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Carbon storage capacity in arable land and pasture across Lund Municipality in regard to management techniques

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Abstract

Due to the increasing CO_2 concentrations in the atmosphere caused by anthropogenic greenhouse gas emissions, there is a need for adaptations and mitigations to climate change. Not only is a drastic reduction of emissions necessary, but the uptake of CO_2 from the atmosphere needs to be increased and stored long-term. One of the more efficient mitigation strategies to reduce CO_2 concentrations in the atmosphere is to increase the storage of carbon (C) in soils. This study aims to calculate the C storage capacity in Lund municipality in arable land and pasture today and examine the change of C sequestration if enhanced management strategies were implemented. This will be done by using different scenarios in time and space.

To conduct this study, a C storage capacity template from "Svensk Kolinlagring'" (Swedish Carbon Capture) was used. As arable lands and pastures have a high CO_2 storage capacity in Lund municipality, they were used in this study. Through data from "Lantmäteriet" (The Land Survey) and "Jordbruksverket" (The Swedish Agricultural Agency), it was possible to detect and locate arable land and pasture in the municipality. Through this, a base scenario was created with the aim to represent the C storage in the best way possible. Then different scenarios were created and applied for different management techniques derived from the C storage capacity template. The different scenarios also included change in area and over time. The differences were then studied and the consequences they brought were discussed.

The results showed that so-called Stacked management methods have the highest potential to increase soil C uptake in the area. The Single management methods also showed an increase of C sequestration compared to the base scenario, but not to the same extent as the Stacked management methods. However, implementing new management techniques can be difficult and several other aspects can conflict, such as economic and land use interests. Long term, C sequestration in the soil will yield economic benefits. However, this is rather the opposite in the short-term perspective. Further studies are needed to deepen the knowledge even more for municipalities to mitigate their CO_2 emissions. For example, municipality-specific studies to account for local conditions, such as soil type and cultivated area.

Keywords: Carbon storage capacity, pasture, arable land, agriculture, climate mitigation, Svensk kolinlagring.

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1 Introduction

Soils are a large pool for carbon (C) in the biosphere. The top of one metre of the soil can hold three times as much C as what is stored in the vegetation above ground. The soil is estimated to contain twice as much C as the atmosphere and 10% of this soil C is located on agricultural land (Land et al. 2021). Like many of the other C pools in the biosphere the soil can act both as a C sink from the atmosphere and as a C source to the atmosphere (Falloon et al., 1998). With increasing temperatures and climate change the frequency and intensity of extreme weather will change, which could lead to droughts, floods and erosion. This could have a large effect on the agricultural sector. Therefore, mitigation and adaptation are important to secure the yield, both animal feed and human food, by using more sustainable land management, such as cover crops and no-tilling (Droste et al. 2020).

One technical solution to reduce carbon dioxide (CO_2) concentration in the atmosphere that is caused by anthropogenic activities (more specific the burning of fossil and renewable fuels) is to increase the uptake of CO_2 through biological processes, but also to store the CO_2 physically and chemically during longer time, this is called Carbon dioxide Capture and Storage (CCS) (IPCC, 2005).

Some factors that affect the C storage capacity in arable soils are: soil type, land management, climate zone and addition of organic matter such as crop residues or livestock manure (Land et al. 2021). Additionally, the soil's physical characteristics also play a role in C storage. The fraction of sand, silt, clay, soil depth and its degree of aggregation are some to mention (Hoyle et al., 2013). When intense crop production occurs over a longer time it reduces the soil organic C stock in the soil (Droste et al., 2020). Land management that is connected with livestock handling usually has better premises to store more C in the soil since organic matter, in the form of stable manure is added on site and usually large areas with grassland and animal feed are cultivated (Land et al., 2021). Further, according to Land et al. (2021), perennial crops and legumes in the crop rotation and variety in the crop rotation and management have positive effects on the amount of organic C in the soil.

An increase of C stock in soils will not only benefit the reduction of CO_2 in the atmosphere but also soil health, both physical and biological (Land et al., 2021). There is a relationship between soil organic carbon (SOC) and soil health. It has been seen that with an increase of SOC (due to changed management techniques) there is an improvement of biodiversity, higher water holding capacity, lower nutrient leakage, lower risk of erosion but also higher resilience against damages and food loss due to climate change (Droste et al., 2020). However, managements such as tilling reduces the SOC stock and therefore the biodiversity. During tilling, the decomposition rate is increased due to the enhanced soil aeration and soil moisture. This leads to an increase of soil respiration rate and therefore the loss of C to the atmosphere (Schlesinger, et al. 2000). The way land is managed will in some way determine if the soil will act as a source or a sink of greenhouse gases including CO_2 (Droste et al., 2020).

Since the start of cultivation, it is estimated that the C stocks have been reduced with 20-60% in cropland, at the same time as conventional agriculture acts as a C source (Olsson et al., n.d.). By improving soil management, 5-20% of the anthropogenic GHG emissions can be neutralised. Barriers that hinder this potential to increase the C capacity are: economic, political, socio-cultural, institutional, legal, knowledge-based and resource-based (Olsson et al., n.d.).

The relationships between soil C sequestration and land management and what affects them are important to understand to potentially reduce the CO_2 concentration in the atmosphere (Falloon et al., 1998). These are essential for policy makers to deal with in relation to climate change, and calls for improved land use planning (Falloon et al., 1998). The Kyoto protocol and United Nations Framework Convention on Climate Change (UNFCC) has drawn attention to the idea to store C in the ground and to put more resources and effort towards it, both towards policy-makers and researchers (Zhang. et al., 2023). Further, the Sustainable Development

Goals (SDG's financed by the United Nations) empower nations to use long-term measures and strategies in regard to mitigating climate change, such as C storage and sequestration (Zhang. et al., 2023).

One example of policymakers that uses C sequestration as a mitigation technique is Lund Municipality, which has as a goal to be fossil-free and have net zero emissions by the year 2030, this to reach the Paris agreement goal. However, 20% of Lund's emissions came from the agricultural sector in 2021 (Lunds Kommun, 2024). One of the prerequisites for the municipality to succeed with their goal is to increase the C sequestration in the soil (Lunds kommun, 2023).

By calculating the C storage capacity subject to land management over a region, and its spatial distribution, stakeholders can use this as a tool for planning more efficient land management in regard to increased soil C sequestration. This will be used to reach the goal towards the Paris agreement 2015 and to stay under the limit of an increase of 2℃ of pre-industrial levels but also to improve the quality, services and functions of the soils (Kätter & Bolinder, 2022).

1.1 Aim

This study aims to calculate the C storage capacity in Lund municipality in arable land and pasture by using the C storage capacity template from "Svensk kolinlagring". The objectives are to:

- Calculate the C storage capacity in Lund municipality in arable land and pasture.
- Examine the change of C sequestration when using more optimised land management methods on arable land and pasture.
- Investigate the potential for increased C storage through several scenarios in time and area of changed management, to evaluate the change of cost and consequences when adjusting management strategies.

1.2 Hypothesis

The current C storage capacity in Lund Municipality is considered to be low due to its intense crop production and land management. It is hypothesised that if arable land and pasture in Lund Municipality would implement enhanced land management practises, the total C sequestration throughout the municipality will increase.

1.3 Assumptions and Limitations

This study is limited to Lund Municipality and only to pasture and arable land where the potential of improving C capacity is considered large. There is, however, potential to expand to other management if other studies are included. This study is also limited to the amount of C that can be stored and does not include other greenhouse gases (GHG) such as methane, nitrous dioxide that also affect global warming (Toensmeier, 2016). Neither will it include the biomass above or below ground such as root-systems, plants nor harvests.

2 Background

2.1 One part of the Carbon Cycle

The flux that connects the C transportation between the atmosphere and ecosystems is called net ecosystem production (NEP) and is a part of the global C cycle (Chapin et al., 2006). Together with the gross primary production (GPP) and the ecosystem respiration (ER), the NEP can be calculated. GPP is defined as the amount of C that is accumulated by photosynthesis while ER is defined as the loss of C through respiration (Chapin et al., 2006). NEP is the difference between GPP and ER (Eq. 1). A negative NEP results in a loss of C to the atmosphere while a positive NEP is a net gain of C to the ecosystem (Chapin et al., 2006).

Equation 1. The relationship between net ecosystem production, gross primary production and ecosystem respiration.

$$NEP = GPP - ER$$

The other way around, i.e. the process where C is transported from the soil to the atmosphere is called soil respiration (autotrophic and heterotrophic) which is the major process that transfers C from the soil to the atmosphere. Autotrophic respiration is connected to the root system and the rhizosphere, the C that is involved in these processes have short residence time in the soil compared to the C that is involved in the heterotrophic respiration. Heterotrophic component is described by Epron et al., (2009) as “originating from soil micro-organisms that decompose the organic material from both above-ground and below-ground litter”. This C has retention time from months to years (Epron, et al. 2009). Increasing temperatures will affect and amplify the soil respiration and therefore affect the soil C stock. The increase of CO_2 concentration in the atmosphere will also enlarge the stock of C in the soil, since there is more C in revenue (Schlesinger, et al. 2000). The rate of respiration is affected by climate, soil type, soil temperature and is therefore thought to change as a feedback from climate change (Epron, et al. 2009).

2.2 Swedish Carbon Capture

Svensk kolinlagring (Swedish Carbon Capture) acts as a platform to connect investors and farmers to increase the amount of C storage in agricultural soils. The goal is to convert the Swedish agricultural land use from a C source to a C sink. With businesses that invest in C storage and farmers who are in charge of the land management, the collaboration between these aims to increase the C capture in agricultural land in Sweden. This will mitigate climate change, but also increase the organic matter content and the fertility of the soil (Svensk kolinlarging, n.d.a).

2.2.1 Carbon Storage Capacity Template

Swedish Carbon Capture initiative has created C storage “reference values” for different land management. These are based on scientific literature since the changes of C storage are difficult to determine over a short period and since there are small changes in form of fluxes that occur naturally over a shorter time period (Svensk kolinlagring, n.d.b). The literature that the C references are based on are limited to Swedish and European data and research. Further, these only include the SOC and not the soil organic matter since there is no proven relationship between these parameters (Svensk kolinlagring, n.d.b). Some of the values in the C reference table are made from model simulations. The unit that is used from this is: t C/ha/yr (Svensk kolinlagring, n.d.b).

Why this template was chosen to be used in this study is since it is a summary of reliable sources that calculated the C storage capacity. Moreover, due to the limited time of this study, the template from Swedish Carbon Capture has a suitable level of detail (Svensk kolinlagring, n.d.a). This summary from Svensk kolinlagring is also one of few summaries of C capacity across different land managements that could be found (Svensk kolinlarging, n.d.a).

2.3 Climate Change Mitigation Strategy

The 2015 Paris Agreement set the goal to not exceed an increase of the global mean air temperature with 2°C and further aims to keep it below 1.5°C compared to pre-industrial levels. To reach the goal, the emissions not only need to decrease but also negative emission is required, i.e. a net uptake of GHG from the atmosphere and store it in alternative pools (Kätter & Bolinder, 2022). Examples of this are air C capture and storage, ocean fertilisation, biochar and soil carbon sequestration (SCS). To reach the goal a combination of several methods is needed, although all techniques are not as relevant as others due to its cost to implement (Kätter & Bolinder, 2022). One of the more cost-effective strategies is SCS that has a high potential to store C. This due to the long experience within the field and the benefit of no need for land use-change. Soils have a potential to store 1.2-3.1 Pg C/yr (Kätter & Bolinder, 2022). A more optimised land management can further increase the uptake with additionally 0.069-1.85 Pg C/yr. The majority of Pg C/yr is dependent on technical resources while the last 0.5 Pg C/yr of the previous value is dependent on economic resources. Additional C sequestration could be possible in the future as a result of enhanced root characteristics after crop breeding, which could add 0.3 Pg C/yr (Kätter & Bolinder, 2022).

2.4 Lund Municipality and their goals

Lund as a municipality has the goal to become climate neutral until 2030 i.e., to have net zero emissions. However, the agricultural sector covers a large part of the municipality and is the source of almost 20% of the total CO_2 emissions in the municipality (Lunds Kommun, 2024). A prerequisite for the municipality to succeed with their goal is to increase the C sequestration in their soils. It is nevertheless not only the agricultural sector that needs to increase its C storage but also the forestry and the wetland sectors. To reach the goal, Lund needs to decrease their CO_2-emission by 80% from 2010, which is 73 452 t CO_2. The remaining CO_2 is then planned to be captured in soils by C farming (Lunds Kommun, 2024). 1 t of C is equal to 3.67 t CO_2 (Land et al., 2021), which means that 20 014 t C needs to be stored the year 2030 (Lunds kommun, 2024). According to Lund Municipality (Lunds Kommun, 2023) they will most probably reach the goal to store more C in soils, but it is more uncertain whether or not they will reach the goal of decreasing their emissions from 2010 with 80% until 2030.

3 Method

3.1 Methodological overview

To create a scenario that represents the C sequestration today in Lund municipality, a base scenario was created. This by looking at the land use distribution in the study area and the management types from The Swedish Agricultural Agency. Further, when investigating the change of C sequestration if implementing more optimised land management methods, different scenarios for the future were implemented. Both in terms of area of conversion but also how much C it would represent under different time scenarios.

3.2 Study Area

This study is conducted in Lund Municipality, which is located south in Sweden (Figure 1). With ca 19 000 ha of arable land (Jordbruksverket, n.d.g) and 4 200 ha of pasture (Jordbruksverket, n.d.b) it is a municipality with almost half of its land area within the agricultural sector (SCB, 2024).

Even though the region of Götaland´s southern plain (which Lund is located in) has low input of soil organic matter (SOM) and intense crop production over a long time, it has higher yield than the average for the rest of the country. 4.3 t/ha is the average yield for Sweden annually, while 5.7 t/ha is produced in the region where Lund is located. Due to this high crop production and intense management the SOC has decreased in this region from 2.7-4.4% down to 1.7% in 50 years, which is an annual decline of 0.5% (Brady et al., 2019). This region is also characterised by its high input of mineral fertilisers and the most common crop sequence is winter rapeseed, grain, sugar beet and lastly grain again, since it gives the highest yield on these lands (Land et al., 2021).

It is seen that areas that have been converted to arable land have lost 25-75% of its C storage over time globally (Land et al., 2021). Only 21% of the arable land in the region is cultivated through land management that restore or favour C storage in the soil, those areas are mainly grassland and a smaller portion of legumes. This makes the region with the lowest fraction of arable land that benefits C storage in the country, where the northern part has up to 75% (Land et al., 2021).

Climate zone, historical managements and soil type are other factors that influence the C storage capacity which makes some of the agricultural land already saturated with C or more leached than others (Land et al., 2021). According to the Köppen-Geiger classification, Lund municipality is located in the climate zone Temperate- humid (Kottek et al., 2006) and the soil type is dominated by till clay (SGU, 2021). Soil C sequestration is more rapid in colder climates compared to warmer due to lower decomposition rate, further the sequestration rate is higher in clay soils compared to sandy soils (Freibauer et al., 2004).

This region is dominated by conventional farming, which is based on yearly tilling, which is one of the managements which creates the least opportunity to store C in the soil (Land et al., 2021). Other managements that have the same effect are low fraction of legume, few areas with grassland farming and low addition of organic matter in the form of livestock manure (Land et al., 2021).

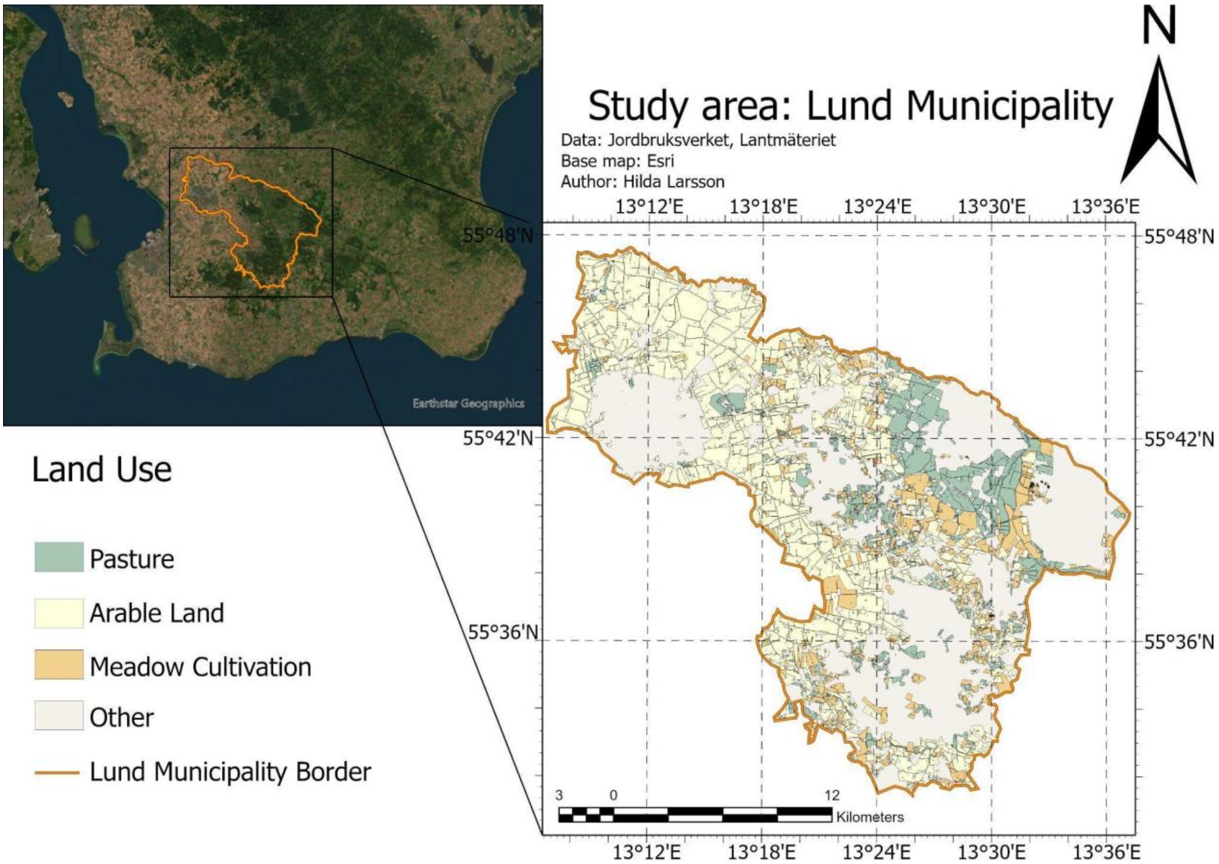

Figure 1. The study area in this study. Lund Municipality in the south of Sweden with the relevant land uses relevant for this study.

3.3 Data

3.3.1 Spatial Data

3.3.1.1 Agricultural Block data, "Jordbruksblock"

The block data from Jordbruksverket, the Swedish Agricultural Agency, is updated every year and the data is collected through the land owners and shows the agricultural land use throughout Sweden (Table 1). This is one of the more accurate data of land use in Sweden that can be found (Jordbruksverket, 2024e). This data was chosen due to the relative high accuracy of classification and the spatial accuracy when comparing to aerial photographs of the area.

3.3.1.2 Vegetation Codes, "Grödkoder"

The Vegetation codes were supplied from The Swedish Agricultural Agency. These give together with spatial data information about the geographical distribution of different crops across Sweden (Table 1). Landowners register the crop and the location of it to the Swedish Agricultural Agency who compile this. The attribute table shows the vegetation code that will be used together with an open excel table with all the classification. The vegetation codes are usable for land owners when applying for financial support and agricultural subsidies (Jordbruksverket, 2024c). The ones that were most commonly distributed in Lund municipality were seasonal crops and meadow cultivation.

Table 1. Data used in this study, with information of source and content.

Data type	Description	Data Type	Resolution	Data Source:
Land use, "Blockdata"	Land uses supplied by *The Swedish Agricultural Agency* with a coverage across the whole of Sweden.	Vector	-	Jordbruksverket, 2024e.
Vegetation codes, "Grödkoder"	Each vegetation is classified with a number ranging between 1-88, the classifications are available in an excel table.	Vector	-	Jordbruksverket, 2024c.
Översiktskartan, 2021	The spatial extent of Lund Municipality is collected from Lantmäteriet, *The Swedish Land Agency*. There is both a line layer of the borders and a polygon layer for the total area.	Vector	-	Lantmäteriet, 2021.
Base map	This is a base map that is collected from ArcGis pro. It is based on satellite images that are updated every 3-5 years.	Raster	0.3 m	Esri, 2024.
Orthophoto	Orthophotos from 2009-2018.	Raster	0.25 m	Lantmäteriet, 2018.

3.3.2 Arable Land

Arable land is defined as land for crop cultivation, which normally is used for this purpose every year but possible with some exceptions, such as fallow (Jordbruksverket, 2024d). Further the land should be able to be usable only with regular agricultural methods and tools/machines. The Swedish Agricultural Agency has three subclasses; arable land in crop rotation, arable land with perennial crops, arable land with permanent grassland (Jordbruksverket, 2024d). This study will divide arable land into two different management techniques (Medium-intensive and Meadow cultivation) according to the C storage capacity template from Swedish Carbon Capture (Svensk Kolinlagring, n.d.b).

3.3.2.1 Medium-Intensive

The class medium-intensive in Appendix 5 from the Swedish Carbon Capture initiative is considered to be representative of the conventional agriculture in Lund municipality, since the most extensive land management in the agricultural field in Sweden is tilling (Land et al., 2021).

Land et al. (2021) classify the medium-intensive as land disturbed by any type of tilling, no matter depth or tools used for disturbance. It includes both medium disturbance (tilling above 40 cm) and high disturbance (below 40 cm).

3.3.2.2 Meadow Cultivation

Bolinder et al. (2017) defines meadow cultivation as cropping of meadow hay, grassland or seed hay at least for 5 years. It should be harvested every year through either grazing by animals or forage crop. This management increases the C capacity largely due to the perennial crop management. The root system is allowed to grow and therefore increase the net primary production below ground. The increased root system also reduces the C loss through erosion (Bolinder et al., 2017). The five vegetation codes (Table 7, Appendix) for the different types of meadow cultivations from The Swedish Agricultural Agency (Jordbruksverket, 2024f) were selected in the attribute table of Vegetation codes, which resulted in an area of 10% (figure 2) of the total land in Lund municipality is meadow cultivation. Meadow cultivation has higher C storage capacity compared to conventional agriculture (Bolinder et al., 2017) and is already implemented at large areas in the region, therefore this will be included in the base scenario.

3.3.2.3 Protected Zones

This management type is located along waterways as seen in the Vegetation code layer. It is cultivated in the same way as meadow cultivation, for example: no fertilisers and herbicides and a minimum duration of 5 years (Bolinder et al., 2017). Since they are located alongside waterways to reduce the nutrient leakage from arable land it is likely that this type of land contains nutrients to result in roughly the same NPP as meadow cultivation. However, there is a lack of literature on this type of management, but since its crop is similar to meadow cultivation the expectation is that these will act in similar ways regarding C sequestration (Bolinder et al., 2017). The protected zones are classified with “77” in the vegetation codes (jordbruksverket, 2024c). Henceforth when Meadow cultivation is mentioned, protected zones are included

3.3.2.4 Fallow Land

Through the vegetation code 60, 4% were also detected as fallow land. This will however be classified as medium-intensive in the base scenario, since the data used in this report covers one year and there is no data of the age of a certain management. Further, different types of fallow are included but without specification, gathered under the same vegetation code (Jordbruksverket, 2024c). A covered or uncovered fallow have different C fluxes, where an uncovered fallow (one year) can emit up to 0.1 t C/ha/yr and “seeded” fallow has a negative C flux (Bolinder et al., 2017), i.e. a flux of C from the atmosphere to the soil.

3.3.3 Pasture

The land use class “pasture” is defined as following according to The Swedish Agricultural Agency: land that is used for grazing, mowing or trimming. Arable land and forest are never classified as pasture, but there is a special class for silvopasture i.e. pasture in forests. It is possible for arable land to be used for grazing during the year. The vegetation that grows on pasture should be used to feed the livestock and consist of grass, herbs and heather (Jordbruksverket, 2024a). 10% of Lund Municipalities area is classified as pasture (figure 2). As mentioned above agriculture has high C storage potential in Lund (Hall et al., 2022), which is the reason why Pasture is included in this study together with arable land.

3.3.3.1 Planned Pasture

The planned pasture sequestration rate is derived from the summary of Toensmeier (2016) where the sequestration rate of pasture and grazing management is between 0.1 and 0.3 t C/ha/yr. These are from two single studies and as seen they have two results with a rather large difference. As mentioned before Swedish Carbon Capture have only used references that could be applicable in a Swedish condition (Svensk kolinlagring, n.d.b), therefore the choice of these two studies to apply to the base scenario for Pasture is based on the more conservative estimate to eliminate the risk of overestimating the capacity of Lund Municipality to store C in pasture.

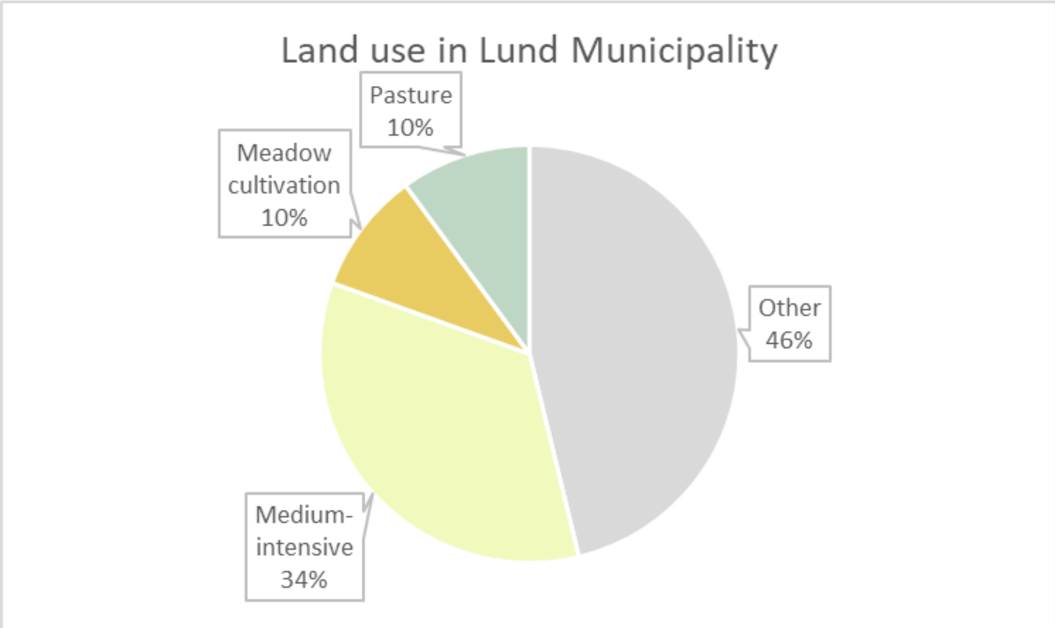

Figure 2. The fraction of different Land uses in Lund Municipality. Including Pasture, Meadow Cultivation and Medium-intensive. Remaining Land uses are classified as "Other". The total area is ca 24 000 ha (Jordbruksverket, 2024c.; Jordbruksverket, 2024e).

3.3.4 Scenarios

3.3.4.1 Single Managements Methods

Managements such as no-tilling, cover crops, and optimised planning of the crop rotation, addition of organic matter and crop residues are some examples of managements that can improve the soil C content (Bolinder et al., 2017). The techniques listed below are a few from Swedish Carbon Capture that are used in different scenarios to estimate the potential improvement of C sequestration in both arable land and pasture.

<u>Including Legumes in the crop rotation</u>

The majority of agricultural land in Sweden is dominated by conventional agriculture without use of crops and management that increases C sequestration, which means that it is also a low fraction of legumes in the crop rotation (Land et al., 2021). This is true also in Lund municipality where approximately 1% of the arable land includes legumes (Jordbruksverket, n.d.g). This is likely due to the high intensity and production rate in the southern part of Sweden within the agricultural sector. The vegetation codes for legumes are 13 and 34 (Jordbruksverket, 2024c). The study from Land et al. (2021) based on the scenario of 6% of the Swedish arable land would include legumes in crop rotation. Additionally, since the fraction of legumes in the crop rotation in Lund is low today and the area is known for its intense cultivation and high yield, this is thought to be implementable. This could however conflict with the high production of the area, but that aspect will be further discussed later on in the report.

Crop residues

Bolinder er al. (2017) states that crop residues on arable land have a positive effect on the C storage capacity since less organic matter is removed compared to if all the crops were to be removed. However, only a portion of the organic matter (carbon-based compounds) will persist on the site in the long run, since the other fraction is respirated to the atmosphere (Bolinder et al., 2017). Further, crop residues are more beneficial in clay soils than in sandy soils. It has also been a decreasing trend through the past 20 years of crop residues due to its use in biogas production instead.

Crop residues also seem to be more common on corn and sugar beet farming. (Bolinder et al., 2017). Lund Municipality has an area of 192 ha of corn and 1 559 ha of sugar beets, which in total results in 11,6% of the arable land (exclusive Meadow cultivation) (Jordbruksverket, n.d.g). Leaving crop residues would thus in theory be an option to increase the C storage on these lands.

Reduced soil cultivation to no-tilling cultivation

There are two ways to replace the typical land management with tilling, either by reduced tilling or no-tilling and direct seeding (Bolinder et al., 2017). The study by Powlson et al. (2014) is a meta-analysis consisting of 43 sites and compared two different tilling systems. The geometric mean of the site data showed a decrease of SOC at the lower depth of tilling (25 cm). Below the topsoil were no significant differences between the practices of conventional tilling and no-tilling. The study from Powlson et al. (2014) showed an increase of 0.3 t C/ha/yr in the upper topsoil. Nevertheless, the modelled value from Land et al. (2021) (0.15 t C/ha/yr) is applied for no-tilling management as a more conservative estimate, since Powlson et al. 2014 had a larger range of C storage capacity values.

Reduced soil cultivation is also suggested to sequester more C than conventional tilling, 0.02 t C/ha/yr according to Land et al. (2021). This could be a step in the right direction of eventual elimination of tilling as a management to increase the C sequestration and reduce the disturbance of the soil. Therefore, both reduced tilling and no-tilling are included in one scenario each, to explore its potential.

Improved grazing

The improved grazing management at pasture includes grazing adapted to season, rotation of grazing and short-term grazing. Contant et al. (2017) reported that improved grazing techniques can help the soil to sequester 0.28 t C/ha/yr, and it is also concluded that the increase of C content is seen in several different regions with varying conditions (Conant et al., 2017). This single method is applied in scenarios as the improved management for pasture.

3.3.4.2 Stacked Methods

These scenarios combine several methods of management, so called stacked methods. These are often more efficient in terms of C storage (Svensk kolinlagring, n.d.b). The scenarios are: conservation agriculture, regenerative agriculture and no-tilling + legumes in crop rotation.

Conservation agriculture

This management aims to use cover crops, crop rotation and reduced tilling to replace the conventional cultivation. The sequestration rate is adjusted to the climate zone, which for Lund means an estimated sequestration rate of 0.38 t C/ha/yr (Project Drawdown, n.d.a). The type of crops that are intended to be used is maize and wheat (Project drawdown, n.d.a), which is seen in 27% extent in Lund municipality (Jordbruksverket, n.d.g), which makes it convenient for potential conversion. The yield is also estimated to increase with 6% after conventional management which would benefit Lund due to its high productivity (Project drawdown, n.d.a).

This management is designed as a transition phase towards a regenerative agriculture (Project Drawdown, n.d.b).

Regenerative agriculture

As the conservation agriculture management, the regenerative agriculture management’s C storage capacity is based on analysis of 40 studies and is dependent on the climate zone which it is applied in. For Lund, the sequestration rate is set to 0.6 t C/ha/yr (Project drawdown, n.d.b). It includes green manure, compost and organic addition is in focus and an extension of the conservative management (Project drawdown, n.d.b).

No-tilling and legumes

The stacked method of No-tilling and legumes included in the vegetation is both mentioned in the single methods one by one. Here they are combined in the same management. The C storage capacity for Legumes in crop rotation is 0.07 t C/ha/yr and in No-tilling 0.15 t C/ha/yr (Land et al., 2021). The C storage capacity of the stacked method is 0.31 t C/ha/yr (Land et al., 2021; Powlson et al., 2014). This stacked method is included to see the difference it can make by combining two single methods into one.

Table 2. Extraction of selected values from Swedish Carbon Capture. The amount of C that can be stored each year is given in t C per hectare. The reference refers to the study that has calculated the C storage capacity for the specific management type.

Land management	Carbon Capacity t C/ha/yr	Reference
Medium-intensive	+0.008	Land et al. (2021)
Meadow Cultivation	+0.6	Bolinder, Freeman och Kätterer (2017)
Planned grazing	+0.1	Toensmeier (2016)
Improved Grazing	+0.28	Conant et al. (2017)
Legumes in crop rotation	+0.07	Land et al. (2021)
Crop Residues	+0.05	Bolinder, Freeman och Kätterer (2017)
Reduced Tilling	+0.02	Land et al. (2021)
No-Tilling	+0.15	Land et al. (2021), Powlson et al. (2014)
Stacked Methods:	Carbon Capacity t C/ha/yr	Reference
Conservation Agriculture	+0.38	Project drawdown (u.å.a)
Regenerative Agriculture	+0.6	Project drawdown (u.å.b)
No-Tilling + Legumes	+0.31	Land et al. (2021)

Area used for conversion

When improving the C storage capacity across a specific area, its functions and services still need to go on. Land owners are dependent on their yield from the land and its outputs. Therefore, a land management conversion of the whole area would result in negative consequences for other aspects, such as yield and diversity. The different scenarios of areas with converted management are set to be 5%, 10%, 20% and 50% of each land use class in this study. As seen with the crop residues and the legumes in crop rotation above, 5-10% would be possible to implement. 50% is set as the "best case scenario", however as mentioned above, this would probably result in lacking efficiency in another aspect. 20% is therefore set as a middle path scenario and as a potential solution for the future if resources allow.

Time spans

The chosen time spans for the different scenarios are set to be 5, 10 and 20 years. According to Paustian et al. (2019) there is a need for a minimum 5-year interval to detect a change of 1% of the soil C stock. Additionally, Lund Municipality's goal towards net zero emissions is 6 years from now on. Therefore, 5 years and 10 years was chosen to be included in the scenarios, since improvements are needed now and it needs to be analysed if they are sufficient in the short term. The 20-year time span is used as a long-term scenario since the EU has set a fixed goal to be climate neutral by 2050, which means to have net zero emissions of greenhouse gases. The aim is legally binding and is synchronised with the Paris agreement (European commission, n.d.). An even longer time scenario would be complementary, on the other hand it is not as reliable when this is a linear scenario and the equilibrium of C saturated soil is absent.

3.4 Calculations

ArcGIS pro version 2.7.0 was used to conduct the spatial calculations and visualisations in this study. The in-data needed to be harmonised by adjusting it to the spatial border of Lund municipality from The Swedish Land Agency. This was done through the tool "Clip" with the municipality polygon as the clip extent (Figure 3). The projection was also seen to be the same (SWEREF99) for each layer. The Blockdata from The Swedish Agricultural Agency was validated by comparing it to the orthophoto from the Swedish Land Agency, to eliminate errors. For example, new infrastructure could be identified. The meadow cultivation and protected zones were selected through their attributes from the Vegetation Codes and exported to a separate layer. These areas were then erased from the Land use data to later be merged, thus having them separated from other land uses in the same layer (Figure 3). The area was then calculated for each class by using the Calculating Geometry tool.

When the areas were calculated and harmonised, Excel version 1808 was used to perform calculations for the different scenarios that would be investigated. The fraction of area that was chosen to be converted to improved management methods were: 5%, 10%, 20% and 50% of the area. The Time scenarios were set at: 5 years, 10 years and 20 years. When calculating the scenarios for Arable Land the different fractions of conversion was applied only on the land management Medium-intensive and not Meadow Cultivation, since meadow cultivation was already seen as an improved management.

The base scenario for pasture was set at Planned Pasture as mentioned above. The conversion was then implemented at different fractions of the whole area (Table 3). This created the amount of C that could be stored in each land use throughout the whole municipality. This was the base for calculating the amount of C that is estimated to be stored across the land use (tonnes (t) of C) and how much that resulted in C storage capacity (t C/ha/yr).

The visualisation of the study area was conducted through ArcGis pro version 2.7.0. The different land use classes that were relevant in this study were classified on the map while the remaining classes were set as "other".

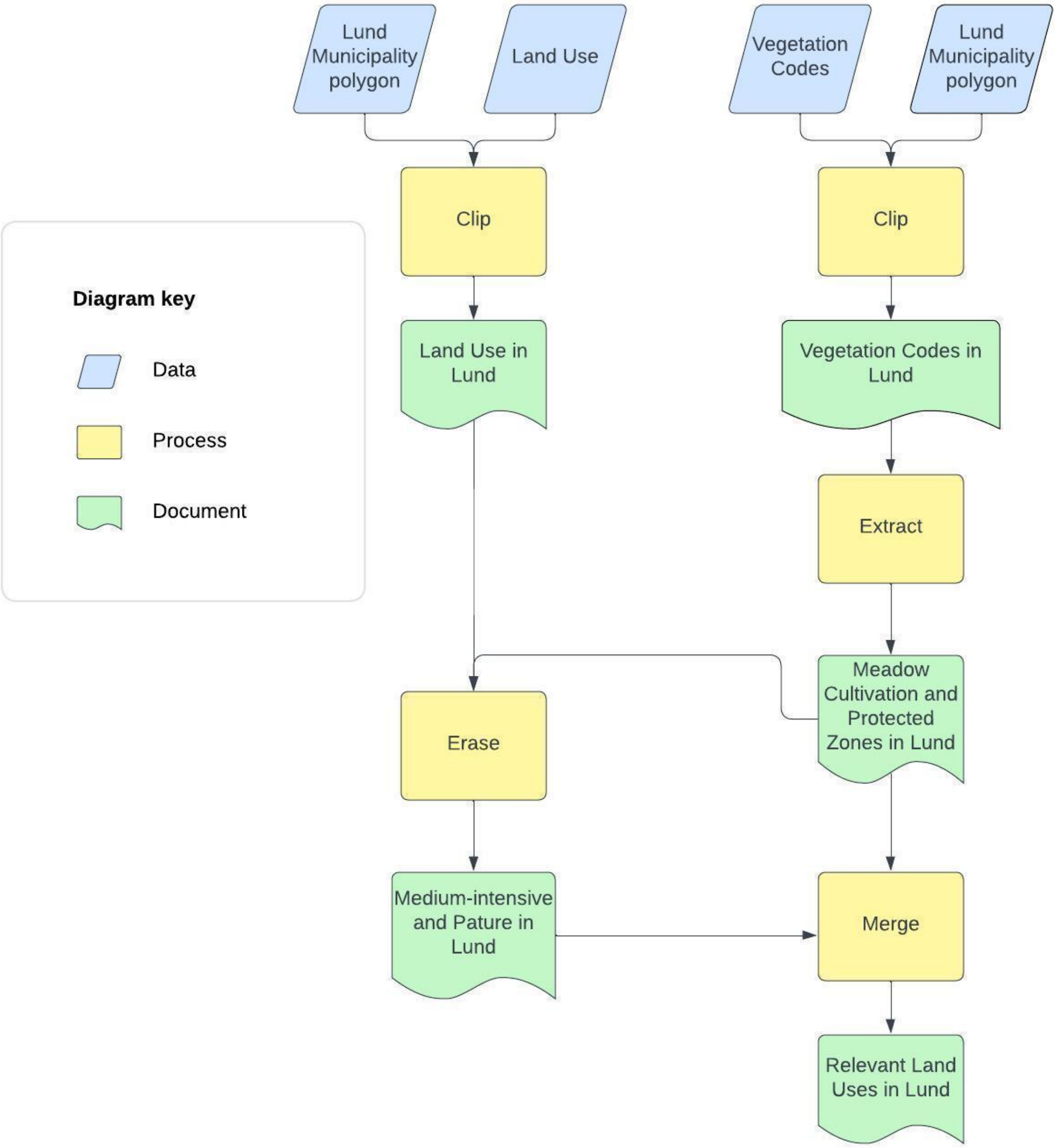

Figure 3. A flow chart over the methodology for the spatial data in ArcGIS pro.

4 Result

Table 3 presents the area for which different management methods are applied, in arable land and in pasture. The total area of arable land (19 235 ha) was approximately four times larger than the total area of pasture (4 425 ha) in Lund Municipality. The land converted from arable land in the different scenarios was calculated from the Arable land excluding Meadow cultivation, which results in an area of 15 090 ha.

Table 3. Number of hectares that represent the different fractions of conversion when optimising C sequestration. The fraction is based on the total area of each land use in Lund Municipality.

Fraction of Converted Land Use	Hectare of Arable Land	Hectare of Pasture
5%	754 ha	221 ha
10%	1 509 ha	443 ha
20%	3 018 ha	885 ha
50%	7 545 ha	2 213 ha

4.1 Pasture

When comparing the Base scenario and the "best case"- scenario with a conversion of 50% of the area, 400 t C/yr extra would be stored. The conversion of 5% of pasture (221 ha) would result in an increase of 39 t C/yr. The conversion of 10% represents an addition of 79 t C/yr over an area of 443 ha, and 179 t C/yr over an area of 885 ha. For the base scenario 0.1 t C/ha/yr will be stored in Lund according to the estimations, as seen in the table extracted from Swedish Carbon Capture. If 50% of the land would be converted to improved grazing this would result in a capacity of 0.19 t C/ha/yr for pasture.

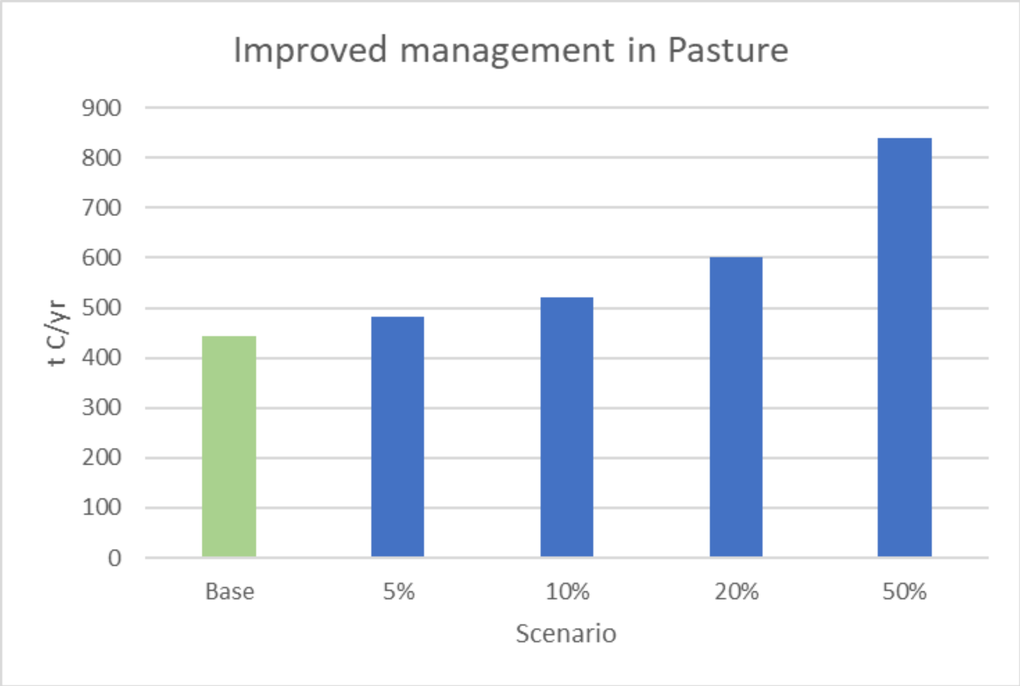

Figure 4. Results of different scenarios when converting land management from Planned grazing to Improved grazing over Pasture in Lund. The percentage is the fraction of pasture in Lund that is converted.

As seen in Table 4 the improved grazing would not lead to a large increase of stored C over a short period of time. A 20-year period would result in an extra stored 1 580 t C in pasture. This is the difference if 10% of the land classified as Pasture would be converted. If 5% of the land would be converted to improved grazing an extra amount of 780 t C is estimated to be stored over the same period, 20 years.

Table 4. The amount of C that is estimated to be stored across Lund in the land use class Pasture when implementing an improved land management over 5% and 10% of the current area of pasture. The two columns of result are the C stored every year and next the C storage capacity after improved land management.

Pasture	t C/yr	t C/ha/yr	t C stored in 5 years	t C stored in 10 years	t C stored in 20 years
Base scenario	443	0.1	2 215	4 430	8 860
Improved grazing 5%	482	0.11	2 410	4 820	9 640
Improved grazing 10%	522	0.12	2 610	5 220	10 440

4.2 Arable Land, Singel management methods

As seen in Figure 5, the most efficient single management is No-Tilling. The difference is almost 1 000 t C each year compared to the base scenario of converting 50% of the land management to No-Tilling. Legumes in the crop rotation increase C storage with ca 500 t C each year for the same scenario. The capacity when converting 50% into Reduced tilling would also result in capacity of 0.14 t C/ha/yr. Conversion of 5% of the areal would create an addition of 10 t C (Reduced Tilling), 32 t C (Crop Residues), 47 t C (Legumes in Crop Rotation) and 108 t C (No-Tilling) each year.

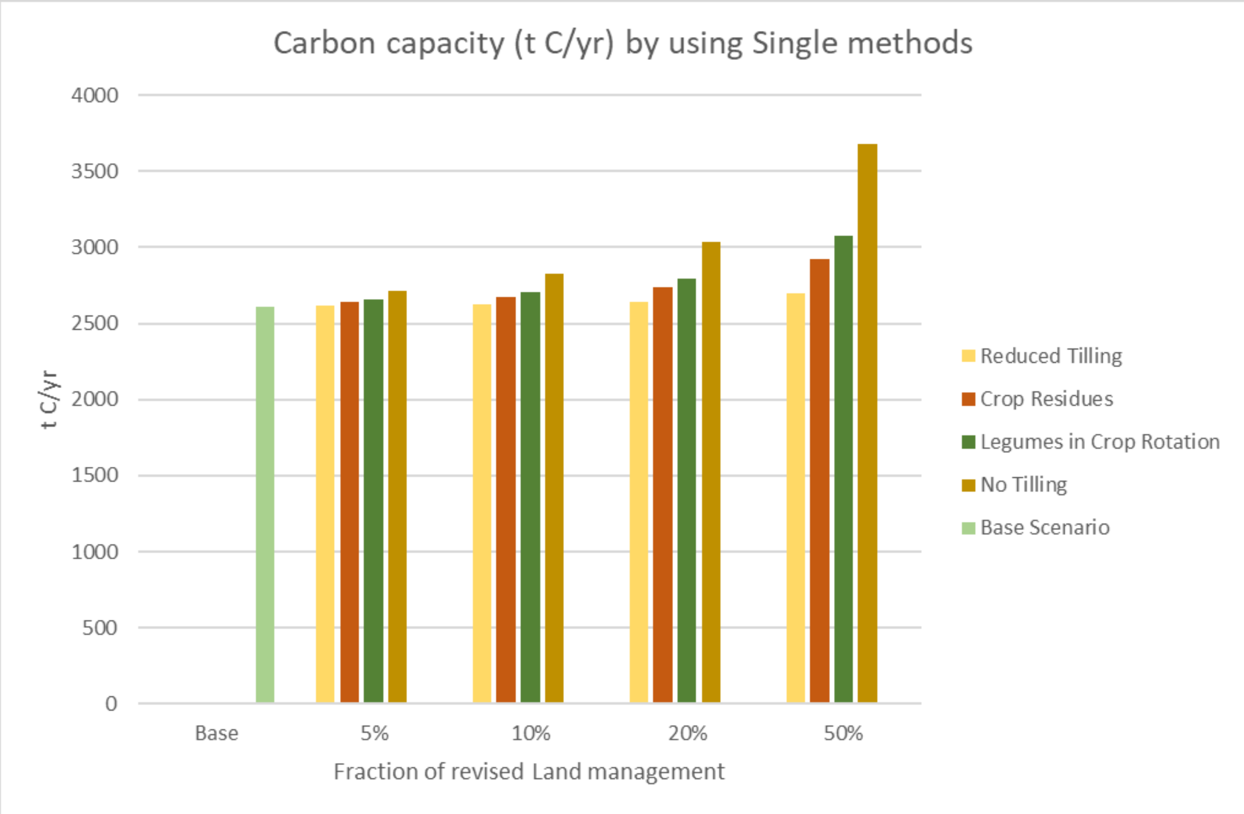

Figure 5. The amount of C (tonnes) that can be stored each year in the arable land in Lund. The Base scenario illustrates the amount that is calculated to be stored today in Lund each year if it is continued at the same rate.

As calculated from the base scenario Lund Municipality is estimated to store 0.136 t C/ha/yr today in arable land which results in 2 608 t C/yr. The management with least predicted C storage capacity is Reduced Tilling with ca 52 400 t C in total over 20 years when converting 1 924 ha (10%) of the arable land. All management gives an increase of C sequestration compared to the Base scenario. The span of single methods over a 20-year period results in a storage between 52 000 and 56 000 t C. The difference between the largest increase for a year is 207 t C/yr, No-tilling 10% compared to Reduced tilling 5%. Table 5 shows that an increase of 0.003 t C/ha/yr results in an extra amount of 320 t C after 5 years.

The amount of C stored when implementing certain managements results in higher C storage even though a smaller area is converted in other managements. For example, a conversion of 5% (754 ha) with crop residues store more C each year than a conversion of 10% (1 509 ha) with Reduced tilling.

Table 5. The amount of C that is estimated to be stored across Lund in the land use Arable Land when implementing an improved single land management over 5% and 10% of the current area of Arable Land. The two columns of result are the t C stored every year and next the C storage capacity after improved land management.

Arable Land, **Single Methods**	t C/yr	t C/ha/yr	t C stored in 5 years	t C stored in 10 years	t C stored in 20 years
Base Scenario	2 608	0.136	13 040	26 080	52 160
Reduced tilling 5%	2 618	0.136	13 090	26 180	52 360
Reduced tilling 10%	2 627	0.137	13 135	26 270	52 540
Crop Residues 5%	2 640	0.137	13 200	26 400	52 800
Crop Residues 10%	2 672	0.139	13 360	26 720	53 440
Legumes in Crop Rotation 5%	2 655	0.138	13 275	26 550	53 100
Legumes in Crop Rotation 10%	2 702	0.14	13 510	27 020	54 040
No-Tilling 5%	2 716	0.14	13 580	27 160	54 320
No-Tilling 10%	2 823	0.147	14 115	28 230	56 460

4.3 Arable Land, Stacked management methods

As seen in figure 6, the regenerative agriculture gets up to the amount of ca 7 000 t C/yr if 50% of the arable land would be converted. Even the No-Tilling and cultivating legumes would result in ca 2 000 t of extra C each year compared to the base scenario.

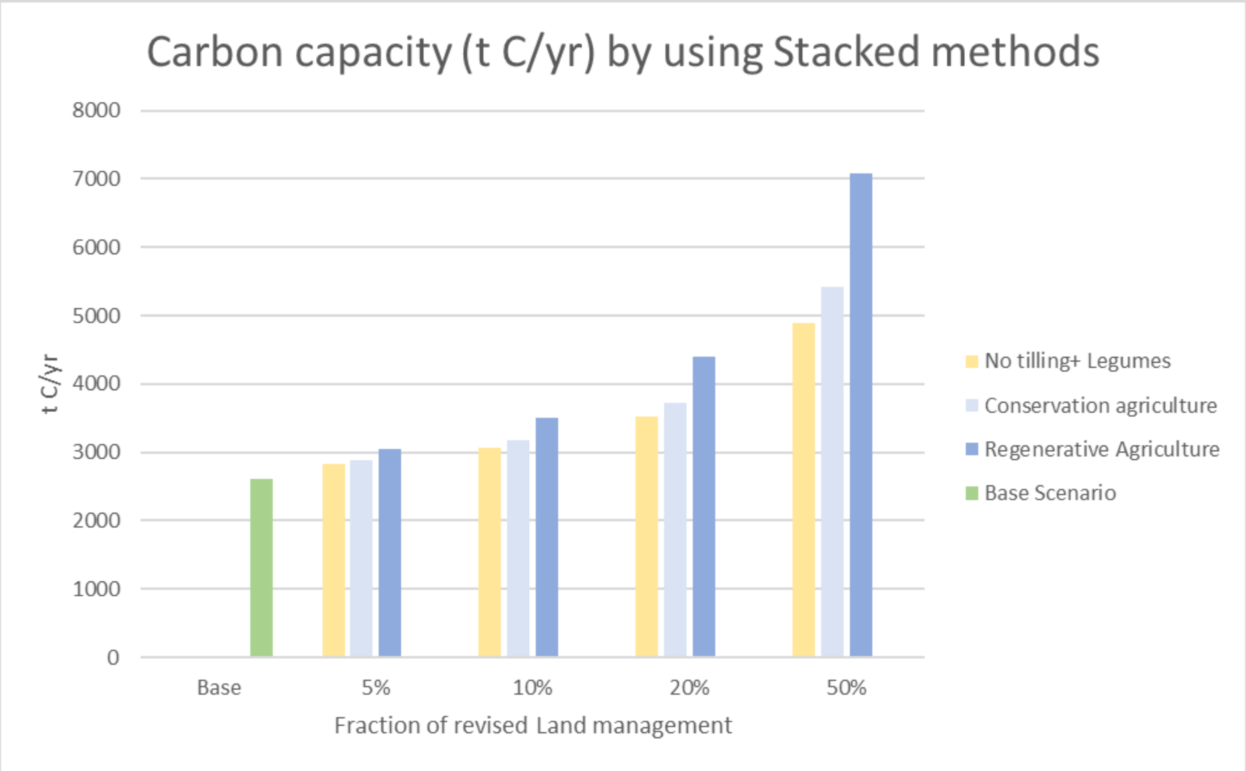

Figure 6. The amount of C in tonnes that can be stored each year in the arable land in Lund by using stacked methods. The Base scenario illustrates the amount that is calculated to be stored today in Lund each year.

Since the results in this study are based on linear relationships, the management with the highest predicted C storage capacity over a time span is regenerative agriculture. It is predicted to store ca 70 000 t C over a 20-year time period if 10% (1 924 ha) of the arable land would be converted, which result in an increase of ca 17 900 t C from the base scenario and a storage capacity of 0.182 t C/ha/yr. This storage capacity is lower than the “best-case-scenario” from Pasture, which had a capacity of 0.19 t C/ha/yr.

The difference between the management with lowest potential (reduced tilling in 5%) and highest potential (No-Tilling in 10%) in the single methods was 4 100 t C over a 20-year period (Table 5). The rather small difference over the period of time shows that the type of improved management does not always tend to be the most important measure, rather that any improved measure is implemented. This is mainly when comparing the different single methods to each other. When comparing the stacked methods over a time it shows that the differences there are even larger (23 000 t C, Table 6) and the more measures that are implemented the more C is stored.

Table 6. The amount of C that is estimated to be stored across Lund in the land use Arable Land when implementing stacked methods to improve land management over 5% and 10% of the current area of Arable Land. The two columns of result are the t C stored every year and next the C storage capacity after improved land management.

Arable Land, **Stacked Methods**	t C/yr	t C/ha/yr	t C stored in 5 years	t C stored in 10 years	t C stored in 20 years
Base scenario	2 608	0.135	13 040	26 080	52 160
No-Tilling + Legumes 5%	2 836	0.147	14 180	28 360	56 720
No-Tilling + Legumes 10%	3 064	0.159	15 320	30 640	61 280
Conservation Agriculture 5%	2 889	0.15	14 445	28 890	57 780
Conservation Agriculture 10%	3 170	0.165	15 850	31 700	63 400
Regenerative Agriculture 5%	3 055	0.159	15 275	30 550	61 100
Regenerative Agriculture 10%	3 502	0.182	17 510	35 020	70 040

5 Discussion

5.1 Further developments and errors

This study bases the C sequestration estimates on a compilation made by Swedish Carbon Capture, which has both disadvantages and advantages. Swedish Carbon Capture only includes scientific studies which are relevant for the Swedish climate which makes them reliable for this area. However, even though the values are adapted for similar climates they are generalised and applied over large regions, similar to the Swedish Carbon Capture's project, that implement the same values for the whole country. A reason could be that Swedish Carbon Capture wants to give all farmers equal prerequisites for the project, no matter where in Sweden they are located. Therefore, more details are needed to carry out a study to increase the accuracy of the C sequestration rate over Lund Municipality and utilise several geographic specific factors that influence the capacity of which the soil can store C. Such as soil type, fraction of organic matter and latitude (Land et al., 2021). But as mentioned, this is not suitable for the extent and time frame of this study.

One issue for this study's decision of using Swedish Carbon Capture as a reference point is the fact that all of their reference values are positive, i.e. a sequestration of C from the atmosphere to the soil, even though Land et al. (2021) showed that non-seeded fallow land and cereal cropping have a negative effect on the sequestration on arable land. This could be the reason that Swedish Carbon Capture are focusing on management techniques that favours C storage in agricultural land. It could be relevant for future studies to include the management with negative impact as well to get a more representative picture of the reality. This might deepen the understanding of the current C fluxes.

Swedish Carbon Capture has investors, which could potentially be a bias and be reflected on the choice of reference and which values that is extracted from them. However, the majority of their references are scientific open-source papers that would possibly be included even though this study did not use Swedish Carbon Capture as a reference point of data values. Additionally, Swedish Carbon Capture aims for the future to be a non-profit organisation (Svensk kolinlagring, n.d.a) which could potentially reduce this eventual bias.

Most references used for C storage capacity values are peer-reviewed scientific articles, based on both literature analyses and field studies. C storage capacity values derived from the literature proved to be more accurate the more studies that were included in the estimates. The same was true also for field studies, such as Powlson et al. (2014) and Land et al. (2021), who saw the number of samples as a parameter that increases the accuracy.

Land et al. (2021) is the reference for several of the management techniques and based its result on literature studies. When conducting the values in Land et al. (2021) several aspects were considered and were given "points" and higher weight on studies which were conducted with more preferable parameters. Some of the parameters were: sample depth, number of sample occasions, spatial relevance and the length of the study. This increases the reliability of this data. Similar to Project Drawdown that based the sequestration rate on the climate zone, which made the values region specific but not to a more detailed level to the specific site.

One large difference between the studies used from the C capacity table from Swedish Carbon Capture is the measurement depth in the different studies. Land et al. gave sources with a sample depth deeper than 25 cm higher weight, further the majority of C stock changes appear in the first 20 cm of the soil according to Conant et al. (2017). Additionally, Powlson et al. (2014) results are based on field work from 43 different sites and compare the storage capacity between No-Tilling and tilling during 5-15 years depending on site. This study states that there is no significant C stock change deeper than 25 cm between soils that have been disturbed by tilling compared to undisturbed soils. Conant et al. (2017) addresses the C stock change due to grassland management and Powlson et al. (2014) addresses the changes due to extent of soil disturbance. This can explain why they might have different conclusions regarding the depth of major stock changes. It can also be due to the different methods, a literature summary of large amounts of scientific sources contra fieldwork at 43 sites. The accuracy of them varies depending on spatial scale; the literature summary of Conant et al. (2017) increases its accuracy due to the number of sources, which makes it more general and applicable on a large spatial scale. Powlson's study is more accurate on a local scale due to the site-specific data and samples. What can be taken from this is that it is difficult to address which source is the most accurate and the suitable sample depth varies depending on management and will influence the estimated sequestration rate.

As seen in the results, arable land has a potential to store 43 000 t C more than pasture in the base scenario over a 20 years span (Table 4 and 5). When considering this and the different goals, both local and global, that are set within a 25-year perspective, stakeholders will need to make a choice on where to put the resources and the effort. As arable land has a larger extent compared to pasture and has higher C sequestration potential, it might be a natural decision to choose to invest in arable land over short-term rather than the pasture. This does not say that pasture should be excluded from the plan of storing C in the municipality completely but to choose which resource to put effort in at the right time.

As seen in Table 2, meadow cultivation and regenerative agriculture has the same C storage capacity (0.6 t C/ha/yr). This is most probably due to similar land management practices, such as low disturbance of the soil and a majority of perennial crops (Bolinder et al., 2017; Project Drawdown, n.d.b). One would then argue to implement more meadow cultivation in Lund Municipality since the occurrence and distribution is already high (22% of the arable land) and put the resources there rather than developing and distributing a “new” management technique. But as Project Drawdown (n.d.b) writes, regenerative agriculture is aimed to replace conventional agriculture and therefore it would be more suitable for Lund due to the high production that this municipality is known for (Land et al., 2021). Whereas meadow cultivation requires a specific type of management (Bolinder et al., 2017), this would change the total yield from Lund and would be difficult to implement since the farmers are dependent on the yield.

Further it is seen in Figure 5 that reduced tilling has a low potential for improved C storage compared to the base scenario and could be considered to have a higher influence since Bolinder et al. (2017) mentioned the improvement of C capacity when reducing the soil disturbance. The capacity of reduced tilling compared to the base scenario differs with 0.012 t C/ha/yr, which explains the low increase even though the changed management.

The vegetation codes collected from The Swedish Agricultural Agency are trusted to be classified correctly, however there is risk of misinterpretation of both farmers and the agency of the correct classification due to similar classifications or updating changed codes. This is thought to be a minor source of uncertainty of the study, but the existence should be acknowledged.

To develop this study further and develop a more representative picture of the C cycle that the agricultural sector is a part of, an expanded list of factors that is included should be considered, such as emissions from transportation. Additionally, this study uses a linear relationship between time and soil C sequestration, while in reality it is non-linear (Freibauer et al., 2004). At some point an equilibrium will be met and the soil decreases its ability to sequester C. This point is reached between 20-100 years depending on soil type, climate, moisture content and additions of organic matter (Freibauer et al., 2004). Even though an equilibrium is not predicted to be met before 20 years of changed land management, the rate is the highest after the implementation of a new management (Freibauer et al., 2004).

5.2 Comparison to other sources

The review conducted by Freibauer et al. (2004), compiles potential C storage capacity in different managements, both inside of Europe and outside of Europe. The base scenarios that this review uses are modelled by Vleeshouwers and Verhagen (2002), where arable land emit a mean of 0.83 t C/ha/yr and grassland have a flux of -1.81 t C/ha/yr (emission) to 2.31 t C/ha/yr (uptake), with a mean of +0.6 t C/ha/yr. The compiled C storage potentials from Freibauer et al. (2004) is considered to have high uncertainty, with high spatial variability as a reason. Nevertheless, it can still be compared to the data used for this study to some extent due to the European conditions that also were used in Swedish Carbon Capture's (Svensk kolinlagring, n.d.b) as a prerequisite for their references. As seen in Kottek et al. (2006) Southern Sweden is classified the same as large parts of central Europe. The reviewed sequestration rate for reduced tilling is less than 0.4 t C/ha/yr while the modelled rate from Land et al. (2021) is 0.02 t C/ha/yr. The lower estimations from the template in Swedish Carbon Capture Appendix 5 is also seen in the management "Crop residues", where the reviewed rate is 0.7 t C/ha/yr compared to 0.05 t C/ha/yr (Bolinder et al., 2017).

The higher estimation of this study´s base scenario is partly due to the limitation of including the emission from the soils. Further, the modelled baseline includes soil organic content as well. Many parameters are needed to model more representative and reliable data for C sequestration rates. High level of details to reduce the high uncertainty and variability. As mentioned the baseline from Vleeshouwers and Verhagen (2002) is modelled which comes with uncertainties when trying to replicate the reality(Freibauer et al., 2004).

The opposite is seen when comparing the management sequestration rate between Freibauer et al. (2004) and the compiled in Swedish Carbon Capture, a lower estimation of the sequestration rates. The exact reason is difficult to pinpoint but as mentioned above, the relationship and fluxes between soil and atmosphere is complex and affected by several factors, where one example is the amount of organic matter in the soil (Freibauer et al., 2004). The importance is the level of detail and adjustment to the site where the rate is about to be estimated. Data for a larger scale will therefore include higher uncertainties and variability.

5.3 Lund Municipality and their goals

As seen in the result it is not enough for Lund municipality to only invest in C storage in the agricultural sector, to reach the goal of storing 20 040 t C by the year 2030, even though the agricultural sectors represent ca 54% (Figure 2). The most effective management in the results were regenerative agriculture which stored 3 502 t C/yr when converting 10% (table 6) and further a storage of 4 395 t C/yr if converting 20% of the arable land (figure 6). This management is time consuming to implement since the conservative agriculture is developed as a transition from conventional farming (Project drawdown., n.d.b). From the result it is also seen that combinations of improved management are necessary to increase the C storage further and implement management at locations suitable for the specific management. For example, if regenerative agriculture would not be suitable for a specific area in Lund but has the possibility to implement reduced tilling in one area and Legumes in Crop Rotation at another, the combination of these two would result in a higher C sequestration than regenerative agriculture even though equal area is converted. Place-specific assessments are therefore needed to make a judgement of which specific measure is suitable to the area to maximise the possibilities to store C in the soil.

5.4 Economical costs and consequences

Today Sweden has a self-sufficiency of cereal production, and because of the high production a fourth of this is even exported every year. Theoretically, the total production of plant-based food is equal to a self-sufficiency of 250% if excluding meadow cultivation

(Linderholm, 2018). That does not mean that meadow cultivation has a negative effect on the possibility of self-sufficiency. Its resilience and suitable in a climate with many hours of daylight in summers and cold winters, meadow cultivation is the major reason why Sweden achieves self-sufficiency in cereal production (Linderholm, 2018). Therefore, it is preferable to not convert the meadow into another management due to its high C capacity and the benefits for self-sufficiency (Linderholm, 2018). Even though Sweden is self-sufficient (of cereal production) today the event of extreme weathers and climate change can change the production and yield. As seen during the drought in 2018, the total production from cereal was 43% lower compared to the predicting five years (Linderholm, 2018). Measures are therefore needed, to account for unexpected events of lower production. As written in Droste et al., (2020) C stock is crucial for soil health to improve its resilience against climate change and extreme weathers. It can then be assumed that C sequestration is important for the reliability of Swedish self-sufficiency in the future and the Swedish food production itself.

Many of the alternative managements projected by Land et al. (2021) have an increase of socioeconomical benefits due to its increase of C storage which in turn increases productivity. This is estimated for a longer period of time, 20 years, which means that the benefits are for the long term, but to change management could be costly and therefore might not be an economic profit in the short term. Hall et al. (2022) writes about similar conflicts for specifically Lund, where there is a great potential for C storage but also for a high yield and building new infrastructure. A certain crop rotation that increases the C storage is also shown to be cost-beneficial, even though the extra costs that come with the change of management. This is not that easy, the economic market does not affect or influence the farmers to change to more optimised management. To change this policy tools are needed and which one to implement is different from case to case. Three different common policy tools are: administrative, economical and informative. In this case the economical instrument would be suitable due to the heterogeneity of the economical cost on the market (Land et al., 2021). There are also cases where combinations of policy tools are needed (Land et al., 2021). This is a good example why policy makers are needed to make a change and direct the development to a certain direction, as here, to store more C and mitigate the CO_2 concentrations in the atmosphere.

6 Conclusion

Both Stacked and Single management methods showed higher potential for soil C sequestration than the Base scenario as was hypothesised. However, since more variables can be included in future research, the representativity of the Base scenario could be improved. This can be improved in the future by considering more site-specific factors that affect C sequestration such as soil type, past management techniques and latitude. Lund Municipality would be advised to implement both short term and long-term solutions to reduce their net carbon emissions. A short-term plan to reach the goal toward 2030 by implementing single methods, such as no tilling which was calculated to be the most efficient single method regarding C sequestration. A long-term solution would therefore be to apply stacked methods, such as regenerative agriculture, to eventually replace conventional agriculture. It is important to do future investigations on the site to optimise its potential. Further, it is thought to improve productivity in the long run with improved C sequestration but would most probably be costly in the beginning of a conversion of management technique. Meanwhile it is important to continue to deepen the knowledge about C sequestration in order for municipalities and other stakeholders to keep working towards the Paris Agreement.

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8 Appendix

Table 7. Summary of the used vegetation codes in the study. With description, reference and class.

Vegetation Code	Class	Description	Reference
6	Meadow	Forage crop classified as meadow if applying for compensation of ecological cultivation.	Jordbruksverket, 2024f
13	Legumes	Mixed grains (legumes and cereal).	Jordbruksverket, 2024c
34	Legumes	Protein crop mixture of legumes and cereal.	Jordbruksverket, 2024c
49	Meadow	Meadow in arable land, not allowed for environmental compensation.	Jordbruksverket, 2024f
50	Meadow	Meadow in arable land.	Jordbruksverket, 2024f
59	Meadow	Grass seed ley, perennial.	Jordbruksverket, 2024f
60	Fallow	Fallow land, subcodes are not included where more details of the cultivation can be found.	Jordbruksverket, 2024c
62	Meadow	Clover seed ley.	Jordbruksverket, 2024f
77	Protected Zone	Protected zones in connection to water ways. Can be used for land both for environmental compensation and not.	Jordbruksverket, 2024c