Final report

Carbon sequestration potential in top- and subsoil – analyzing soil databases and long-term trials

Project number: # O-18-23-048

Budget: 3 000 000 kr

Project period: 2019-01-01 – 2021-12-31. The project was extended until 2022-12-31.

Main applicant: Thomas Kätterer, Professor, Department of Ecology, Swedish University of Agricultural Sciences (SLU), thomas.katterer@slu.se

Co-applicant(s): Martin A. Bolinder, Department of Ecology, (SLU), martin.bolinder@slu.se; Ievina Sturite, Norwegian Institute of Bioeconomy Research (NIBIO), ievina.sturite@nibio.no; Fredrik Hansson, Rural Economy and Agricultural Society fredrik.hansson@hushallningssallskapet.se

Collaborators: Gunnar Börjesson & Holger Kirchmann (Department of Soil and Environment, SLU); Lorenzo Menichetti & Rong Lang (Department of Ecology, SLU).

Part 1.1: Detailed summary in Swedish.

Mull består till ca 60 procent av kol och är den viktigaste faktorn för markens bördighet och kvalitet. Kolinlagring i jordbruksmark har också en viktig plats i dagens klimatdebatt för att minska utsläpp av växthusgaser. Eftersom de årliga förändringarna i kolförråden är små och inomfältsvariationen är stor tar det lång tid tills de blir verifierbara. Som stöd för att kvantifiera effekten av odlings- och skötselåtgärder på förändringar i markens kolförråd används främst tre olika metoder som kompletterar varandra: långliggande fältförsök (LF), återkommande markinventeringar och kolbalansmodeller.

Syftet i detta projekt var att ta ett helhetsgrepp om den kunskap som kan dras av de svenska bördighetsförsöken och andra LF på kolinlagringspotentialen i både matjord och alv, samt att utveckla den lärdom vi kan dra utifrån svenska markinventeringar. Detta genomfördes genom nya provtagningar och datasammanställningar av detaljerade markprofiler i LF med fokus på effekten av vall samt en analys av tre svenska markdatabaser.

Detaljerade analyser av markprofiler i bördighetsförsöken visade att jämfört med den växtföljd som bara har annuella grödor så var kolförråden i matjorden för växtföljder med vall och stallgödsel 3,3 respektive 8,8 ton kol högre per hektar i Mellansverige respektive Skåne. På samma sätt visades det också att jämfört med kontrollrutorna utan kväve så var kolförråden i matjorden 2,9 och 4,7 ton kol högre per hektar i Mellansverige och Skåne i de försöksrutor som fick den

högsta kvävegivan. Vi uppskattade matjordens nedre gräns till 25 cm för försöken i Mellansverige och till 30 cm för försöken i Skåne.

En om-analys av arkiverade jordprover från de skånska bördighetsförsöken styrker den ökning i kolförråd vi ser ner till 30 cm djup. De stödjer också hypotesen att den minskning vi ser i kolkoncentration över tid för 0-20 cm djup till ungefär hälften sannolikt beror på en inblandning av kolfattigare jord från alven p.g.a. en förändring över tid i plöjningsdjup eller en inblandning av alv med matjord vid skörd av sockerbetor.

Markprofiler i andra svenska LF visade en positiv effekt av kvävegödsling på kolförråden ner till 30 cm djup för stråsäd, samt att en växtföljd med 75% vall ledde till högre kolkoncentrationer ner till 30 cm djup jämfört med en växtföljd av enbart stråsäd. En kombination av rötslam och kvävegödsling påverkade kolförråden ända ner till 40 cm djup. Effekten av kalkning var däremot inte signifikant, och olika förnyelsestrategier för gräsmarker i norska LF hade begränsade effekter på kolförråden.

Vår analys av data från Jordbruksverkets markinventering (2013) och normalskördar antydde att de svenska målvärdena för både fosforgödsling och pH borde justeras uppåt. En slutsats som var samstämmig med data från bördighetsförsöken. En analys av kolkoncentrationer i 576 jordprover (0-20 cm) mellan två inventerings tillfällen över en 10-årsperiod från den återkommande Mark- och grödoinventeringen visade att mjölkgårdar med mycket vall lagrade in ca 0,4 ton kol per hektar och år, medans kolinlagringen var hälften så stor för växtodlingsgårdar. Vår analys av markdatabasen från jordbrukarnas rutinanalyser för Skåne län som innehöll 69 313 analyser av mullhalter mellan 1996 och 2020 tyder på att den kan eventuellt komplettera data från Mark- och grödoinventeringen, åtminstone till viss del. Detta verkar särskilt meningsfullt när man tittar på sammanslagna analysvärden över en period snarare än på årsbasis och på kommunnivå. Däremot måste det utvärderas mer och på ett större underlag för fler län och kommuner.

Resultat har under projektets gång förmedlats till intressenter inom jordbrukssektorn. Den vidareutveckling vi gjort med kolbalansmodellen ICBM har integrerats i den svenska klimatrapporteringen, och är också användbar för rådgivningsverktyget Odlingsperspektiv.

Projektet visar att även om påverkan på kolförråden varierar mellan olika odlings- och skötselåtgärder är det viktigt att ta prover djupare ner i profilen än standarddjupet för provtagning (20 cm) för att analysera den totala effekten på kolförråd. Att försumma djupare jordlager kan i många fall, men inte för alla LF, leda till underskattningar. Vår analys av regionala markdatabaser visar att de är ett bra stöd till en del av de observationer som görs i LF. I synnerhet som visas av den positiva effekten av vall på kolinlagring som också spåras upp i Mark- och grödoinventeringen, samt de gemensamma effekterna i Jordbruksverkets markinventering och bördighetsförsöken gällande pH och fosforgödsling. Det skulle vara fördelaktigt att arbeta mer med jordbrukarnas rutinanalyser för att ytterligare utforska dess potential att komplettera trender i mullhalter som observeras inom den fortgående Mark- och grödoinventeringen.

The project has been funded by:

Stiftelsen Lantbruksforskning

Part 1.2: Main report (max. 10 pages).

Background and aim of the project

Soil organic C (SOC) is the most important indicator for soil quality and because the total quantity of SOC in world's soils is huge, even a small change in SOC stocks can influence CO_2 concentrations in the atmosphere. Consequently, it is important to identify the effect of management practices (MPs) on SOC stocks (Paustian et al. 2016; Stockmann et al. 2013). The main purposes of this project were to study SOC stock changes including subsoil layers for various MPs in long-term field experiments (LTEs) with a focus on the effect of forage crops, and by analyzing records of SOC from three different Swedish soil-monitoring programs (SMPs). We also worked on further developing the SOC model ICBM. The results are particularly useful for Swedish extension services in advising farmers, the Swedish national greenhouse gas (GHG) reporting system, and for better evaluating the Swedish potential contribution to the international *4 per mille initiative*.

Materials and methods

Soil sampling & analyzing data from LTEs

Swedish sites

We sampled the most extreme treatments in seven Swedish LTEs for assessing the effect of MPs on changes in SOC in top- and subsoils. For that purpose, soil cores were taken down to a 60 cm depth and the samples were divided into small depth intervals around the intersection with the plough layer. With the exception of one LTEs, Lanna-36, where soil cores were taken down to a 1 m depth using wider depth intervals. All samples of the detailed soil profiles were analyzed for SOC and N contents by dry combustion and pH. Except for two LTEs (Lanna and Vreta Kloster), we were also taking measurements of dry soil bulk density (BD) with triplicate cylinders (7.2-cm diameter, 10-cm height) for the arable soil layer (5- to 15-cm depth) in each replicate for the selected treatments. Gravel (2-20 mm) and smaller stones (>20 mm) were determined in each cylinder allowing us to calculate the volume fraction of gravel and stones assuming a rock density of 2.6 g cm^{-3}.

The following LTEs were sampled. **#1. Vreta Kloster.** This site is part of the series R3-9001 with soil fertility trials in central Sweden initiated 1966. The soil fertility trials are comparing a crop rotation (I) that reflects a dairy production system containing leys receiving a manure application (once per rotation) where all aboveground crop residues are removed from the plots, with a crop a cash-crop rotation (II) without manure applications and containing only annual crops where all aboveground crop residues are left in the plots. Both rotations receive mineral fertilizers as a combination of four PK rates and four levels of N including a control with no PK and no N, respectively. With complementary financing (Royal Swedish Academy of Agriculture and Forestry, KSLA, Grant no. VX2019-0008), we also measured phospholipid fatty acid (PLFAs) on selected soil samples to study treatment effects on soil microbial communities. **#2 and 3. Säby and Röbäcksdalen**. These sites are part of the series R3-0020 with humus balance trials initiated 1970 in central and 1980 in northern Sweden, respectively. They are comparing the effect of straw removal vs. straw retention (main plots), each subject to four N treatments (0, 20, 80 and 120 kg) for a continuous spring cereal rotation. We sampled the 0 and 120 kg N treatments for the plots with straw retention. **#4 and 5. Säby and Röbäcksdalen**. These sites are part of the series R3-

0021 with humus balance trials and run in parallel with the R3-0020 series. They are comparing four N treatments (0, 50, 100 and 150 kg) in a continuous grass-clover ley rotation that is re-established in spring cereals every fourth year, where the ley biomass is removed from the plots twice each year and the cereal straw removed in the year the ley is re-established. We sampled the 0 and 150 kg N treatments. # **6. Igelösa**. This is one of two LTEs initiated in 1981 with sewage sludge (SS) applications in southern Sweden. The trial is comparing treatments receiving 0, 4 or 12 Mg DM ha^{-1} of SS every fourth year (A, B, C treatments), and each treatments receives no, half or full dose of N (0, 1, 2 treatments). There are four blocks but because of unfavorable conditions at the time of sampling, we only took samples in two blocs. We sampled the A0, A2, C0 and C2 treatments. # **7. Lanna-36**. A LTEs initiated 1936 that is part of the series R3-1001 studying the interactive long-term effects of liming and P application in south-west Sweden. We sampled four treatments, plots receiving no lime and plots limed twice (1936 and 1970 with 6 Mg CaO ha^{-1} at each occasion), both plots are receiving either no P or yearly P applications. More details on these LTEs are found in Carlgren & Mattsson (2001), Mattsson (2002), Börjesson & Kätterer (2018) and Börjesson & Kirchmann (2022).

We were analyzing data from **Vreta Kloster** in combination with unpublished data (from previous projects including SLF) from two other LTEs (Högåsa & Bjertorp) of the same series in central Sweden (Rong et al. 2023a), as well as unpublished data of the same series of LTEs (Orup, Ekebo & Fjärdingslöv) and another site (Örja, Kirchmann et al. 2013) in southern Sweden (Rong et al. 2023b). In the latter, we included also the results from archived soil samples (see below). The data for these other sites were obtained between 2010 and 2019 with the same sampling strategy and included PLFAs analyses. The central and southern sites are meta-replicated (i.e., have identical treatments) in a nested design, the southern sites have 4-year rotations and include sugar beet, while those in central Sweden are 6-year rotations (1 year more leys and no sugar beet). The southern sites were corrected for carbonates and reported as Organic C whereas total C are reported as total C (i.e., in Fig. 1. to 3). We estimated BD of fine soil and calculated SOC stocks using the equivalent soil mass (ESM) method. Site-specific linear regression of BD with SOC content in 0-20 cm soil were compared with the predictions from the pedotransfer function of topsoil (model 8, Kätterer et al. 2006), which resulted in estimating BD of topsoil using site-specific regressions at four sites (except Örja). For the rest of sites, BD of fine soil was estimated using the pedotransfer functions of topsoil and subsoil with soil texture data collected from previously described profiles (Carlgren & Mattson, 2001). Gravel contents in the subsoil and topsoil with no sampling were assigned with values from the previously described profiles. We used the highest N treatment for rotation I as reference soil in the ESM calculations to avoid adjusting soil depth beyond the sampled depth, and further corrected the volume fraction of gravel in estimating SOC stocks.

The statistical analysis on SOC contents and stocks was made with mixed effect models, and we did a regression of total PLFAs with SOC content using the glm procedure in SAS. The nested structure of the experimental design was accounted for by setting up multiple levels of random effects, and the auto-correlation between soil depths at one sampling point was accounted for by selecting the covariance structure. Treatments including rotation, PK, N fertilization level (NL), sampling depths, and their interactions were set as fixed effects in the full model. Those three-way and four-way interactions not significant in the F test were dropped in the reduced model, and the least-square means of interested treatments at the same depth were compared by slicing the interactions of treatments with sampling depths.

Norwegian sites

In our collaboration with Norwegian colleagues, we sampled and analyzed data from three Norwegian long-term grassland experiments (Saerheim, Fureneset and Svanhovd), which were initiated between 1969 and 1975. Two grassland renewal strategies, i.e., re-seeding after ploughing every third or sixth year, were compared with permanent grassland. Soil C concentrations and BD were measured in 2019 to a depth of 60 cm and SOC stocks were calculated based on equivalent mass principles.

Archived soil samples

We re-analyzed archived samples (1962) from the topsoil (0-20 cm) and upper subsoil (20-40 cm) for selected treatments in four soil fertility trials in southern Sweden (Orup, Ekebo, Fjärdingslöv & Örja). This provided complementary information to the assessment of the effect of MPs on subsoil SOC, and it allowed us to test the hypothesis that a change in ploughing depth over time affect topsoil SOC concentrations. For that purpose, we made a literature review on average changes in the depth of ploughing for different periods in agricultural soils, and we retrieved SOC data from sheets in the soil analysis archive from older soil profiles (1959) by Agerberg (1961). This work also received complementary financing from KSLA (see above).

Analyzing & harmonizing data from SMPs

We used data from three Swedish SMPs:

#1. SJV-SMP. We analyzed data from the Swedish Board of Agriculture SMP for topsoil (0-20 cm) in combination with data from the soil fertility LTEs in central and southern Sweden (Carlgren & Mattsson, 2001. The SJV-SMP performed in 2013 is the most comprehensive SMP with 12 554 samples distributed over 90 yield survey districts in central and southern Sweden (Djodjic, 2015), enabling site identification for specific agricultural MPs. The objective of this analysis was to identify agricultural MPs that sustain yield increases, make the best use of nutrients while limiting negative environmental impacts, and in particular, verify if the conclusions obtained from the SJV-SMP and yield survey districts are similar to those from the LTEs.

#2. SEPA-SMP. We used 576 sampling points from the second (Eriksson et al. 2010) and third (Eriksson, 2021) Swedish Environmental Protection Agency SMP inventories with the same coordinates to analyze changes in topsoil (0-20 cm) SOC concentrations on arable land for dairy farms compared with beef-, pig- and cash-crop farms. The Swedish Farm Register was used for retrieving information on farm type, its total area of arable land, and the amount of this area as forage crops. The objective was to test if the SEPA-SMP could be used for detecting decadal changes in SOC for different farm types and how it relates to geographical regions and soil properties. This was made in collaboration with another SLF project (Grant no. R-18-26-136).

#3. HS-SMP. The Rural Economy and Agricultural Society (Hushållningssällskapet, HS) is managing Swedish farmers' routine soil analyses using a digital tool (https://markkartering.se/) that includes measurements for soil properties in the arable layer since 1996 representing several Counties. Soil organic matter (SOM) was calculated from loss of ignition and clay content, and SOC was calculated by dividing SOM by 1.72. Unlike the SJV- and SEPA-SMP, the HS-SMP does not follow any sampling design and the coordinates of sampling locations were rounded to 1000 m. The data acquired from HS-SMP consisted of two Counties, Skåne and Östergötland. Only mineral soil samples (≤7% SOC) were considered in the analysis. There were 69313 samples from 1997 to 2020 in Skåne and 6444 samples from 2005 to 2020 in Östergötland. Östergötland was excluded from the analysis considering the spatial distribution and the limited number of samples. We extracted soil samples within Skåne from HS-SMP and the last three inventories of the SEPA-SMP. Thereafter, we checked the number of samples each year and compared means of SOC between the HS-SMP and the SEPA-SMP during two inventory periods, aiming to evaluate whether the HS-SMP could complement the SEPA-SMP at the County and commune levels.

Integrating results supporting extension services & policy decisions

We continued our work on improving the ICBM SOC model. This included a new calibration and further work related to the climatic factor of ICBM by extending our work with the Tea Bag Index (TBI) data collected in previous projects. ICBM is used for calculating changes in SOC stocks within the Swedish national GHG reporting system (NIR, 2021), used by the Swedish farmers' advisory service in the tool "Odlingsperspektiv" and within life cycle analyses (LCAs). Upon invitation, we were writing a synthesis chapter in the book *Understanding and fostering soil carbon sequestration*. The objective of the chapter was to integrate our knowledge from research projects on the effect of MPs that improves SOC sequestration in upland soils.

Results & Discussion

Soil sampling & analyzing data from LTEs

Swedish sites

Vreta Kloster and data from the other soil fertility trials of the same series: Rotation I resulted in significantly higher topsoil C content than rotation II with only annual crops at both central and southern sites (Fig. 1). Notably, the boundary for the topsoil is around 25 cm and 30 cm for the central and southern sites, respectively. The difference in the boundary of the topsoil might be due to crop types and management, e.g. growing sugar beet associated with excavation during harvest at southern sites are likely mixing soils below 25 cm with topsoil. No significant differences were observed in subsoil C content between the two rotations.

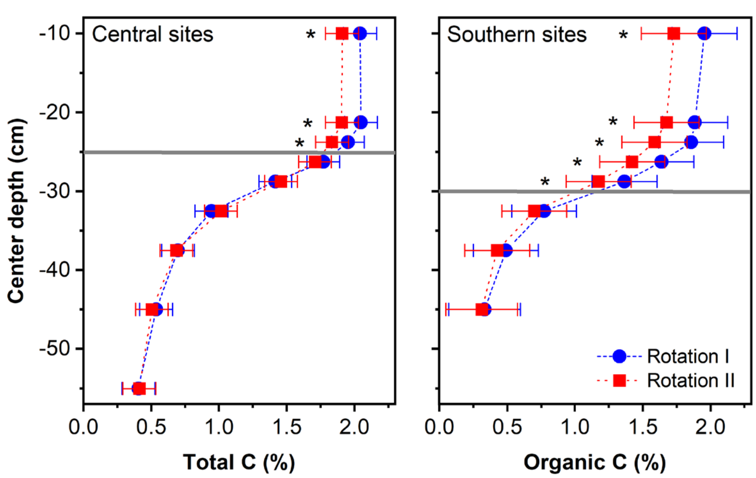

*Fig. 1. Rotation effect on the distribution of soil C content in soil profiles. *Represents significant difference in ls-means comparison between rotation I and II at same sampling depth (p<0.05). Grey line represents the lower boundary of the topsoil.*

Compared to the control without N fertilization (N level 1), topsoil C content was higher in the treatments with the highest N application rate (N level 4), but the differences were statistically significant only at 22.5-25 cm for central sites and at 20-22.5 & 25-27.5 cm for southern sites (Fig. 2). In contrast, the distribution of C in the subsoil showed an inconsistent pattern, i.e. central sites had higher subsoil SOC content in treatment without N fertilizer at some depths compared to treatments with the highest N fertilization rate, while southern sites had an opposite trend in C content and the differences between two N levels were small.

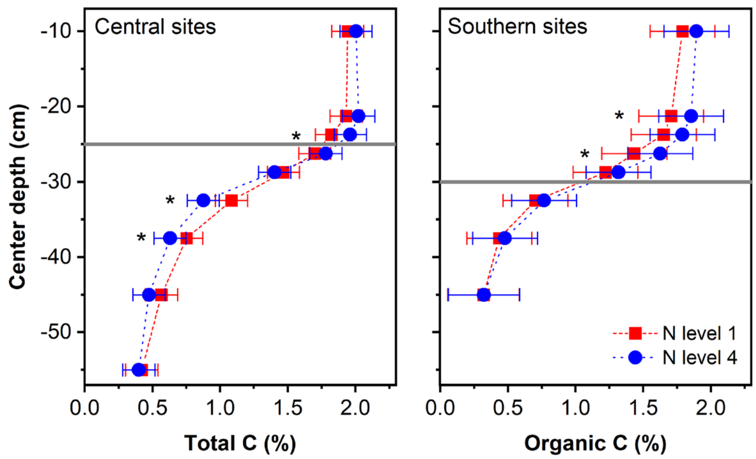

*Fig. 2. Nitrogen fertilization effect on the distribution of soil C content in soil profiles. *Represents significant difference in ls-means comparison between N levels at same sampling depth (p<0.05). Grey line represents the lower boundary of the topsoil.*

Topsoil C stocks showed similar trends for the rotation and N level effect as in the comparison of SOC content, and the differences were larger at southern sites (Table 1). Compared to rotation II with only annuals, rotation I stored 3.3 ± 1.6 and 8.8 ± 1.6 t C ha^{-1} more C in topsoil at central sites and southern sites, respectively. The treatment with the highest N application rate stored 2.9 ± 1.6 and 4.7 ± 1.6 t C ha^{-1} more carbon than in treatment without N fertilizer for central sites and southern sites, respectively. However, the differences in subsoil C stocks between treatments were relatively small compared to differences in the topsoil, indicating a limited impact of crop rotation and fertilization on subsoil C stocks. Furthermore, topsoil stores more carbon than subsoil, e.g. at central sites, carbon stocks in 35 the cm thick subsoil were 56-63% of those in the top 25 cm of the soil.

Table 1. Rotation and nitrogen fertilization effect on cumulative soil carbon stocks (t C ha^{-1}, ls-means ± standard error) in the topsoil and subsoil. Stocks in the subsoil are calculated below 25 cm for central sites and below 30 cm for southern sites. Different letters between rotations or between N levels indicate significant differences in soil C stocks at the same sampling depths (p<0.05).

	Central sites				Southern sites[a]			
Depth (cm)	Rotation I	Rotation II	NL 1	NL 4	Rotation I	Rotation II	NL 1	NL 4
0-20	51.5 ± 2.2	48.7 ± 2.2	49.0 ± 2.2	51.2 ± 2.2	52.5 ± 6.1A	46.4 ± 6.1B	48.0 ± 6.1	50.9 ± 6.1
20-22.5	57.8 ± 2.2	54.7 ± 2.2	55.0 ± 2.2	57.5 ± 2.2	59.0 ± 6.1A	52.1 ± 6.1B	53.9 ± 6.1A	57.2 ± 6.1B
22.5-25	63.8 ± 2.2A	60.5 ± 2.2B	60.7 ± 2.2	63.6 ± 2.2	65.3 ± 6.1A	57.5 ± 6.1B	59.5 ± 6.1A	63.3 ± 6.1B
25-27.5	6.3 ± 2.2	5.9 ± 2.2	6.0 ± 2.2	6.1 ± 2.2	71.2 ± 6.1A	62.8 ± 6.1B	64.9 ± 6.1A	69.2 ± 6.1B
27.5-30	11.5 ± 2.2	11.5 ± 2.2	11.5 ± 2.2	11.5 ± 2.2	76.2 ± 6.1A	67.4 ± 6.1B	69.5 ± 6.1A	74.1 ± 6.1B
30-35	18.6 ± 2.2	19.7 ± 2.2	19.7 ± 2.2	18.7 ± 2.2	6.0 ± 6.1	5.8 ± 6.1	5.8 ± 6.1	6.1 ± 6.1
35-40	23.4 ± 2.2	25.0 ± 2.2	25.0 ± 2.2	23.4 ± 2.2	9.9 ± 6.1	9.4 ± 6.1	9.4 ± 6.1	9.9 ± 6.1
40-50	30.2 ± 2.2	32.3 ± 2.2	32.3 ± 2.2	30.2 ± 2.2	15.8 ± 7.1	14.9 ± 7.1	14.8 ± 7.1	15.9 ± 7.1
50-60	35.6 ± 2.2	38.3 ± 2.2	37.9 ± 2.2	36.0 ± 2.2				

[a]Örja site was excluded due to different sampling depths and treatments.

As a measure of viable microbial biomass, total PLFAs were highly correlated to C content across all sites, regardless of sampling depths and treatments (Fig. 3). Moreover, the regression slopes of total PLFAs with C content were similar across sites except for Bjertorp. Although Bjertorp and Vreta Kloster had similar levels of C content in 0-20 cm soil, a more clayey texture at Vreta Kloster did not result in more viable microbial biomass. Rotation with leys and manure application favored bacteria communities over fungi at central sites, but this was not observed at southern sites (data not shown). Sugar beet residuals are easy to decompose and rich in N compared to straws from cereals and oilseed crops, which may explain different effects of crop rotation and manure application on soil microbial communities.

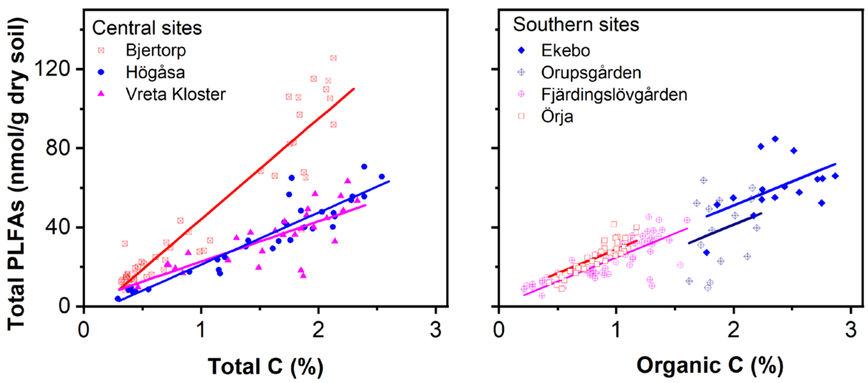

Fig. 3. Regression of total PLFAs with soil C content in Central and Southern sites. Ekebo and Orupsgården had only 0-20 cm samples.

Säby & Röbäcksdalen: At both these sites, belonging to the series of humus balance trials, the N fertilization resulted in higher SOC concentrations in the 0-30 cm depth in the continuous cereal rotation, and this effect was present in the 20-25 and 25-30 cm depth but not beyond 30 cm depth. There was no clear effect of N fertilization in the continuous ley rotations. This is similar to results found for the other two sites (Lanna & Lönnstorp) in the same series of LTEs (Börjesson et al. 2018). For the Säby site, there was also a long-term effect of continuous ley on SOC compared to the continuous cereal rotation down to 30 cm depth, which was slightly more pronounced for the un-fertilized treatment. This is also in agreement with previous observations at Lönnstorp. This effect, below the plough layer, is more difficult to assess at Röbäcksdalen. Compared to the other three sites, the continuous cereal and ley LTEs that run in parallel are not situated adjacent to each other and had different initial SOC contents, partly because this experimental site is poorly drained and is unevenly water saturated during parts of the year (Bolinder et al. 2020). Since we now have detailed soil profiles for all four experiments of the humus balance trials, we will apply the same approach that we used for analysing the soil fertility trials (as described above) because we have exactly the same information, using the sites as replicates greatly improves the statistics.

Igelösa: The treatments receiving SS at this site, and in particular, the treatment with 12 Mg DM ha^{-1} every fourth year and full dose of N showed a significant increase in SOC concentrations down to 40 cm depth. On an equivalent soil mass basis to 40 cm depth, almost half of this increase due to SS application occurred in the 20-40 cm depth. This is similar to what we found in the sister experiment at Petersborg (Börjesson et al. 2018). However, the proportion of SS remaining as SOC to an equivalent soil mass depth of 40 cm at Igelösa was 35% (average of the no N and full N treatments), which is higher than that estimated at Petersborg (18%). The site at Igelösa has a higher clay content (26%) than that at Petersborg (14%), indicating the importance of clay as an important factor contributing to stabilizing the C inputs from SS.

Lanna-36: Compared with non-limed treatments, there was a long-lasting residual effect on crop yields in the liming and re-liming treatments (both for those receiving no P or yearly P applications), i.e., 16% higher yields (Börjesson & Kirchmann, 2022). The SOC contents in soil samples taken before and after the second liming were not significantly different. Samples from our detailed soil profiles showed that liming had a positive effect on pH even in deeper layers, although not statistically significant because of few replicates (i.e., only two blocks). We hypothesized that the higher yields due to liming would be reflected in higher SOC contents in the subsoil. However, SOC concentrations did not differ between treatments, indicating that the positive effect of liming on crop yields and C inputs may have been counterbalanced by a corresponding stimulating effect on decomposition.

<u>Norwegian sites</u>
The three grassland sites are very rich in carbon. SOC stocks ranged between 188 and 239 t ha^{-1} across treatments and sites to 60 cm depth. At two out of three sites, significant treatment effects on SOC stocks were found, but only in the upper 20 cm. Grassland renewal every third year at Saerheim and every sixth year at Fureneset resulted in lower SOC stocks compared with permanent swards. However, SOC stocks to an equivalent depth of 60 cm did not differ significantly between treatments. Thus, the investigated renewal strategies seem to have a minor impact on total SOC stocks. In addition, we compiled experiences from Norway and Sweden regarding the effect of leys in rotation on SOC in a book chapter (Sturite et al. 2023).

<u>Archived soil samples</u>
Our analysis showed that SOC concentrations in the 20-40 cm depth were lower than those in the arable layer (0-20 cm) in 1962 at Orup and Ekebo. This was less pronounced at the other LTEs, in agreement with the relative distributions observed in 1959 by Agerberg (1961). On average, for the 4 LTEs in southern Sweden examined here, the SOC concentrations in the 0-20 cm layer have decreased from 1.15 to 1.01% between 1962 and 2014. The analysis is not yet complete, but indicates that ploughing depth had increased by about 5 cm since 1962. This would imply that the addition of SOC-poor subsoil into the "new topsoil" (0-25 cm) may explain about 50% of the decrease in SOC observed between 1962 and 2014 in the 0-20 cm layer. Such a change of 5 cm is within the range we found in our literature review on average changes in ploughing depth over time for agricultural soils (Rong et al. 2023b).

Analyzing & harmonizing data from SMPs
The analysis of the SJV-SMP and soil fertility LTEs was published in Kirchmann et al. (2020). It was shown that crop yields were significantly affected by soil pH, SOC and plant-available phosphorus (P-AL), and by mean annual temperature. With the exception of potatoes, plant-available potassium and magnesium in soil did not significantly influence crop yields. Soil pH (water) had the highest potential to affect crop yields, even at values >6.5. It was concluded that current Swedish agricultural recommendations require updating and in particular, high-yielding crops would benefit from receiving more plant-available P. Excluding soils with a SOC content >5.81 (considered organic soils), the SOC content in mineral soils of central and southern arable land in Sweden ranged from 1.75 to 3.50% and had an indirect negative effect on crop yields, which was explained by lowering pH values for soils with higher SOC content. A new target value

of pH 7 for all crops (except potatoes) has been recommended. At this level of application and for the purpose of this study, differences in analytical methods for SOC analysis between the SJV-SMP and LTEs database did not influence the conclusions.

The analysis of changes in SOC using the SEPA-SMP was published in Henryson et al. (2022). We found a significantly higher concentrations of SOC at dairy farms (3.0%) compared to arable and pig farms (2.3 and 2.4%, respectively), but they were nog significantly different from beef farms (3.1%). The SOC stocks in the topsoil (0-20 cm) increased by 0.38, 0.14 and 0.21 Mg C ha^{-1} yr^{-1} on dairy, beef and arable farms, respectively. For dairy farms, this corresponds to a relative increase of about 0.5%, thereby meeting the "4 per mille" goal, and it was also shown that accounting for these changes have a substantial positive impact on the climate footprint associated with milk production. The proportion of leys grown on each farm was positively correlated to SOC concentrations. However, there is a need also for improving the analysis of changes in SOC with the SEPA-SMP, e.g., by including data for crop types at the field level (instead of at the farm level) associated with each coordinate of the sampled points and using information from digital elevation models.

For the HS- and SEPA-SMP comparisons in Skåne County, the number of samples differed substantially over the years (Fig. 4). The number of samples in the HS-SMP ranged from 66 in 2002 to 8920 in 2011, whereas there are 548, 310 and 327 samples in the SEPA-SMP from inventory I, II and III, respectively. Yearly means of SOC showed a greater discrepancy between the HS-SMP and the SEPA-SMP during the inventory II period (2001-2007) than during the inventory III period (2011-2017), which could partly be attributed to a relatively small number of samples during the inventory II period. On the other hand, the HS-SMP had a large number of samples in 2008 and 2009 but the means of SOC were low, suggesting that not only the number of samples but also the spatial distribution of samples matter in indicating the general trend of SOC at the County level.

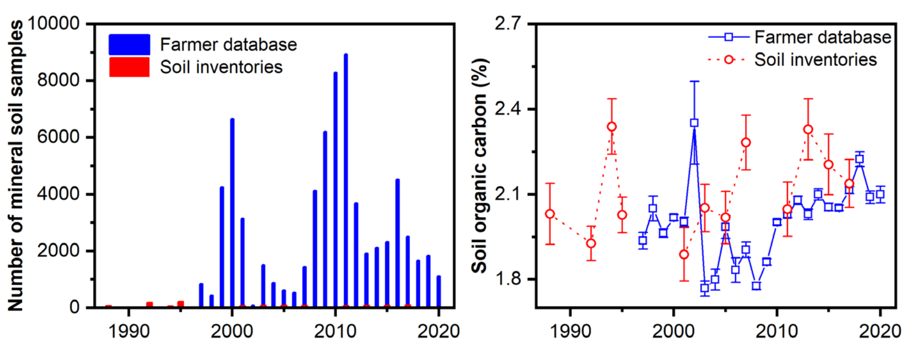

Fig. 4. Number of soil samples from the farmers' database and the national soil inventories within Skåne County (left) and means of soil organic carbon across years (right). Error bars are standard errors.

Both the mean and median values of SOC were smaller in the- pooled samples from the HS-SMP than those from the SEPA-SMP. Moreover, the distribution of SOC in the pooled samples during the inventory II period showed a larger difference between the HS-SMP and the SEPA-SMP, compared to the difference during the inventory III period (Fig. 5). For example, the mean and median of SOC in the HS-SMP were 0.16 and 0.22% lower than the values in the SEPA-SMP for the period 2001-2007, and 0.12 and 0.07% lower during 2011-2017.

At the County level, data from the HS-SMP can complement those from the SEPA-SMP to some extent, but it is more meaningful to look at the distribution of pooled samples over a period rather than on a yearly basis. We checked communes with a high density of samples, for example, Trelleborg showed a relatively stable and increasing trend of SOC over time in both the HS- and SEPA-SMP databases (results not shown). In summary, monitoring SOC at the commune level from the farmers' routine soil analyses requires high sample density and good spatial coverage. The rounded coordinates to 1000 m limited the direct usage for spatial analysis, further analysis based on coarse resolution grids may provide more information on the spatial pattern of changes in SOC.

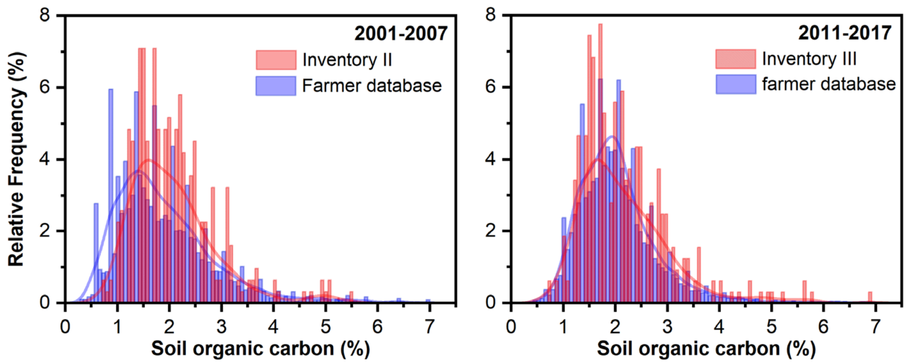

Fig. 5. Histograms of soil organic carbon for mineral soil samples within Skåne County during the periods of inventory II (left) and III (right).

Integrating results supporting extension services & policy decisions

Compared to our previous calibration, a major difference was updating of functions used in the calculation of the climatic parameter, which we validated on data from European bare-fallow LTEs (Menichetti et al. 2023). Work on a larger database where we combined TBI results from Swedish and Austrian LTEs supported the usefulness of the ICBM climatic parameter that integrates the interactions between climatic and edaphic conditions (Gmach et al. 2023). The calibration showed that using two SOC pools such as in ICBM is sufficient to capture the dynamics of SOC in the Swedish LTEs. Since 2022 this new calibration is integrated in the Swedish national GHG reporting system. This improved the comparability between ICBM simulations with data from the SEPA-SMP regarding national SOC stock changes. Since agroforestry is a now a MPs considered to contribute to the *4 per mille initiative*, we developed an ICBM framework ($ICBM_{Agroforestry}$) that can be used for these ecosystems (Menichetti et al. 2020), and the updated functions used for calculating the climatic parameter were compiled into an R package that is available in a GitHub repository (https://github.com/ilmenichetti/reclim). These two latter aspects will be useful for the Swedish farmers' advisory service tool "Odlingsperspektiv". Our book chapter (Kätterer & Bolinder, 2022) highlights that SOC changes are highest when comparing perennial versus annual crops and lowest when comparing the effect of MPs including legumes in crop rotations versus monocultures. Whereas the effect of no-till versus conventional tillage on SOC changes is detectable for an equivalent depth of 30 cm but not when considering the soil profile to a depth of 60 cm. We have contributed to work including changes in subsoil SOC in LCAs (e.g., Moberg et al. 2022), and we have disseminated our key-results throughout the project in several popular scientific publications and oral presentations to all stakeholders in the agricultural sector (see result dissemination).

Conclusions

Detailed soil profiles in Swedish LTEs showed that leys and nitrogen fertilization in crop rotations in many cases significantly increased SOC stocks down to 25 cm depth in Central Sweden and down to 30 cm depth in southern Sweden. The combined effect of sewage sludge and nitrogen fertilization increased SOC even deeper, down to a 40 cm depth. Not all MPs examined in this study affected SOC stocks. The effect of liming was not significant, and different renewal strategies for grasslands in Norwegian LTEs had limited effects on SOC. Analysis of soil databases at the country level showed that they support some of the observation made in the Swedish LTEs. For instance, the positive effect of leys on SOC also showed up in the SEPA-SMP, and the effect of soil pH, SOC and plant-available phosphorus were common in both the SJV-SMP and the Swedish soil fertility trials. A comparison of data on SOC between the SEPA- and HS-SMP showed that these databases may be complementary, although the number of samples were highly variable over the years in the latter. However, this assessment was only made for the Skåne County and the analysis needs to be extended, examining this for a larger number of Counties and in particular also at the commune level appears promising.

Relevance and recommendations

Although variable between MPs, in order to fully assess their effect on SOC sequestration our study suggests that it is important to sample deeper than the standard sampling depth of 20 cm, at least down to 35-40 cm depth. Neglecting deeper soil layers may in many cases, but not for all LTEs, lead to underestimates. Current Swedish agricultural recommendations require updating, in particular high-yielding crops would benefit from receiving more plant-available P, and liming requires more attention when assessing the known benefits of SOC on soil quality and crop yields. It would be beneficial to do more work on the HS-SMP to further explore its potential to reveal trends in SOC at high spatial resolution complementing the information obtained from the SEPA-SMP.

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Part 1.3: Result dissemination.

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	Kätterer T. Intervju om kolkrediter i Land Lantbruk 10 mars 2023
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	Kätterer T. Inbjudet föredrag om markbördighet och kolinlagring, KSLA, Kommitté Morgondagens odlingssystem 1 feb 2023
	Kätterer T. Inbjudet föredrag "Kolinlagring för bördighet och klimatet – Odling i Balans temadag, Elite Stora Hotellet, Linköping, 24 jan 2023.

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	Kätterer T. Inbjudet föredrag ”kolinlagring i jordbruksmark”, seminarium för lantbrukare och rådgivare organiserad av Greppa Näringen och Länsstyrelsen, Suderby Herrgård, Gotland 17 nov 2022.
	Kätterer T. Inbjudet föredrag ”kolinlagring för bördigheten och klimatet”, årligt möte av trädgårdsnäringen, LRF Trädgård, Linköping 16 nov 2022.
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	Kätterer T. Inbjudet föredrag ”Mellangrödors roll för kolinlagring i växtodlingssystemen och hur det kan inkluderas i klimatrapporteringen”. Digital seminarium om mellangrödor organiserad av SLU Fältforsk ämneskommitté Vatten och Hushållningssällkapet. 12 maj 2022
	Kätterer T. Inbjudna reflektioner till EASAC:s rapport om ”Regenerativt jordbruk i Europa”, 7 april 2022, KSLA https://www.ksla.se/aktivitet/regenerativt-jordbruk-i-europa/
	Kätterer T. Inbjudet föredrag ”Kolinlagring i svensk jordbruksmark”, seminarium organiserat av MatLust, 6 april 2022 https://matlust.eu/best-practice-carbon-action-plattform-for-kolinlagring/
	Kätterer T. Inbjudet föredrag ”Biokol, vad är det och kan det vara av intresse för lantbruket?” Östgötaslams Slamdag, organiserad av HS Östergötland, 28 mars 2022.
	Kätterer T. Inbjudet föredrag ”Mellangrödors betydelse för markstruktur och kolinlagring” vid webinarium ”Mellangrödor i praktiken”, KSLA 22 mars 2022 https://www.ksla.se/aktivitet/mellangrodor-i-praktiken
	Kätterer T. Intervju i P3 Dystopia https://sverigesradio.se/avsnitt/nar-jordarna-dor 3 mars 2022
	Kätterer T. Intervju i Land Lantbruk ”Det är inte kolinlagringen som kommer rädda världen” 17 feb 2022
	Kätterer T. Inbjudet föredrag ”Jordbruksmarken som kolsänka”, Hydrotekniska sällskapets vattendag, Ultuna, 2 feb 2022. http://hydrotekniskasallskapet.se/wp-content/uploads/2022/03/Thomas-Katterer_Vattendag_2feb2022.pdf
	Kätterer T. Inbjudet fördrag ”Hur påverkas organiskt kol i åkermark av intensiv jordbearbetning?” Digital seminar organized by Formas and KSLA 1 feb 2022. https://www.ksla.se/aktivitet/sa-kan-vi-oka-kolinlagringen-i-svensk-jordbruksmark/
	Kätterer T. Intervju i tidningen Mat & klimat, ”Läckage av antibiotika också en klimatfråga”, 31 jan 2022 https://matochklimat.nu/lackage-av-antibiotika-ocksa-en-klimatfraga/
	Kätterer T. Inbjudet föredrag “Kol i mark” vid den regionala växtodlings- och växtskyddskonferens, Uddevalla 20 Jan 2022. https://www.slu.se/institutioner/mark-miljo/faltstationer/lanna-forsoksstation/uddevallakonferensen/

Oral communication ***to sector, students, etc.*** **Cont'd**	Kätterer T. Inbjuden till rundabordssamtal ”Kan svensk jordbruksproduktion öka, samtidigt som läckaget av näringsämnen och växthusgaser minskar?”, Östersjökommitté, KSLA 14 jan 2022.
	Kätterer T. Invited talk “The potential to reduce agricultural emissions” at the EU webinar “LULUCF and its potential to support achieving the EU climate goals” organized by Renew Europe Group in the European Parliament 12 Jan 2022. https://www.reneweuropegroup.eu/events/2021-12-13/lulucf; https://app.livecasts.eu/lulucf-and-its-potential-to-support-achieving-the-eu-climate-goals/program
	Kätterer T. Intervju SR Vetenskapsradion ”Oplöjda åkrar ger kraftigt minskade klimatutsläpp i Kanada”, 5 jan 2022. https://sverigesradio.se/artikel/oplojda-akrar-ger-kraftigt-minskade-klimatutslapp-i-kanada
	Kätterer T. Inbjudet föredrag vid rundabordssamtal ”Klimat och jordbruk”, KSLA, 17 december 2021.
	Kätterer T. Inbjudet föredrag ”Odlingsåtgärders påverkan på kolinlagring”, Södra Sveriges växtodlings och växtskyddskonferens, Växjö 8 Dec 2021 https://www.slu.se/ew-kalender/2021/12/sodra-sveriges-vaxtodlings-och-vaxtskyddskonferens/
	Kätterer T. Inbjudet föredrag ”Slamspridning på åkermark – betydelse för mullhalten”, vid ett seminarium organiserad av SYSAV Utvecklings AG, Bjärsjölagård slott, Sjöbo, 3 december 2021
	Kätterer T. Inbjudet föredrag ”Så kan kolinlagring beskrivas med fältförsök” vid seminariet ”Går det att mäta kolinlagring i mark?” organiserad av KSLA och Greppa Näringen, Nässjö 2 dec 2021. https://adm.greppa.nu/arkiv/anmalan-kurser/2021-11-16-gar-det-att-mata-kolinlagring-i-akermarken.html
	Kätterer T. Intervju SVT Nyheter 30 nov 2021: Smältande glaciärer kan bli framtidens klimatvänliga jordbruk | SVT Nyheter
	Kätterer T. Inbjudet föredrag ” Kolinlagring i mark från slam och biokol” vid ett webinar organiserad av Svenska Näringsplattformen som har ett 20-tal medlemmar från VA-sektorn och teknikleverantörer. 29 nov 2021 https://www.ri.se/sv/svenskanaringsplattformen/event
	Kätterer T. Inbjudet föredrag ”kolinlagring i jordbruksmark” vid den årliga sammankomsten av rådgivare, Svenska lantbrukssällskapens förbund (SLF) i Finnlad, Hotell Scandic Waskia, Vasa., 9 Nov 2021.
	Kätterer T. Intervju i GP om markhälsa och nedbrytning, 4 nov 2021
	Kätterer T. Inbjudet föredrag ”mull och bördighet” för trädgårdsrådgivare, LRF Trädgård 1 okt 2021
	Kätterer T. Inbjudet föredrag ”Markkol och kolbalans i svensk åkermark”, KSLA seminarium ”Koll på kolet! En resa i tre dimensioner”, 30 sept 2021, Stockholm. https://www.ksla.se/aktivitet/koll-pa-kolet/
	Kätterer T. Inbjuden digitalt rundabord om kolinlagring i mark, Väderstad AB, 24 sept 2021
	Kätterer T. Inbjudet föredrag ”Kolinlagring, vad kan en lantbrukare göra redan nu för att bidra?”, Rektors möte med politiker i samband med besök av Emma Wiesner vid SLU, 23 sept. 2021
	Kätterer T. Inbjudet föredrag ”Hur påverkar alven kolinlagringen? Greppa Näringen webbinar 15 sept 2021
	Kätterer T. Intervju i P1 om kolinlagring i mark, God morgon världen, 29 aug 2021
	Kätterer T. Inbjudet föredrag, ”Kolinlagring i mark för bättre bördighet och minskad klimatpåverkan”, Swedbank 15 juni 2021 (103 handläggare som arbetar med jord/skog). Video som spelades in i NIBIOs regi: https://www.youtube.com/watch?v=HWDGSNia7jI; Jakten på jordkarbonet video Vimeo
	Kätterer T. Invited talk ”Biochar and its practical application to restore degraded lands – experiences from field experiments in Kenya” at GLF (Global Landscapes Forum) Africa Digital Conference: Restoring Africa's Drylands, 2 Juni 2021. https://www.globallandscapesforum.org/presentation/biochar-and-its-practical-application-to-restore-degraded-lands-experiences-from-field-experiments-in-kenya/
	Kätterer T. Inbjudet föredrag ”Kolinlagring i jordbruksmark”, webbinarium organiserad av Partnerskap Alnarp, 20 maj 2021. https://www.slu.se/centrumbildningar-och-projekt/partnerskap-alnarp/motesplatser/dokumentation/seminarier--och-evenemang-2021/

Oral communication ***to sector, students, etc.*** **Cont'd**	Kätterer T. Inbjudet fördrag ”Mellangrödor för mullbildning“ vid Webbinarium ”Skogsträds- och växtförädlingens roll i klimatpolitiken”, Kungl. Skogs- och Lantbruksakademien, KSLA, 5 maj 2021.
	Kätterer T. Intervju i Dagens Nyheter, publicerad 28 april 2021 https://www.dn.se/insidan/kommer-det-ga-att-ata-kott-med-gott-klimatsamvete/
	Kätterer T. Inbjudet fördrag. Greppa Näringens grundkurs för klimatrådgivare. 22 april 2021
	Kätterer T. Invited presentation. Overview of the CarboSeq project. EJP Soil stakeholder meeting 16 april 2021. https://adm.greppa.nu/arkiv/enkater/2021-02-24-greppa-naringens-grundkurs-jordbruket-och-klimatet.html
	Kätterer T. Inbjudet föredrag ”Framtidens hållbara jordbruk och den ekologiska drömmen”, Folkuniversitet och Vetenskap och Folkbildning, 13 aril 2021. Föreningen Vetenskap och Folkbildning i samarbete med Folkuniversitetet, Uppsala, 13 april 2021. Youtube-kanal: https://www.youtube.com/watch?v=G01fIi0lCx4
	Kätterer T. Intervju ALT-Lantbrukets Affärer ”Förnyelsebar produktion en grundpelare för hållbarhet”” publicerad 6 april 2021. https://www.atl.nu/skog/fornyelsebar-produktion-en-grundpelare-for-hallbarhet/
	Kätterer T. Inbjuden presentation vid webbinarium ”Infångning och användning av koldioxid – hur och till vilket pris?”, organiserad av IVA, 18 mars 2021. https://www.iva.se/event/infangning-och-anvandning-av-koldioxid--hur-och-till-vilket-pris/
	Kätterer T. Inbjudet föredrag “Kolinlagring i jordbruksmark”, vid webbinarium organiserad av Ekotankesmedja i Finland, 17 mars 2021 https://www.ekonu.fi/ekotankesmedja-2021-forelasningsmaterial-och-videoinspelningar/
	Kätterer T. Invited lecture ”Carbon sequestration in agricultural soils”, digital international seminar organised by Väderstad AB, 23 February 2021.
	Kätterer T. Inbjudet föredrag ”Hur kan man öka kolinlagringen i en höstvetebaserad växtföljd?”, digital seminar, Lovang-gruppen, 9 feb 2021
	Kätterer T. Inbjuden föreläsning ”Fotosyntesen som hjälp att minska klimatpåverkan från jordbruket”, Malmö Latin, gymnasium, 5 feb 2021
	Kätterer T. Inbjudet föredrag ”Kolinlagring och bördighet”, webinar, Agro Sörmland 29 jan 2021. https://youtu.be/hbC_BGp23Po
	Kätterer T. Intervju i Södermanlands Nyheter om kolinlagring, 28 jan 2021, Fredrik Ericsson, https://sn.se/lokalt/sormland
	Kätterer T. Inbjudet föredrag vid Lantbruksdagar, HS Skåne, webinar 14 jan 2021. https://www.youtube.com/watch?v=d0UQo7rij90
	Kätterer T. Invited presentation at roundtable ”Koll på biokol - Universalkur eller kejsarens nya kläder?” organized by KSLA, 3 dec 2020.
	Kätterer T. Inbjuden presentation ”Vad har de långliggande försöken lärt oss om kolinlagring”, seminarium organiserad av Ämneskommitté växtnäring, SLU, 26 nov 2020. Möten, protokoll med mera | Externwebben (slu.se)
	AGFO Talk: Kolinlagring som ny affärsmodell – rätt väg framåt? 17 nov 2020. Webinar https://www.youtube.com/watch?v=vw1vZD29uVo&feature=youtu.be
	Torsdagen 3 december 2020Kolets kretslopp, grundläggande om markkol”, KSLA Intervju, LRF Media, 6 nov. 2020 för webinar riktat till förtroendevalda inom LRF. maja_thomas_kort_3.mp4
	Webinar Bjerking, 4 nov 2020. Disa Löfvendahl, Karin Winroth, Thomas Kätterer “Kolsänkor i staden - utformning av grönytor för att maximera kolinlagring” https://lnkd.in/eeySXNd
	Kätterer T. Interview in Poddenlandet 21 Oct 2020: Landbygdsnätverket webbnyhet, Soundcloud, Facebook, Twitter, Instagram, Linkedin
	Kätterer T. Invited lecture at digital course. Greppa grundkurs för klimatrådgivare. 1 okt 2020
	Kätterer T. Intervju i tidskriften Mat och Klimat, 25 Sept 2020 Stenmjöl på åkermark - en mirakelkur för klimatet? http://matochklimat.nu/ny-studie-stenmjol-pa-akermark-en-mirakelkur-for-klimatet/
	Kätterer T. Intervju i Miljömagasinet 25 Sept 2020 om stenmjöl på åkermark: Stenmjöl på åkermark, en mirakelkur för klimatet? – MILJÖMAGASINET (miljomagasinet.se)
	Kätterer T. Inbjudet föredrag, fältvandring och föredrag hos Kjell och Ylva Sjelin, Hånsta Östergärde väster om Vattholma, Hånsta 74, 18 sept 2020, på uppdrag av LS Uppsala, LS Stockholm, Landet Lär, EU, Greppa Näringen.

Oral communication *to sector, students, etc.* **Cont'd**	Kätterer T. Invited zoom-lecture ”Kolinlagring i jordbruksmark”, Stifelsen Växtnäringsforskning, 9 sept 2020.
	Kätterer T. Intervju, P4 Uppland direktsändning, om Ramförsöket vid SLU, 31 juli 2020, 4 minuter https://sverigesradio.se/avsnitt/1544435
	Video om ramförsöket, Sveriges mest kända försök: https://www.facebook.com/slu.sweden/videos/365075801122222
	Kätterer T. Intervju ”Kolinlagring”, Land Lantbruk 25: 8-9, 12 juni 2020. https://www.landlantbruk.se
	Kätterer T. Intervju, ”Världsunikt kolinlagringsförsök på SLU i Ultuna”, Land Lantbruk 24, sida 13, 5 juni 2020. https://www.landlantbruk.se/
	Kätterer T. Intervju ”kolinlagring det nya svarta” i Lantbrukspodden, 4 juni 2020 https://www.landlantbruk.se/lantbruk/lantbrukspodden-kolinlagring-det-nya-svarta/
	Kätterer T. Intervju, Porträtt ”Forskare som sitter på svaren” i Lantmannen 6: 46-51, juni 2020 https://www.lantmannen.nu/
	Kätterer T. Intervju i ”Odla med P1”, trädgårdsprogram,18 maj 2020 https://sverigesradio.se/odlamedp1
	Kätterer T. Intervju för tidskriften ETC av Izabella Rosengren. Publicerad i ETC 7 maj 2020
	Kätterer T. Intervju i podden ”Feeding your mind”, Jord, kor och klimat. SLU Future Foods 16 april 2020 https://www.slu.se/ew-nyheter/2020/4/jord-kor-och-klimat/
	Kätterer T. Invited lecture ”kolinlagring i mark” 60 minutes, at webinar organised by NorFor Klimat, 18 March 2020.
	Kätterer T. Invited talk ”Så ökar vi kolinlagringen i marken”, Lantbrukskonferens - odla jorden klimatsmart, hållbart, miljösäkert och lönsamt, Organized by Hälsingborg Kommun, LRF och Energi- och klimatrådgivarna i Skåne, Ängelholm 28 feb 2020 (about 120 participants). https://foretagare.helsingborg.se/bransch-och-service/detta-galler-for-din-bransch/lantbruk-och-odling/
	Kätterer T. Invited talk ”Odlingssystemens effekter på kolinlagring i jordbruksmark”, Vallkonferens 2020; www.slu.se/vallkonferens2020, SLU, Uppsala, 4-5 februari 2020
	Kätterer T. Invited talk ”Möjligheterna med biokol – utsläppsminskningar och klimatanpassning”. Seminarium i Sveriges Riksdag i samband med klimatpolitiska vägvalsutredningen 28 jan 2020.
	Kätterer T. Interview kundskapspodden 30 jan 2020. http://kunskapspodden.se/
	Kätterer T. Invited talk ”Kolinlagring i mark” at Jordhälsokonferensen 2020, organised by SLU RådNu och Gröna Möten, attended by about 100 farmers and advisors, Lundsbrunn 22-23 jan 2020. https://youtu.be/BHLAb1YOP40
	Kätterer T. Invited talk ” Kolinlagring i marken för bördigheten och klimatet” at seminar: Fossilfritt kött - Hållbarhetens Ö, organised by LRF Gotland och Gotlands Slagteri, attended by about 60 farmers and advisors, 17 jan 2020, Suderbys Herrgård, Gotland
	Kätterer T. Invited to roundtable ”Kolinlagring i mark”, Väderstad AB, www.vaderstad.com Väderstad 11 dec 2019.
	Kätterer T, invited talk “Kol och vallodling. Hur hänger det ihop?”, Upplands Vallförening, 2 dec 2019, Uppsala.
	Kätterer T, invited talk “Kolinlagring i jordbruksmark”, LRF, 29 Nov 2019, Stockholm
	Kätterer T, invited lecture ”Vallens (och gödselns) betydelse for bördighet och kolinlagring i marken” at Alnarp mjölkdagen arrangerad av SLU-Alnarp Inst. f. biosystem och teknologi, Skånemejerier, Skånesemin, LRF Skåne och Partnerskap Alnarp, Alnarp 19 Nov 2019.
	Kätterer T, invited lecture ”Kolinlagring för bördigheten och klimatet”. Caféafton anordnad av Ingenjörer för Miljön www.ingenjorerformiljon.se och Läkare för Miljön www.lakareformiljon.org i samarbete med Ekocentrum, Göteborg 13 Nov 2019.
	Kätterer T, invited lecture ”Den ekologisk drömmen”. Seminar organized by Pensionärsföreningen SPF i Sunnersta. Sunnersta kyrka 6 Nov 2019.
	Kätterer T, invited lecture “Hur får vi med utsläppen från jord- och skogsbruk i en klimatstrategi?” at the conference ”Climate change leadership” organized by CEMUS for employees in Swedish municipalities working with climate strategies, Uppsala, 5 Nov 2019.

Oral communication *to sector, students, etc.* **Cont'd**	Kätterer T, panel member at seminar "Så klarar det svenska jordbruket klimatmålen", 16 Oct. 2019, KSLA, Stockholm.
	Kirchmann H, Börjesson G, Bolinder MA, Getahun GT. & Kätterer T. Demonstration of field experiment for farmers (SOILCARE project), Orup, Skåne 19 June 2019.
	Kätterer T, invited lecture "Kolinlagring för bördigheten och klimatet" at Hallfredagen, which is an annual meeting for farmers (about 150 farmers) organised by LRF, Hushållningssällskapet and Greppa Näringen. Gotland 9 July 2019.
	Kätterer T, invited lecture at the seminar "Vad vet vi om markkol idag" organiszed by Partnerskap Alnarp, Alnarp 17 June 2019.
	Kätterer T, invited lecture "Kolinlagrin i mark från vallen – vad är det värt?" at Stenhammardagen, organised by SLU and Stenhammar godsförvaltning, Stenhammar 12 juni 2019 (ca. 100 personer inkl Ers Majestät Konungen).
	Kätterer T, invited lecture "Kolinlagring i mark och dess betydelse för att balansera jordbrukets klimatpåverkan" at the seminar organised by SLU for "Gamla Gardets Socialdemokratiska Förening", Uppsala 20 Maj 2019.
	Kätterer T, project presentation at the second global network meeting organised by SLU Global, Uppsala 14 May 2019.
	Kätterer T, inbjuden till Rundabordsamtal med temat "klimat och kunkurrenskraft", 13 maj 2019, KSLA, Stockholm.