Final report for the project H1233013

How do catch-crops, harvest residues, manure and mineral fertilizers affect yield potential and soil organic matter?

Kätterer T., Bolinder M.A., Börjesson G., Aronsson H., Myrbeck Å., Kirchmann H.

Background

Soil organic carbon (SOC) content is the most significant indicator for soil fertility because it influences the majority of soil properties that are important for crop production (Carter et al. 1997). Even small decreases in SOC can result in reduced harvest potential because of weakened soil physical properties (e.g., soil structure, porosity, and water holding capacity), increased soil erosion, and problems with compaction that further leads to greater need for tillage operations (Blair et al. 2006; Watts et al. 2006). All of these aspects influence the farmers' economy. It is also well established that SOC sequestration can be an effective and cost-effective measure for mitigation of climate change. Since soils contain more than twice the amount of carbon in the atmosphere, even small changes in SOC are important (Smith, 2012). Most studies on SOC sequestration potential for agro-ecosystems focus on the topsoil (0-30 cm) and there is a need to better account for changes occurring in the subsoil. Annual C inputs to soil is the most important factor responsible for the buildup and sequestration of SOC, and any management technique that result in higher yields implies that more C is added through above- and below-ground (roots and rhizodeposits) crop residues (Bolinder et al. 2007). The use of catch-crops and small-grain straw removal are also two factors that influence annual C inputs to soil. Ecosystem models, developed on data from field experiments, are useful tools in order to assess the impact of different soil improving cropping systems (SICS) on both soil fertility and SOC sequestration. Where a SICS refers to any combinations of crop rotations (e.g., cereal-based systems with oilseed crops, cereal-bases systems with root crops) and management techniques (e.g., catch-crops, manure applications). Since the changes in SOC are often small, compared to the generally high amount already present in soil, data generated by long-term field experiments (LTE) are of particular interest to test and improve SOC models. Sweden has more LTEs than many of its neighboring countries (Debreczeni and Körschens, 2003), and that has allowed SLU to build a framework, the Introductory Carbon Balance Model (ICBM), which is used to study SOC dynamics for agro-ecosystems. It is used at various scales such as within the Swedish national reporting system for SOC changes (Swedish Environmental Protection Agency, 2013), in life cycle assessments (Goglio et al. 2015) and as a component in other GHG assessment tools that evaluate the global environmental footprint of entire farms (e.g., Bolinder et al. 2006). The objectives of this project, using existing data after a quality assessment and completed with new measurements for selected LTEs and treatments were to study (1) the impact of SICS on SOC stocks, (2) the influence of SICS on SOC stocks in the subsoil, (3) the effect of SICS on crop yields and (4) to integrate the results using ecosystem modelling, needed for research and environmental monitoring programs, with an emphasis on promoting the usefulness of ICBM for extension services.

Materials and methods

The data used for this project mainly comes from several Swedish LTEs, many of them have been described (location, layout and treatments, etc.) in earlier publications (Aronsson and Torstensson, 1988; Carlgren and Mattsson, 2001; Mattsson and Persson, 2006; Myrbeck et al. 2012). The new measurements and details for other sites (one from Italy and one in North America.) we included in the analysis can be found in the manuscripts we published (and references cited therein) in this project (see publications list).

Catch-crops and crop residue management experiments. Three LTEs (16-24 yrs) at two different sites in south-western Sweden (Mellby and Lanna) were used to study the effect of a ryegrass (mainly undersown) catch-crop; the main crop was mostly spring cereals. The yield of the main crop and above-ground biomass for the catch-crop were measured frequently during the duration of the experiments, and soil samples in the arable layer (0-20 cm) were taken in 2013 to determine SOC and dry soil bulk-density (BD) in all experiments. A North American site was also included in the analysis for catch-crops, which allowed us to compare seven pairs of catch-crop/no catch-crop treatments.

Six LTEs (27-56 yrs) were used to study the effect of crop residue management, one in northern Sweden (Röbäcksdalen), three in central (Lanna, Lönnstorp, Säby) and two in southern Sweden (Hvilan, Petersborg), which allowed us to compare sixteen pairs of straw removal/no straw removal treatments. Crop yields, SOC contents as well as other soil properties (e.g., texture, pH) for these sites were obtained from a database managed by SLU. A site from Italy with an additional set of five pairs of similar treatments was also included in the analysis.

Experiments used to determine SOC stocks in the subsoil.
The subsoil was sampled in selected treatments in about 10 LTEs during 2013-15 (Mellby, Igelösa, Petersborg, Lönnstorp, Bjertorp, Fjärdingslöv). Below the plough layer, soil was sampled in depth increments of 2.5 cm for obtaining a high resolution of SOC in the transition zone between topsoil and subsoil.

Soil fertility experiments (organic and mineral fertilizers). We compiled information from five sites in central Sweden (Bjertorp, Fors, Högåsa, Klostergården, Kungsängen) and six sites in southern Sweden (Ekebo, Fjärdingslöv, Orup, Ugglarp, Västraby, Örja), that were all initiated in the early 1960s, most of them still ongoing. Crop yields, SOC contents as well as other soil properties (e.g., texture, pH) were obtained from a database managed by SLU. Only some measurements (from earlier publications and handwritten archived data sheets) of BD (necessary to calculate a SOC mass balance) were available, consequently, a few sites (Ekebo, Fjärdingslöv, Orup and Bjertorp) were re-sampled for a quality assessment of BD data.

Furthermore, the methodology used to determine SOC contents has changed historically through time, with wet-combustion and loss on ignition measurements made in the earlier years, followed by dry-combustion shortly after the 1980s. This can have an effect, in particular, when estimating the initial SOC mass, which is crucial for modelling purposes. Therefore, a quality control was made by sending archived initial soil samples (for all sites) and time-series of samples for selected sites (Ekebo, Fjärdingslöv, Örja) to another laboratory for an independent re-analysis of SOC by dry-combustion (H.H. Janzen, Agriculture and Agri-Food Canada, LA). Since some of the sites (Fjärdingslöv, Fors, Klostergården) are calcareous (presence of limestone or black shales in the parent material) all re-analyzed samples were also assessed for carbonates.

Ecosystem modelling with ICBM.

All the LTEs were modelled with ICBM. Daily climatic data covering the entire experimental periods, needed to calculate the soil climate-management parameter of ICBM (Bolinder et al. 2008), were retrieved from the nearest weather station managed by the Swedish Meteorological and Hydrological Institute (SMHI). The main driving variable of ICBM, the annual C inputs to soil, were calculated on the basis of yield data, using principally the C allocation coefficients described by Bolinder et al. (2007) together with assumptions for root distribution with depth presented by Kätterer et al. (2011). Some of the sites had sugar beet and potato included in the rotations and we developed specific C allocation coefficients for these two crop types within the current project (Bolinder et al. 2015).

Results & Discussion

The quality assessment made for the soil fertility experiments showed that the data for initial SOC content generally corresponded well with those we had retrieved from the digital database and sheets in the archive at SLU. The data for carbonates somewhat confirmed those determined in a series of soil profiles published (Acta. Agric. Scand; 1993 to 2005) by prof. H. Kirchmann. However, for some experimental plots and sites, carbonates can be a source of concern since they are often present irregularly as shales that are not readily dissolvable in the standard acid solution, which make them difficult to account for appropriately, both in terms of soil sampling in the field and in sub-sampling for laboratory analysis. The data for BD on re-sampled sites also largely confirmed those from the database at SLU and from earlier publications, albeit there is still a necessity for further improvement. Since the impact of SICS on changes in SOC are often relatively small and it is difficult to have field experiments with completely uniform initial SOC stocks, we also developed an alternative methodology to analyze treatment effects using empirical equations that can be used to account for such initial differences (Poeplau et al. 2016b).

Impact of SICS on SOC stocks

The catch-crops had a significant impact, both on topsoil (0-20 cm) SOC stocks (Fig. 1.) and on SOC sequestration rates (0.32 ± 0.28 Mg C ha^{-1} yr^{-1}) at all Swedish sites (except one) and the Italian site (Poeplau et al. 2015a). For the crop residue management experiments, for an average time period of 36 years, the mean measured SOC stock change was 1.67 Mg C ha^{-1} yr^{-1} (Poeplau et al. 2015b). However, this effect of straw incorporation was not significant and apart from one site (Lanna), the expected constant accumulation of SOC through time was not detected, instead, the paired treatment comparisons became parallel (i.e., no difference) soon after the start of the experiments. The Swedish soil fertility experiments showed that, on average across different N-fertilization intensities, the effect of manure applications in the ley-based crop rotations increased SOC stocks by 0.13 Mg C ha^{-1} yr^{-1}. They also indicated that SOC stocks can increase with 1-2 kg

C for each kg of mineral fertilizer applied, which was attributed to a higher NPP and therefore more annual C inputs to soil from crop residues (Kätterer et al. 2013a). However, under N-limited conditions, we found that PK-fertilization stimulated mineralization rates and would even deplete SOC stocks (Poeplau et al. 2016a). An analysis of unpublished data from 4 other Swedish LTEs (the humus balance experiments) together with 11 published long-term studies conducted under Nordic conditions indicates that, compared to continuous annual cropping systems, ley-arable rotations can retain about 0.50 Mg more C per year (Kätterer et al. 2013b).

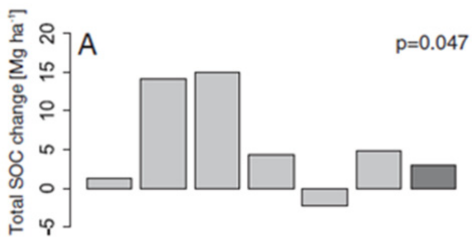

Fig. 1. The impact of catch-crops on SOC stock (Italian site in dark). The ryegrass increased SOC stocks for six out of seven pairs (range from – 2.0 to + 14.8 Mg C ha^{-1}). The only negative effect occurred at one of the Mellby sites but may have been an outlier attributed to differences in initial SOC stock values (from Poeplau et al. 2015a).

Effect of SICS on crop yields

The catch-crops experiments investigated in this project generally (with the exception for one comparison where main crop yields slightly increased) showed no influence on the main crop yields. Consequently, no noticeable effect was detected in relation with the increased SOC stocks for cropping systems with catch-crops (Poeplau et al. 2015a). A comprehensive statistical analysis of the whole data set from the fertility experiments is currently conducted by a PhD-student co-supervised by T. Kätterer (SLU) at the department of Ecology (Audrey St-Martin) who will present her thesis in early 2017.

Influence of SICS on SOC stocks in the subsoil.

In general, treatment-induced changes in subsoil SOC occurred in the same direction as those in the topsoil. Significant treatment effects were observed in several LTEs to 40 cm depth after decades of SICS.

Some of these datasets have been published. For example, the effect of sewage sludge addition has been shown to increase SOC directly through C input and indirectly through stimulation of NPP (Kätterer et al., 2015). Between 16% and 32% of C added with sludge was retained in the topsoil after 13 to 53 years at the different sites. At the two sites where whole soil profiles were studied, between 28% and 36% of sludge-derived C was retained to 40 cm depth (Fig. 2).

Since almost 50% of these changes occurred below 20 cm depth and about one third below the Ap-horizon, C changes in upper subsoils need to be considered in soil C balance studies. The key question whether the C increase below the topsoil was due to more roots or dissolved organic C leached remains to be answered. Indirect positive feedbacks of sludge addition on soil fertility such as an increase in the microbial biomass (Börjesson et al., 2012) should also be considered.

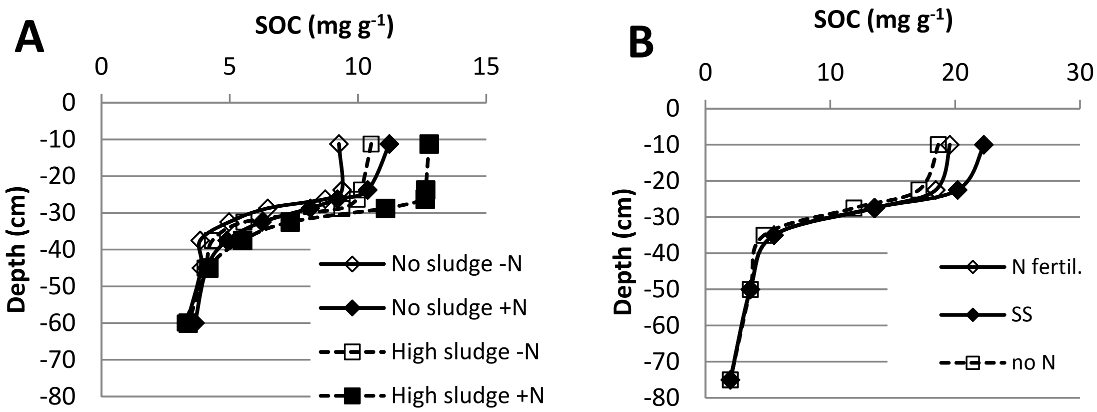

Fig. 2. Soil organic carbon concentrations along the soil profile in sludge-amended treatments (SS) *vs* N fertilized and unfertilized treatments at Petersborg (A) and Lanna (B) (from Kätterer et al. 2015).

<u>Ecosystem modelling with ICBM.</u>

The ICBM model parameter *h*, the humification coefficient, was calculated for the ryegrass catch-crop experiments as a measure of SOC sequestration efficiency (Poeplau et al. 2015a). It carries information on substrate quality, the efficiency of the microbial community, as well as on abiotic site conditions. The mean *h-value* was 0.33 ± 0.27, which is comparable to that of other efficient organic amendments such as manure and sewage sludge. The highest *h-value* obtained was 0.6, which is comparable to that for peat materials. The ICBM *h-value* was also used to quantify the effect of straw incorporation for the crop residue management experiments (Poeplau et al. 2015b). We then used an extended version of ICBM that allowed us to characterize the *h-value* for straw and roots separately. Since the straw incorporation only had minor effects on SOC stocks in the majority of the experiments, the *h-value* for straw was very low, ranging from about 0.00-0.09. They were also correlated with clay content (only the sites with clay content greater than 30% showed a significant gain in SOC), with a linear regression: *h-value* = -0.044 + 0.0036 x % clay (R^2 = 0.75), and somewhat influenced by N-fertilization (*h-values* slightly increased with higher N applications). These experiments also confirmed the higher stabilization of root-derived C (*h-value* about 0.3) as compared to straw. A single-pool first order model, similar to ICBM, was also applied to data for some of the experiments used to determine the influence of SICS on SOC stocks in the subsoil in order to calculate *h-values* (Kätterer et al. 2014a). In that study, results showed that the contribution of organic amendments to SOC was in the order compost > manure > roots > sewage sludge > green manure, with the highest *h-value* (0.9) for domestic waste compost, those for manure and crop residues were similar to earlier estimates by Kätterer et al. (2011). However, *h-values* were higher when considering also SOC stocks present in the subsoil, showing that organic amendments can be translocated to the upper subsoil, and that humification coefficients can be underestimated when only SOC changes in topsoil are accounted for. Furthermore, the six soil fertility experiments in southern Sweden were used to assess the variability in *h-values* for a larger number of site/treatment combinations (N = 96, i.e., a combination of four PK-levels, each associated with 4 N-levels per LTE). This was done using a similar optimization procedure and assumptions as in

Kätterer et al. (2014a) with linear equations (one per treatment). Results showed that the mean *h-values* per LTE for above-ground crop residues ranged from 0.027 to 0.071, and in some cases, they tended to increase with N applications (unpublished data).

The modelling with ICBM has been considered in different extension service-oriented actions (Fig. 3). Furthermore, the SOC balance is a crucial component in LCA studies, which can also be used for the extension services, and several leading Swedish research groups are now using ICBM within their LCAs (Cecilia Sundberg and Per-Anders Hansson at SLU, Pernilla Tidåker at JTI and Lovisa Björnsson and Thomas Prade at Lund University). Work has been initiated in cooperation with Göte Bertilsson and Hans Nilsson (Greppa Näringen) to build a more complete, user-friendly, web-based soil fertility decision-tool for Swedish farmers. This tool is under development by combining "Odlingsperspektivet", a tool presently used by the Swedish extension service to introduce environmental and soil fertility issues to farmers (within the national advisory program Focus on Nutrients) with the ICBM model.

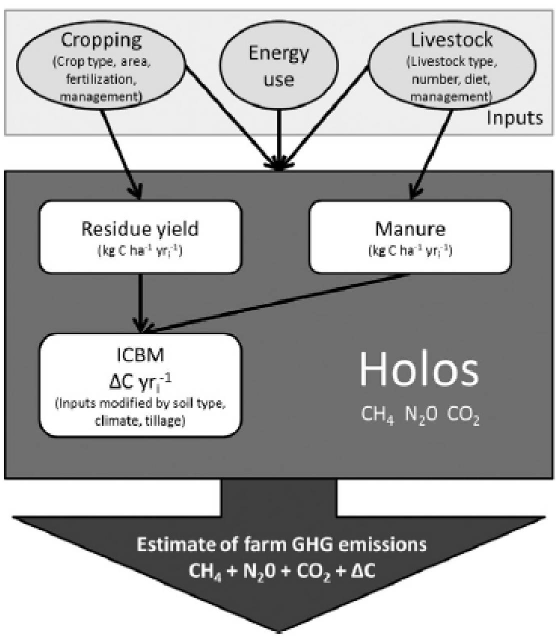

Fig. 3. Conceptual representation showing ICBM incorporated into Holos. Holos is a holistic framework, developed to estimate mitigation options for GHGs emissions of whole-farms and includes SOC stock changes as a sub-component (from Kröbel et al. 2016).

Conclusions

- In the LTEs analyzed in this study, the impact of SICS on SOC stocks were greatest for ley-arable rotations, followed by catch-crops and manure applications. The impact of straw management on SOC was variable and may be relatively unimportant for light-textured soils (less than 30% clay).
- After several decades, experimental treatments had affected both topsoil and subsoil, generally in the same direction. The effect of SICS on SOC could be quantified for different management options.

- The magnitude of yield increase due to increased SOC varied between sites and crops. The positive yield response was due both to increased nutrient turnover in soils with high SOC and better soil structure.
- The SOC modelling with ICBM clearly confirms that the humification coefficient of roots is at least twice as high as that for above-ground crop residues, and quite similar to that for manure. The results also indicate that the humification coefficient for above-ground crop residues may have been slightly overestimated in previous applications with ICBM, especially in sandy soils. In particular for small-grain cereal straw and that the coefficient for such organic materials could eventually be modified accordingly with soil texture as well as N-fertilization rates. It was also found that when considering SOC changes in deeper soil layers leads to higher humification coefficients. This information has been transmitted to various service extension-oriented tools.

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Bolinder M.A., VandenBygaart A.J., Gregorich E.G., Angers D.A., Janzen H.H. 2006. Modeling soil organic carbon stock changefor estimating whole-farm greenhouse gas emissions. Canadian Journal of Soil Science. 86: 419-429.

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Publications entirely or partly derived from this project

Peer-reviewed international journals, book chapters and conference proceedings

Kröbel R., Bolinder M.A., Janzen H.H., Little S.M., Vandenbygaart A.J., Kätterer, T. 2016. Canadian farm-level soil carbon change assessment by merging the greenhouse gas model Holos with the Introductory Carbon Balance Model (ICBM). Agricultural Systems. 143: 76-85.

Poeplau C., Bolinder M.A., Kirchmann H., Kätterer T. 2016a. Phosphorus fertilisation under nitrogen limitation can deplete soil carbon stocks - Evidence from Swedish meta-replicated long-term field experiments. Biogeosciences 13: 1119–1127.

Poeplau C., Bolinder M.A., Kätterer T. 2016b. Towards an unbiased method for quantifying treatment effects on soil carbon in long-term experiments considering initial within-field variation. Geoderma 267: 41–47.

Bolinder M.A., Kätterer T., Poeplau C., Börjesson G., Parent L.E. 2015. Net primary productivity and below-ground crop residue inputs for root crops: Potato (*Solanum tuberosum* L.) and Sugar beet (*Beta vulgaris* L.). Canadian Journal of Soil Science. 95: 87–93.

Kätterer T., Bolinder M.A., Poeplau C., Börjesson G., Kirchmann H., Bergkvist, G. 2015. Swedish long-term agricultural field experiments – soil carbon stock changes are affected by management. Valuing long-term sites and experiments for agriculture and ecology, Association of Applied Biologists, May 27-28, Cockle Park farm, Newcastle University, Morpeth, Northumberland. Aspects of Applied Biology. 128: 119-124.

Poeplau C., Aronsson H., Myrbeck Å, Kätterer T. 2015a. Effect of perennial ryegrass cover crop on soil organic carbon stocks in southern Sweden. Geoderma Regional 4: 126–133.

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Kätterer T., Börjesson G., Kirchmann H. 2014a. Changes in organic carbon in topsoil and subsoil and microbial community composition caused by repeated additions of organic amendments and N fertilisation in a long-term field experiment in Sweden. Agriculture, Ecosystems & Environment 189: 110–118.

Kätterer T., Kirchmann H., Börjesson G., Bolinder M.A. 2014b. Carbon sequestration in cropland – management strategies evaluated in long-term field experiments in northern Europe. Pages 21-26. *In* Halldórsson G., Bampa F., Þorsteinsdóttir A.B., Sigurdsson B.D., Montanarella L., Arnalds A. (Eds.). Soil carbon sequestration for climate food security and ecosystem services – proceedings of the international conference, May 27-29, Reykjavik, Iceland. JRC Science and Policy Reports. Publications Office of the European Union, Luxembourg. ISBN 978-92-79-35595-0, http://dx.doi.org/10.2788/17815

Kätterer T., Bolinder M.A., Berglund K., Kirchmann H. 2013a. Strategies for carbon sequestration in agricultural soils in northern Europe. Acta Agriculturae Scandinavica. Section A. 62: 181-198.

Kätterer T., Bolinder M.A., Thorvaldsson G., Kirchmann, H. 2013b. Influence of ley-arable systems on soil carbon stocks in Northern Europe and Eastern Canada. EGF Series 'Grassland Science in Europe', Vol 18: 47-56.

Dissemination of results to the agricultural & horticultural sector

Sweden

Extension communications (press release, newspapers, seminars, etc; in Swedish)

Wirsenius S., Röös E., Kätterer T., Strandberg G. 2016. Jordbruket måste ta sitt klimatansvar. Debattartikel i Tidningen Land, Lantbruk & Skogsland, March 26. http://www.lantbruk.com/debatt/jordbruket-maste-ta-sitt-klimatansvar

Kätterer T. 2016. Odlingsåtgärder som leder till kolinlagring i marken. Oral presentation at a seminar organized by SLU and Greppa Näringen, February 10, Alnarp (attended mainly by farmers and

representatives from farmer organizations (38 persons and an unknown number of people through video-link)).
Press release April 14, 2015: Vintergrön åkermark bra för klimatet. Presenterades bl.a. som Greppa Nyhetsbrev: http://www.greppa.nu/arkiv/nyhetsarkiv/2015-05-08-fanggrodor-binder-in-kol-i-jordbruksmark.html
Börjesson G., Kätterer T. 2014. Vad säger de svenska bördighetsförsöken? Oral presentation by Börjesson, June 25, Borgeby Fältdagar.
Kätterer T. 2014. Miljöhänsyn och resurseffektivitet – utmaningar inom växtodlingen. Invited oral presentation at Stenhammardagen med tema ”Ett lantbruk som håller i längden”, organiserad av SLU och Stenhammar Godsförvaltning, June 9.
Kätterer T. 2013. Hur påverkas marken av växtföljd, tillförsel av organiskt material och jordbearbetning. Föredrag inom utbildningsmodulen ”Växtföljd och bördighet” in Greppa Näringen. October 23, Uppsala.
Cederberg C., Berndes G., Nordborg M., Kätterer T., Röös E. 2013. Betande djur kan inte rädda klimatet. Tidningen Land, Lantbruk & Skogsland 52. http://www.lantbruk.com/debatt/betande-djur-kan-inte-radda-klimatet

Education of students (including new agronomists)
Kätterer T., Bolinder, M.A. 2015. Ph. D. Course (Soil carbon models at field or regional scale in the context of LCAs), November 9-13, SLU. The basic principles for dynamic ecological modelling were introduced using the Introductory Carbon Balance Model (ICBM) that integrates the findings from long-term field experiments within the current project. This part of the course was designed mainly for students who are interested in or working with simple soil carbon models at field or regional scale, for example in the context of Life Cycle Assessments (LCAs).

T. Kätterer is regularly teaching in courses at SLU within different education programs of agronomist, landscape architects and civil engineers. Results from this project are integrated in several lectures.

International

Scientific presentations (oral and poster at workshops & conferences)
Kätterer T. 2016. Integrated production of food and bioenergy on arable land – impacts on soil carbon sequestration. Oral presentation at network meeting “Effects of bioenergy production from forests and agriculture on ecosystem services in Nordic and Baltic landscapes”, April 4-5, Jeløya.
Bolinder M.A., Kätterer T. 2015. Root-derived carbon inputs to soil from agricultural crops – regional differences and variability in estimates. Poster presented at the 2nd international workshop “Evaluation of Soil Organic Matter Balance methods as practice-applicable tools for environmental impact assessment and farm management support“ (SOMpatic2), December 7-10, Rauischholzhausen, Germany.
Poeplau C., Kätterer, T. 2015. Root:shoot ratio of spring barley as influenced by soil texture and fertiliser regime. Poster presented at the 2nd international workshop “Evaluation of Soil Organic Matter Balance methods as practice-applicable tools for environmental impact assessment and farm management support“ (SOMpatic2), December 7-10, Rauischholzhausen, Germany.
Kätterer T., Bolinder M.A., Poeplau C., Börjesson G., Kirchmann H. 2015. Roots contribute relatively more to soil organic matter than above-ground crop residues, as revealed by analysis of Swedish long-term agricultural field experiments. Poster presented at the 2nd international workshop “Evaluation of Soil Organic Matter Balance methods as practice-applicable tools for environmental impact assessment and farm management support“ (SOMpatic2), December 7-10, Rauischholzhausen, Germany.
Kätterer T., Bolinder M.A., Poeplau C., Börjesson G., Menichetti L., Kirchmann H. 2015. Roots contribute relatively more to soil organic matter than above-ground residues according to analysis of long-term agricultural field experiments in Sweden. Invited talk (IT 2.1) by Kätterer at the 5th International Symposium on Soil Organic Matter, September 20-24, Göttingen, Germany.
Poeplau C., Bolinder M.A., Herrmann A.M., Kirchmann H., Kätterer T. 2015. Soil organic carbon stock depletion after phosphorus fertilization – Evidence and involved mechanisms. Oral presentation (O 2.1.01) by Poeplau at the 5th International Symposium on Soil Organic Matter, September 20-24, Göttingen, Germany.

Kätterer T., Bolinder M.A., Börjesson G., Kirchmann H. 2015. Changes in soil organic carbon along the soil profile affected by management in Swedish long-term field experiment. Oral presentation SUBSOM Symposium: Organic matter storage and turnover in subsoils; April 28 to May 1, Raesfeld Castle, Germany.

Poeplau C., Bolinder M.A., Börjesson G., Kätterer T. 2015. Influence of cover crops and crop residue treatment on soil organic carbon stocks evaluated in Swedish long-term field experiments. Oral presentation by Poeplau at session SSS10.3, EGU General Assembly, April 12-17, Vienna, Austria. Geophysical Research Abstracts.

Kätterer T. 2015. Field trial sites in Sweden. Invited talk at the workshop "Research Infrastructure at the academia-industry interface: The role of European networks" organized by Science Europe and hosted by DFG, February 18-19, Bonn, Germany.

Kätterer T. 2014. Management options for soil carbon sequestration in Nordic agriculture. Oral presentation – invited by Faculty of Life and Environmental Sciences, November 28, University of Iceland, Reykjavik.

Kätterer T., Kasimir Å. 2014. Focus areas in Sweden with relevance to the Global Research Alliance. Oral presentation by Kätterer at the Cropland Group meeting of the Global Research Alliance on Agricultural Greenhouse Gases, August 28-29, Hotel Divinus, Depbrecen, Hungary.

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