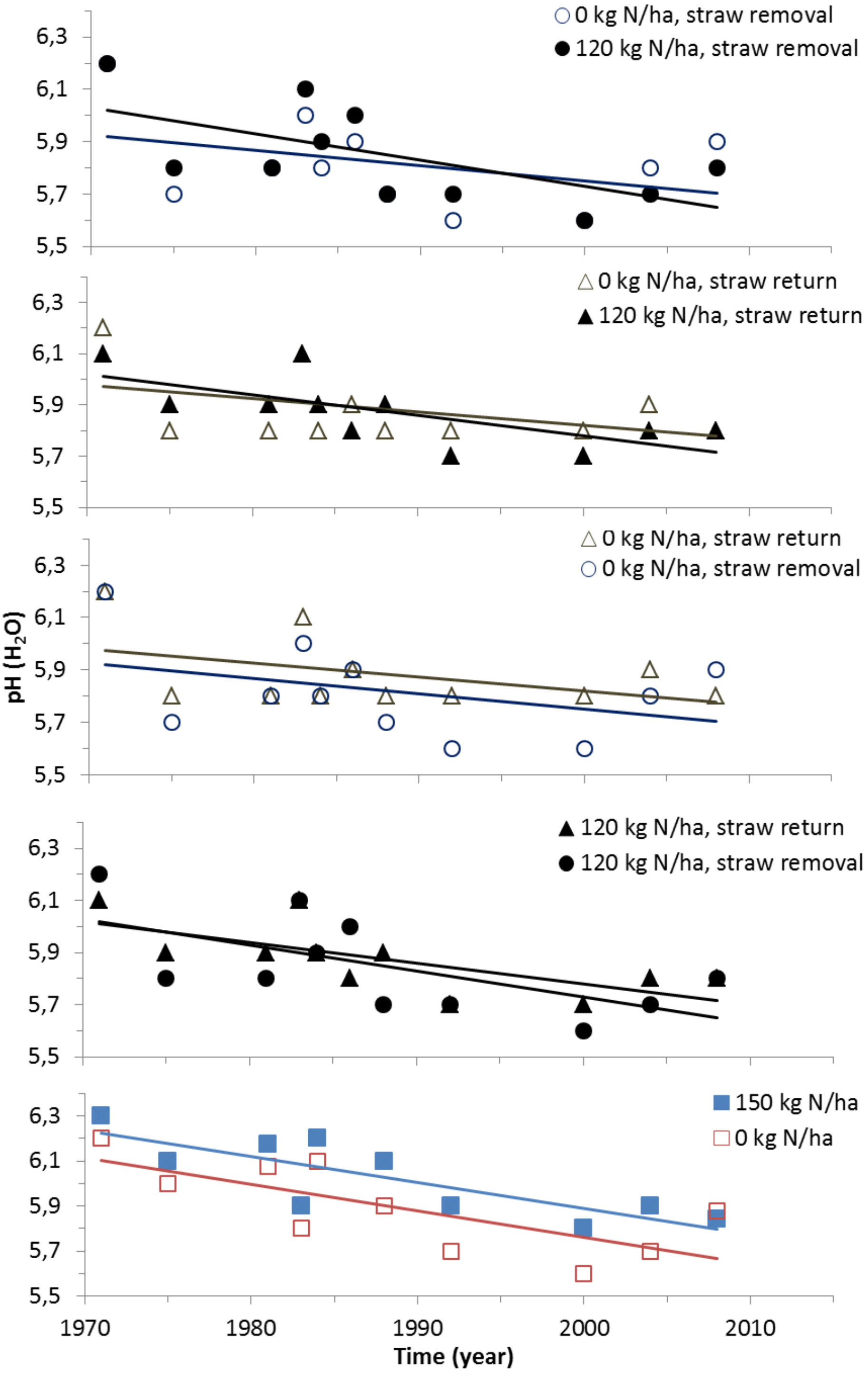


Figure 9. Soil pH development at Säby in the different treatments.

3.4 Changes in carbon versus pH in soil

3.4.1 Site Lönnstorp

When correlating soil organic C and pH, data from the cereal systems showed that pH increased with an increase of organic C. However, in the ley system, soil pH values decreased or remained constant when organic C increased (Figure 9).

3.4.2 Site Lanna

The correlation between organic C and pH showed a clear trend in the ley system where pH decreased when soil C increased. In the cereal system, same trend was found although it was less pronounced (Figure 10).

3.4.3 Site Säby

The same trend as in the Lönnstorp soil was found, a higher soil C resulted in higher pH values in all treatments (Figure 11).

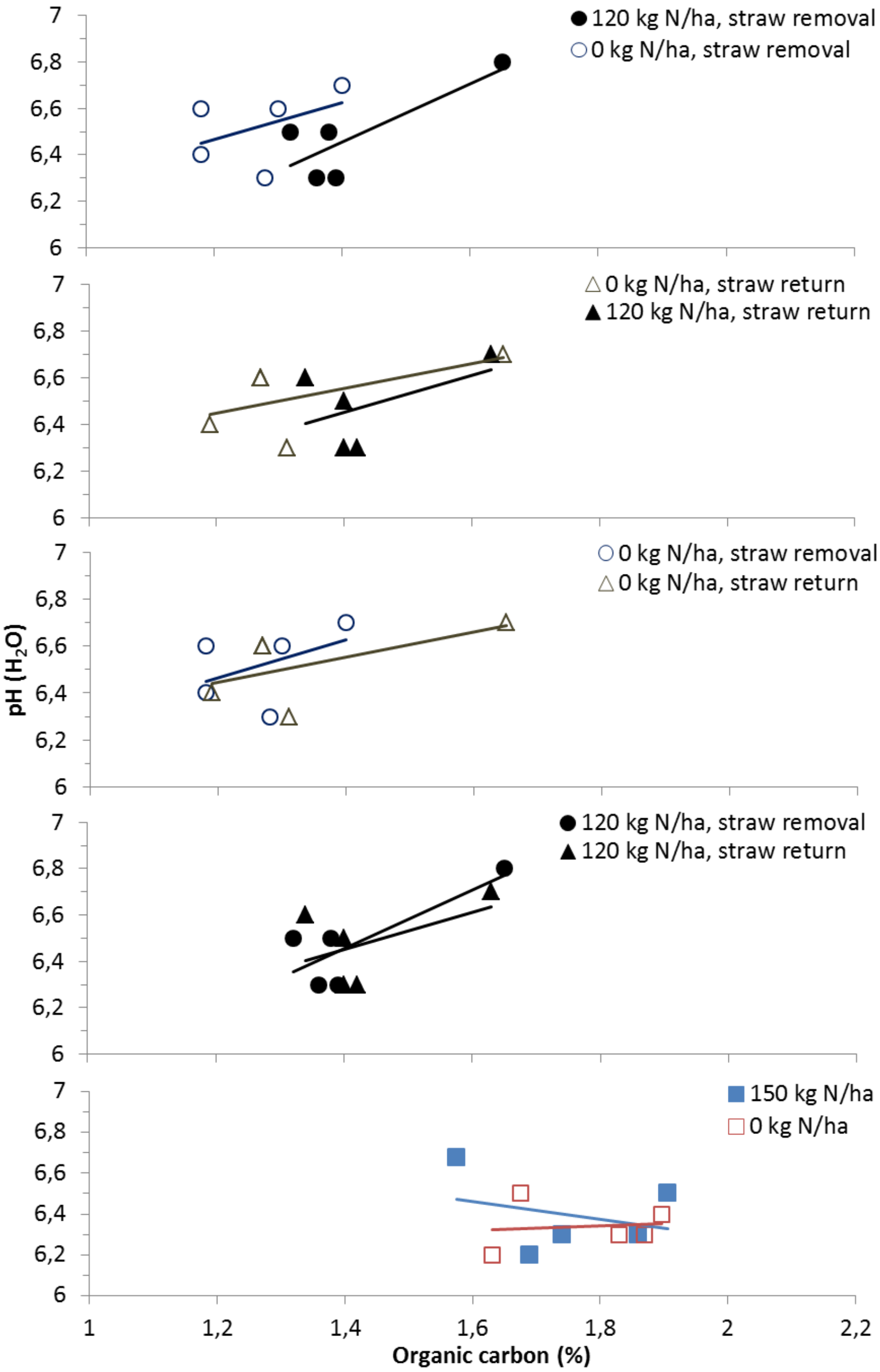


Figure 10. Soil carbon development versus pH changes at Lönnstorp.

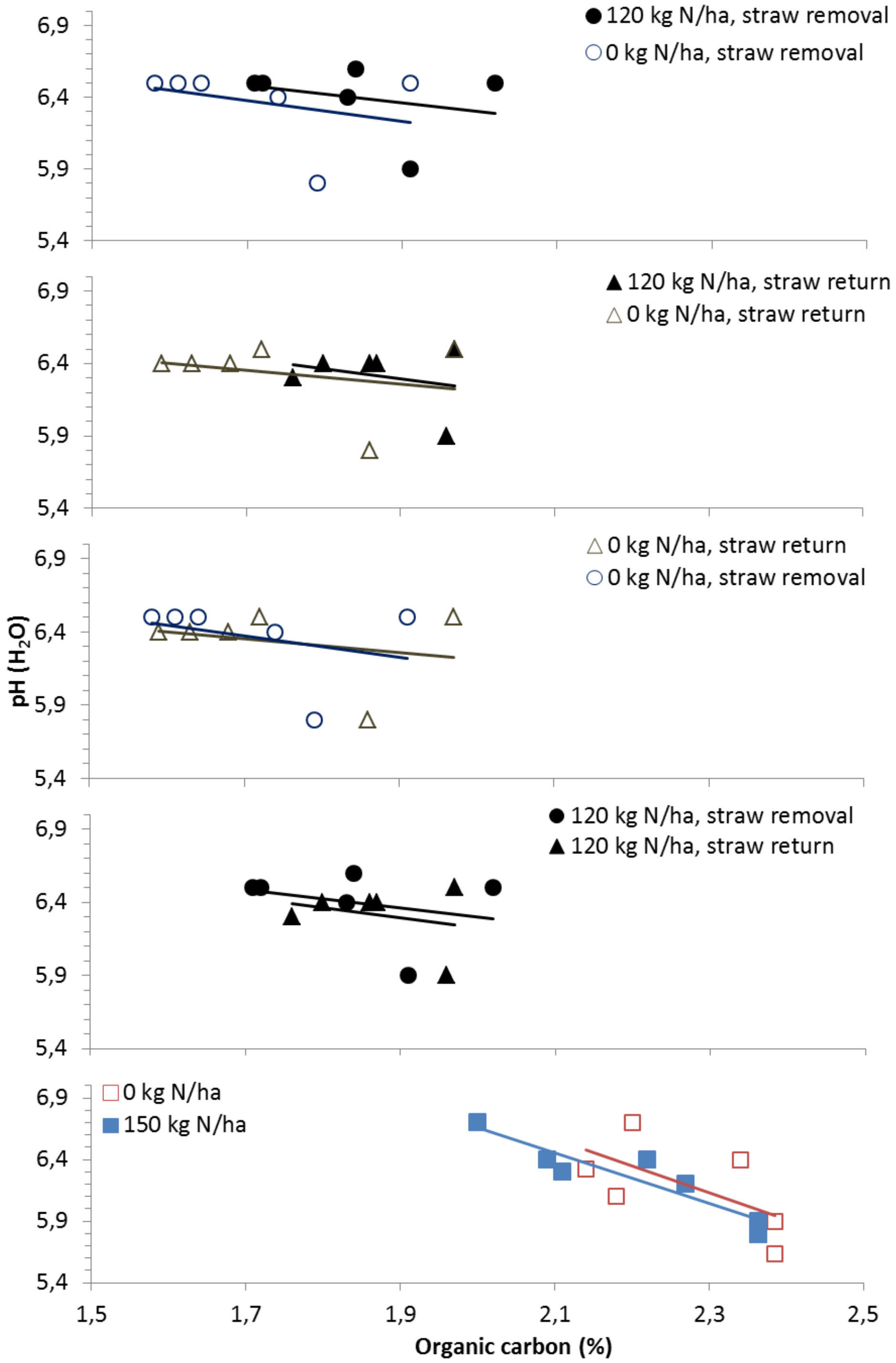


Figure 11. Soil carbon development versus pH at Lanna.

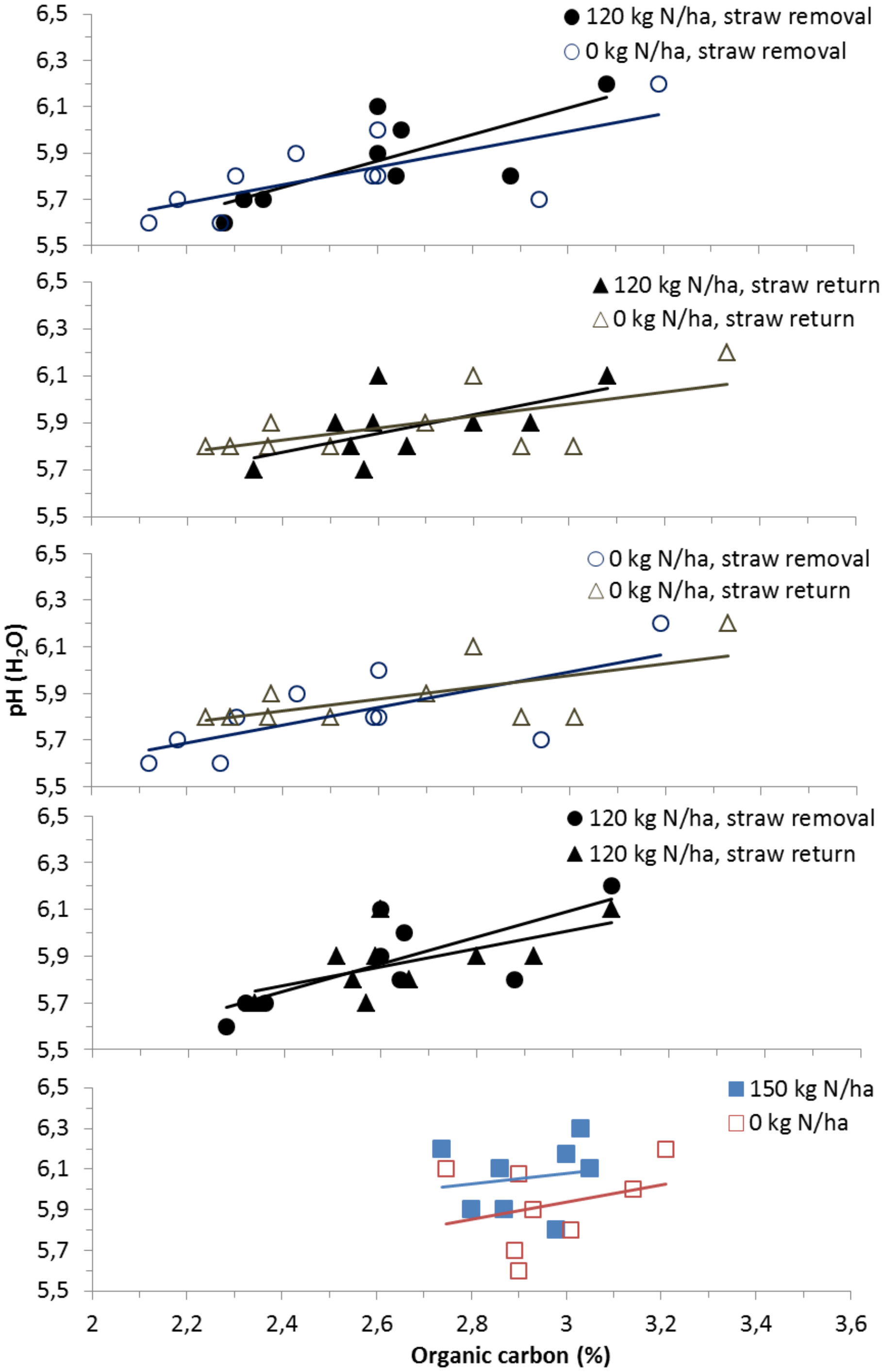


Figure 12. Soil carbon development versus pH changes at Säby.

3.5 Statistical evaluation

3.5.1 Soil carbon changes

The non-fertilized cereal treatments had the significantly lowest soil C contents compared to the other treatments after 30 or 40 years of cropping. The fertilized treatment with straw return had a significantly higher soil C content than the one with straw removal. The ley systems had significantly higher soil C contents than the cereal systems. However, between ley systems with or without N fertilizer application, no significant differences in soil C contents after 30 or 40 years of cropping were found. Soil C contents increased over time in the ley system but decreased in the cereal systems. Still no significant results about the development were obtained. The only significant difference in C development was between fertilized ley and non-fertilized cereals where straw was removed, which the later had the largest decrease in C and the ley system had the largest increase in C.

3.5.2 pH changes

Soil pH values after 30 or 40 years were significantly higher in the cereal treatments without N fertilization and straw removal than in high N fertilization cereals with straw return and in the ley systems. The soil pH in the non-fertilized ley system had a significant lower final pH value compared to the cereal system, but it was not significantly different from the fertilized ley system. Soil pH values decreased significantly over time in the ley systems compared to the cereal systems. In the cereal systems, the non-fertilized treatments decreased significantly less compared to the treatment with N fertilization and straw removal over time.

Table 1 Statistics for yield, organic C and pH (mean values from year 2010) from all locations. Values with the same letter are not statistical significant. Yield n= 4 for organic C and pH n= 3.

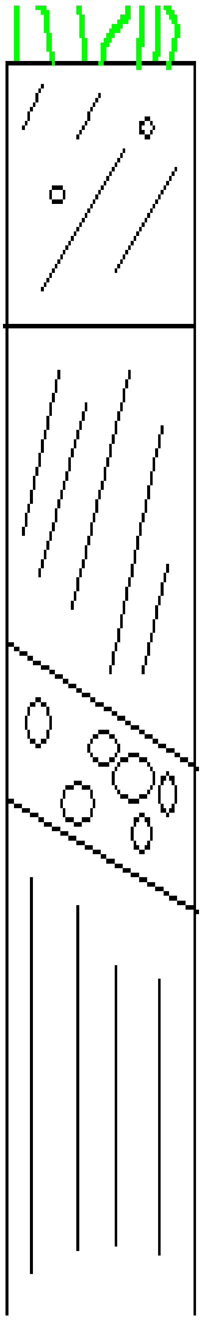
Treatment	Yield	sd	Organic C	sd	pH	sd
0 kg N/ha N straw removal	1931 [a]	876	1.78 [a]	0.50	6.13 [a]	0.21
120 kg N/ha straw removal	4187 [ab]	1574	1.85 [b]	0.47	6.10 [ab]	0.26
0 kg N/ha straw returned	2041 [a]	1043	1.79 [a]	0.56	6.07 [ab]	0.23
120 kg N/ha straw returned	4176 [ab]	1719	1.94 [c]	0.57	6.00 [b]	0.17
0 kg N/ha	5535 [b]	2213	2.39 [d]	0.50	5.85 [c]	0.20
150 kg N/ha	8156 [c]	1428	2.42 [d]	0.54	5.91 [bc]	0.16

Table 2 Statistical results for the slope of mean values over time for all locations. Values with the same letter are not statistical significant. Yield n= 4 for organic C and pH n= 3.

Treatment	Yield	sd	total C	sd	pH	Sd
0 kg N/ha N straw removal	-29.37 [a]	27.73	-0.001 [ab]	0.008	-0.004 [a]	0.002
120 kg N/ha straw removal	-14.43 [b]	38.24	-0.011 [ab]	0.004	-0.008 [b]	0.002
0 kg N/ha straw returned	-27.57 [abc]	30.12	-0.016 [a]	0.005	-0.004 [a]	0.001
120 kg N/ha straw returned	-13.30 [bd]	41.79	-0.008 [ab]	0.003	-0.007 [ab]	0.002
0 kg N/ha	-15.30 [bcd]	99.36	0.002 [ab]	0.008	-0.018 [c]	0.020
150 kg N/ha	-9.46 [bd]	97.59	0.058 [b]	0.094	-0.017 [c]	0.010

3.6 Descriptions of the soil profile at Lönnstorp

Lönnstorp Soil (27 June 2012)
Location: Sweden, Skåne, Lönnstorp. 60 m South of Lönnstorp research station and 100 m East of motorway E6 and E22. The topography is flat and the profile is in the intermediate part of a plain landform. No micro relief is present.
Climate: Mean annual temperature is +7.7 C° and mean annual precipitation is 569 mm.
Vegetation and land use: Arable field with annual rotation of cereals. At the time of the profile description barley was grown. The field is ploughed and drained.
Parent material: Post- glacial deposits that consist mainly of moraine.
Legend
The soil at Lönnstorp has its origin from post glacial deposits. The top horizon, Ap, is greatly affected by agricultural practices, such as ploughing and contains plant residues. The upper layer of the subsoil, horizon Bw1, is strongly compacted and the amount of roots drastically decreases. There is a thin horizon where flint stones have been deposited and beneath that layer the clay content increases. Mottling indicates that the soil is water logging during some parts of the year.



Ap, 0-27 cm. Dark brown (10 YR 2/3 moist) sandy clay loam with very few, fine and distinct yellow/brown mottles; few coarse angular gravels. Subangular blocky structure; slightly hard consistence; friable; sticky. Very low porosity, no compaction, common with medium sized roots, few earthworms, incorporated plant residues. Clear wavy boundary.

Bw1, 28-44 cm. Dark olive brown (2,5 Y 3/3) sandy clay loam without mottles, few coarse angular gravels. Angular blocky structure; slightly hard; friable; slightly sticky. Very low porosity, continuous-discontinues, compacted, massive layers. Common with fine roots, no earthworms. Abrupt smooth boundary.

Bw2, 45-50 cm. Olive brown (2,5 Y 4/6) clay loam with very few, fine and distinct yellow/brown mottles. Abundant with angular fresh or slightly weathered stones (flint stone). Stony structure; soft; very friable; sticky. Some porosity; no compaction, very few fine roots; no earthworms. Abrupt smooth boundary.

Bw3, 51-68 cm. Olive brown (2,5 Y 4/5) silty clay with very few, fine and distinct yellow/brown mottles. Few coarse angular gravels. Subangular, blocky structure; soft; very friable; sticky. Very low porosity; no compaction; very few fine roots; no earthworms.

4 Discussion

4.1 Barley yields

Yields of barley grain were generally higher when N was applied, as it ought to be, since N is one of the most limiting factors for crop production (Figure 1). Yield levels increased significantly over time when N was applied compared to the unfertilized treatments. However, an analysis of yields after 30 or 40 years did not reveal any significant yield differences between N-levels. This might be due to non-favorable weather conditions that particular year (Table 1). In addition, yield levels in Figure 1 did not differ if the straw was removed or returned to the field. More nutrients are retained in the field through straw return. One explanation might be that barley, which is the dominating crop in rotation, has a short shoot and hence the amount of crop residues returned as straw will be low. In addition, all nutrient withdrawal through straw and grains is replaced in all treatments with fertilizer.

Carlgren and Mattsson (2001) examined other trials with and without N fertilization-found that the yield development, increased when N fertilizer was applied and decreased when not fertilized. In the trials examined in this thesis, yields developed in the same direction both with and without fertilizer in the cereal system (Figure 1). This may indicate that the location had a greater impact than N treatment. Comparing the results when only barley was grown and when other cereals (Appendix 1) were also grown, yield levels were more uniform for only barley. This is probably due to that yield potential of crop types differ. Therefore only barley was used as comparison between sites and treatments. The results from the long-term trials at Hoosefield and Broadbalk showed that maximum yields have remained stable at both sites, at Hoosfield since the 70´s and at Broadbalk since the start for 160 years ago (Johnston et al, 2009). These results are surprising though varieties, cultivation and pesticides have evolved since then and hence there should be a greater yield potential over time. The yields in this trial have not remained stable and one possible explanation for the decline in yield could be that soil-born pests might have evolved at some of the sites since there is no diversity in the crop rotation. Nonetheless, pesticides are used and above-ground pests should not be a large problem. Thus pest effect on yield would differ if it is above or soil-born pests infecting the plant and therefore give a variation in yield level. However no data about pests was found when examine the results collected from the trials.

4.2 Ley yields

Yields were throughout higher in fertilized ley than of the one which had not received any fertilizer at all sites (Figure 2). Moreover, yields between N treatments differ between sites and differences are larger at Lanna and Röbäcksdalen than at Säby and Lönnstorp (Figure 2). Röbäcksdalen had the greatest proportion of legumes in non-fertilized leys compared to fertilized leys (Appendix 2) and therefore should have the largest N fixation potential in the unfertilized plots. Yet yield differences were larger between fertilized and non-fertilized leys at Röbäcksdalen compared to other sites. So, one can draw the conclusion that the N-fixation does not compensate for the fertilizer dose of 150 kg N/ ha when considering the trendlines. Also, final yield were significantly higher when fertilizing ley, although this might be random since it can be due to weather conditions that specific year (Table 1). However, no significant difference in the yield development over time was found between N-levels (Table 2). This can have a possible explanation due to legumes in the non-fertilized ley providing sufficient N. Since nodule growth in legumes is not restricted when fertilized (Whitehead, 1995), which may result in the same total N supply in unfertilized and fertilized plots. Yet another more likely explanation would be the difference in yield development negative and positive between the sites bring about insignificant results. Therefore the main conclusion drawn can be that the legumes does not compensate 150 kg/ha N fertilizer.

The variation in yields between years is large which bring uncertainties to the result. At Säby and Lönnstorp, there are some clear trends, an increase and decrease respectively, and at Lanna and Röbäcksdalen they have remained quite stable. The results from a fertilizer trial in the south of Sweden showed that forage yields increased independently of the fertilizer level over time (Carlgren and Mattsson, 2001). This is the opposite to the results obtained from Lönnstorp in this study, which also is located in the south of Sweden where forage yields declined in all treatments when comparing the yield trend over time. When examine the profile at Lönnstorp a compaction with drastically fewer roots were found in the upper subsoil and this might impede root development and hence reduce yield potential. At Rothamsted, the long-term ley yields did not show any significant decrease or increase over time neither for fertilized or unfertilized plots (Jenkinson et al., 1994). When the slopes for yield trends are examined, lines are both increasing and decreasing depending on the site. So no clear conclusions can be drawn as the underlying reasons for different trends are so far not known.

4.3 Barley and ley yields

At Lanna and Säby, ley yields are increasing but barley yields are decreasing. At Lönnstorp, it is the opposite (Figure 1 and 2). These results are surprising and cannot be explained by meteorological factors. As the plots been managed (apart from the treatments) in the same way there should not be any difference between barley or ley management. The most likely explanation is that the crops react differently to the treatments and that the response differs between the sites. It might has to do with the difference in root development, roots of barley grow deeper compared to leys roots. Hence barley has a larger soil volume to capture water and nutrients from and therefore drought affects barley less then ley. The concentration of CO^2 in the atmosphere has increased since the start of the trial with about 50 ppm. From earlier studies it has been shown that when increasing the CO^2 concentration the plant production increases (Rosenweig & Hillel, 1998). This would also implement for an increase in yield, but this have not been observed in the trials, since most of the segments has a declining yield trend.

As the percentage of organic C decreased at all sites for all cereal treatments but yields increase at some sites, no clear correlation between higher yields and an increase in the levels of organic C as suggested in other studies (Bot & Benites, 2005, Brady & Weil, 2002, Johnston et al, 2009) can be found. The yield potential ought to be lower when organic C contents decrease but this cannot be verified since the cereal yield increased at Lönnstorp and at the same time the organic C decreased. Also in the ley systems, there does not seem to be a clear correlation between an increased ley yield and higher organic C contents. For example, at Säby ley yields increased but organic C decreased. At Röbäcksdalen and Lanna yields remain stable but organic C is decreasing at Röbäcksdalen and increasing at Lanna.

4.4 Soil carbon changes

In this thesis it was hypothesized that the ley system should increase soil organic C. At Säby, the soil C contents did not increase with ley but, on the other hand, they did not decline as much as in the cereal system. However, at Lönnstorp and Lanna soil organic C increased when growing ley. Lanna and Lönnstorp are sites where ley yields showed a small increase and there could be a possible correlation between the yield development and increase in organic C. However, the below-ground is difficult to estimate and hence a larger C input to the soil is possible despite a low increase of ley yields. Soil carbon values were significant higher in the ley system compared to the cereal system (Table 1). Leys normally have a large root biomass and the C input to soils is high as ley root systems are left undisturbed for at least two years. In an undisturbed system, living roots can grow over longer periods and roots are not decomposed to the same extent as in a ploughed system (Brady & Weil, 2002). However, when comparing the development of C over time between the cereal and ley system, it was shown that there was only a significant difference between two extreme treatments concerning C input - fertilized ley and unfertilized cereals with straw removal.

According to Johnston et al., (2009) soil organic C can be stabilized by clay but when comparing the clay content of the sites with the organic C development, there was no correlation. Säby and Lanna have the highest clay contents but organic C declined at Säby for all treatments and at Lanna in the cereal system. In addition, clay soils can hold more water and can be more often saturated, which slows down decomposition hence leaving more SOM in the soil.

Another hypothesis of this thesis was that when applying a high N level, soil organic C will increase due to a high crop production and large root biomass. This hypothesis was only corroborated through the ley system where the application of N fertilizer resulted in higher soil organic C contents. There is a difference in the decline of organic C when fertilizing and not fertilizing at all sites (Figure 3, 4 & 5) and the decline is smallest in the treatments which received a high N supply. Further the N level did not give any significant result in the ley system regarding the final total %C, which can be due to a similar biomass as rhizobium can compensate for N. In the cereal system there was a significant difference in the final tot C% when fertilizing or not, the fertilized segments had a significant higher C content compared to those how was left unfertilized. This is probably due to the higher biomass production when fertilizing. Yet no significant results regarding the development of tot C % over time where observed between any of the cereal segments (see Table 2).

In the trials at Broadbalk winter wheat trial the C content was 0.19% higher after 100 years when applying a higher level of N. When fertilized with even more N the C content increased with 16% (Johnston et al, 2009). At the Hoosefield trial the C content was in general 10% higher in the fertilized plots compared to the unfertilized plots after 100 years. In yet another trial at Morrow, a similar result was obtained (Brady & Weil, 2002). However Raupp (2001) found no increase in C content when increasing the fertilizer dose. Yet he did not find a decrease either as it was in some of the segments in this trial. So these results show the opposite of the one found in this examination. It might be due to the original C content, in an organic soil C content decrease independent of yield level due to an increased aeration. The examined soils are not organic yet their initial C content might have been higher the soils from earlier investigations and thus their C content development resembles those from an organic soil.

As it was shown that a higher N level increased the concentration of organic soil C content in the cereal system and as N fertilizer production has a big climatic impact it would be interesting in future to calculate the net effect N fertilizer has on the greenhouse gases when taking C sequestration in consideration.

At Lönnstorp, Säby and Lanna the largest decline in organic C% is when the plots are not fertilized and when straw is returned (figure 3, 4 & 5). According to the hypothesis the largest decline should have been when the trial is not fertilized and when straw is removed. Does the return of straw increase decomposition of stabile soil organic matter when N is not supplied? A possible explanation why straw return is not resulting in significantly higher soil C contents may be because barley has a short shoot and not much residues are actually returned. When Mattsson (2002) estimated decomposition rates of organic matter in soil for the low N cereal system, these were higher when straw were returned compared to when straw were being removed from the field. So according to his estimations the result fits. But logical it does not make since a higher C input ought to leave more C in the soil and why the trendlines shows this must most possible be explained by the barley short straw. The statistical analysis of soil data after 30-40 years showed a significantly higher organic C content when cereals were fertilized and straw was retained compared to fertilized treatments where straw was removed.
Soil organic C measurements deviate between years showing that sampling and actual conditions during sampling (more or less roots and so on) can affect results and it is difficult to rely on too few measurements to establish trend curves At Rothamsted and Woburn, straw removal and return was compared with regard to changes in soil C contents. Results were similar to this study, at Rothamsted there was an increase in soil C when returning straw but at Woburn soil C contents decreased after 16 years of straw return (Johnston et al., 2009). In another trial in England, no difference was found between return and removal (Hazarika et al., 2009). Concentration of C may be decreasing when straw is removed due to an enhanced decomposition when the straw is returned if it is incorporated to the soil. Further the straw may also give a poorer seedbed compare to when it is removed.

Mattsson (2002) also calculated C input and decomposition rates at the different sites. At Lanna he found that changes in soil C were both positive and negative, which is accordance with the cereal system, as it is a declining and in the ley system an increasing soil C content. According to his estimations, at Säby net addition of C should be larger than decomposition, which is in contrast to the findings in this thesis.

Johnston et al (2009) found that the C content decreased more in plots with a higher initial C content when applying chemical fertilizer compared to those which had a lower initial C content. Säby is the location in this trial which had the highest initial C content and it is the only location where all treatments gives a decrease in % organic C, which then is coherent with Johnstons results. This implements that the C input from the leys was lower than the decomposition of soil OM at Säby, since there was a high initial C content. Further when considering the hypothesis that ley cultivation increases soil C it is correct if the initial C content is low.

4.5 Soil pH changes

One hypothesis of this study was that pH would decline less when ley with N fertilizer is grown compared to unfertilized ley, because acidification is higher through N fixation by rhizobium than through N fertilizer application (Brady & Weil, 2002). Marschner and Römheld (1983) found in a pot trial that clover without fertilizer had an acidifying effect but when pots fertilized with N soil pH increased. At all sites soil pH decreased more when no N was applied (figure 6, 7 & 8), however the difference was small and might be regarded as negliable. There were no significant results between the different ley segments, neither for the final pH value or the development over time (Table 1 & 2). However, since the pH development and the final pH values differed between the locations the variation is large and thus makes it difficult to do a statistic analysis of the data. As trends are unclear between sites and no significant results were obtained, it is difficult to draw conclusions.

Another reason why leys could be more acidifying than cereals is because leys remove more cations compared to cereals (Mattsson, 2002).When Mattsson (1996) measured pH development in another long term trial in Sweden with both ley and cereals, he found that pH decreased in all systems but more in the ley system. This result correlates to the one found at Lanna but not at Säby or Lönnstorp (Figure 6, 7 & 8). When comparing yields between the sites there is no large variation and the result cannot be explained by a higher withdrawal of cations due to a higher yield level at any of the fields. Statistical analysis of pH development showed that leys caused more acidification in soil than cereals as it was stated in one of the hypotheses. Still, one-time measurements after 30 or 40 years did not result in significant differences (Table1).

A further hypothesis was that removal of crop residues from soil would be more acidifying than return. When the trend lines for the pH development were examined, the decline was larger when straw was removed than returned at Säby and Lanna but the difference was small. At Lönnstorp, it was the opposite. The observed effect on pH can be the result of the return of cations through straw. However, when Hazarika (2009) compared soil pH values, in a system similar to the cereal system in the present study he found no significant differences when straw was removed or returned. The statistical analysis of pH values after 30 or 40 years showed that these were lowest in fertilized treatments with straw return. This indicates that removal of cations through higher crop yield must also be considered. The only significant result from the trend line analysis was that unfertilized treatments with straw removal decreased less compared to N fertilized with straw removal.

4.6 Relationship between organic carbon and pH

Both pH and organic C declined at Säby for all treatments and in the cereal systems at Lönnstorp when plotted against each other (Figure 9 & 11) which is the opposite to the results from previous studies (Adams & Adams, 1983; Curtin et al., 1998; Kemmitt et al., 2005; Andersson et al., 2009). At Hoosfield, soil pH increased with the C content but the pH was low to start with, 4 (Rousk et al., 2009). A low pH value means a low solubility of soil organic matter and C contents rather increase than decrease through cropping at low pH (Bot & Benites, 2005). It may be that the yields are high and the withdrawal gives rise to a large reduction of the cation concentration, hence decreasing pH. Yet, when comparing the yield development at these sites they differ, at Lönnstorp the barley yields increase but at Säby they are decreasing. The correlation between yield, pH and C development did not explain changes in pH and soil C, other factors not considered in this study must have had an impact on soil pH.

Correlations were found between pH and C at Lanna in all treatments and at Lönnstorp in ley treatments (figure 10 & 11). However, the correlations are of opposite directions for the ley and cereal system at the two sites (Figure 9, 10 & 11). This supports the hypothesis that pH should decrease in leys and increase in cereals and that organic C should increase in leys and decrease in cereals. The reasons were discussed above.

4.7 Restrains regarding the statistical analysis

Since no replicates for treatments have been examined over the years, statistical analysis of soil data are restricted to mean values from each treatment. This is a severe limitation causing uncertainties of the results related to soil C and pH development. Initial values differed between sites and values might also have been different between plots of the same treatment. Differences between plots at the same site and same treatment may be regarded as normal field variance as the plots are located close to each other Mean values of treatments from the different sites are used as replicates.

The soil data were examined with regard to slopes of the trend lines and values after 30 or 40 years. Trend lines were also used to make comparisons between different treatments. The statistical analysis was limited to these measures. Concerning yield data, replicates for each treatment existed. The statistical evaluation could be based on site-specific data and replicating treatments by using sites could be excluded.

5 Conclusions

The following conclusions about soil organic C and pH development can be made. Soil C contents decreased less when nitrogen was applied to the cereal treatments as compared to the no N treatment. Straw management, return vs removal, did not affect soil C contents. The cereal system reduced soil carbon more than the ley system. It seems as initial carbon content has a greater influence than management over an increase or decrease in soil carbon content. In unfertilized leys, pH decrease was more pronounced compared to fertilized ones indicating the acidifying effect of biological nitrogen fixation. The main conclusion from the yield results showed that application of N fertilizer increases yield. Nitrogen fixation in the legumes did not compensate for an application of 150 kg N/ha in the ley systems. However, the remaining hypothesis did not show to be true as the effects of different treatments differed from location to location. Therefore it would be more suitable to study in detail the different soil parameters that differed between the sites and by that compare the result obtained from the trial. No correlation between yield development and soil C content was found as suggested by literature. Since the results differ between locations a conclusion about sustainable farming practices is hard to do. However the ley system resulted in higher soil C than the cereal system, thus indicating that the ley system is more sustainable than the cereal system.

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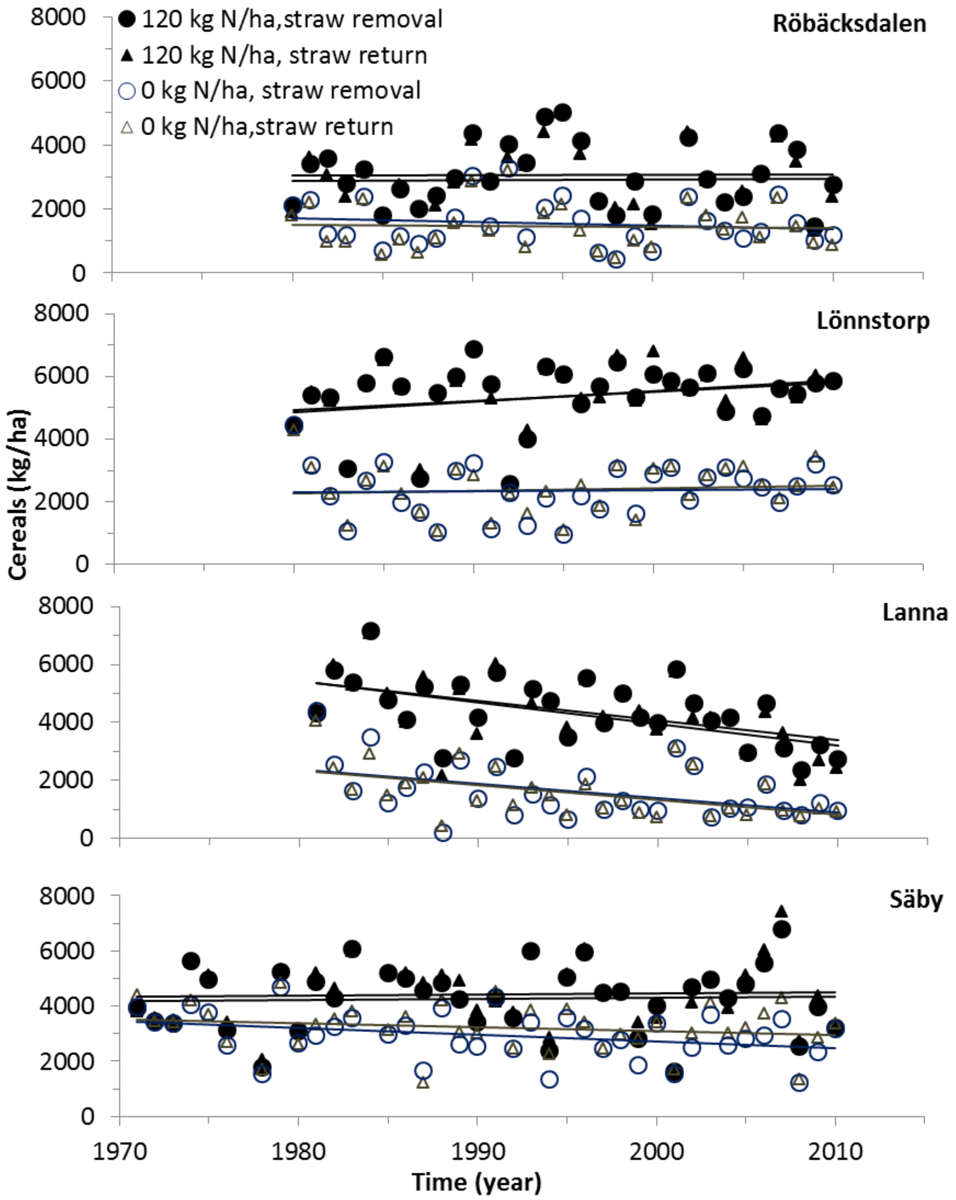
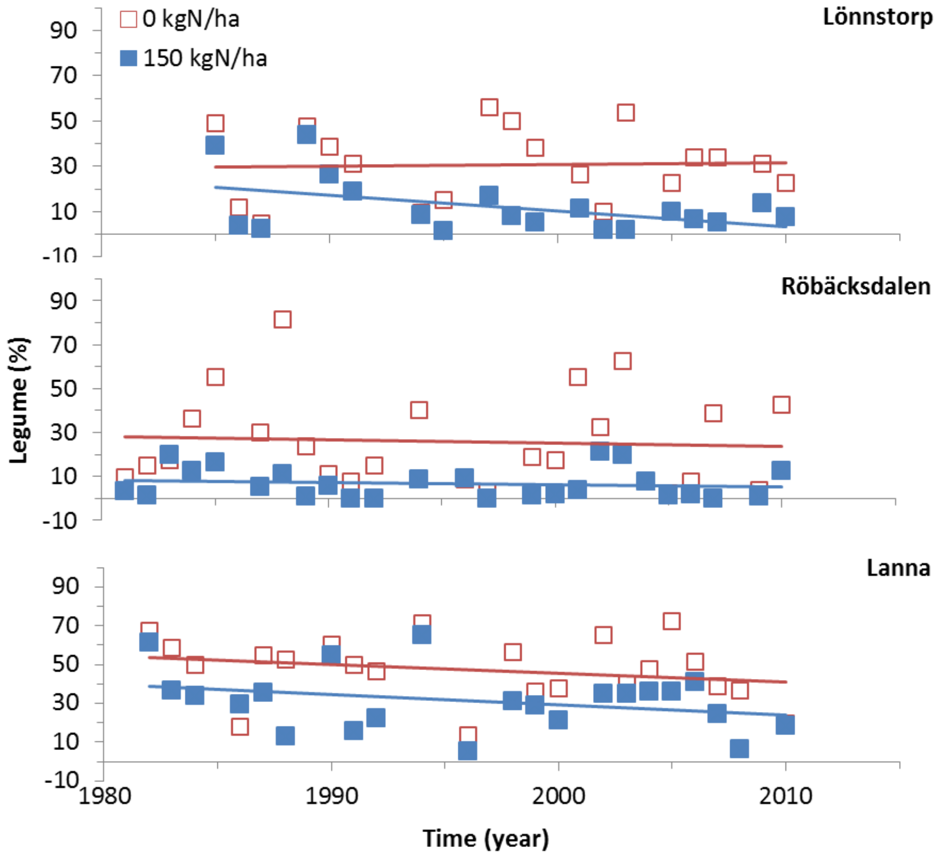
7 Apendix



Appendix 1. Cereal yield development (kg/ha) at the different locations.



Appendix 2. Legume proportion over years at Lanna, Lönnstorp and Röbäcksdalen.