Soil organic matter management in agriculture

Assessing the potential of the 4per1000 initiative

Book of abstracts

Braunschweig, May 2018

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Editorial

With the international agreements to hold climate change below a warming threshold of 2°C, all options to reduce or reverse greenhouse gas emissions are in discussion, including soil organic carbon sequestration. A new focus on soil carbon and its role for climate mitigation and adaption has been achieved via the 4per1000 initiative that was launched by the French Ministry of Agriculture in December 2015. Enhanced soil organic carbon stocks can help to mitigate climate change and make soils more resilient to climate change. Furthermore, a sustainable management of soil organic matter is the key for soil fertility and it supports food security. However, the “simple” question how much carbon can technically and realisable be sequestered in soils at national, continental and global scale is mainly stuck with a theoretical potential. The complex interactions of biogeochemical cycling, pedo-climatic drivers and land use and management under different socio-economic conditions of land managers, currently hamper reliable estimates of how much carbon sequestration can realistically be achieved in soils. Moreover, other greenhouse gases, indirect effects and leakages may offset the positive climate mitigation effects of soil carbon sequestration. Thus, soil organic carbon management has to be closely linked to efficient nutrient management.

Soils are open systems and carbon inputs via biomass, like crop residues, is the prerequisite to maintain or enhance soil carbon stocks. The transformation pathway of carbon-input to the soils to long-term stabilised carbon is still insufficiently understood and difficult to quantify and predict. Moreover, systematic and holistic approaches are required to understand and optimise carbon fluxes beyond field scale.

The International Symposium on Soil Oganic Matter Management in Agriculture held 29/30 May 2018 in Braunschweig addresses the question how much soil carbon can contribute to climate mitigation and adaptation. It aims at

i) discussing and assessing efficient management options of soil carbon sequestration in different regions and at different sites for European and global agriculture,
ii) discussing the use and development of analytical tools and models for improving reliable large scale monitoring and prediction of soil organic matter stocks and dynamics.
iii) identifying research gaps on both topics.

In this book of abstract you will find all contributes to this symposium. With this symposium, we hope to bring together a critical mass of knowledge, expertise and ideas to further develop the ideas of the 4per1000 initiative.

This symposium is organized in partnership with the 4per1000 initiative and is kindly supported by the German Federal Ministry of Food and Agriculture.

Braunschweig, May 2018

Dr. Axel Don, Dr. Christopher Poeplau, Prof. Dr. Heinz Flessa

Challenges and pathways towards 4 per 1000 implementation

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As part of the Lima-Paris Action Agenda (LPAA), France proposed a voluntary action plan: 'The 4 ‰ initiative on soils for food security and climate', which was designed to be accompanied by an ambitious international research agenda but also to meet the requirements of numerous field practitioners for scientific support. This initiative proposes the storage each year of 4 ‰ of the standing carbon stock by the adaptation of locally adapted management practices. This intends to offset anthropogenic CO_2 emissions. At the same time this additional storage could be highly beneficial in terms of all other ecosystem services provided by soil and result in healthy soil as the basis of sustainable agriculture. The notion of linking together, management of natural resources, food security issues and mitigation of C emissions has strong political appeal and as a result soil management received attention by a large variety of actors and stakeholders from multiple sectors. Implication of the 4p1000 initiative requires collaboration of actors with contrasting interest, objectives and culture. Crucial for its success is the establishment of partnership and common incentives between multiple sectors. Communication is needed to demonstrate the on-farm benefits of building up SOC to farmers and stakeholders, encourage investment and to allow for capacity building and adaptation of innovations at numerous levels.

This presentation will highlight the strategic roadmap for the successful implementation of the 4 ‰ initiative. Achieving such agenda will put soil for the first time as new driving force in geopolitical decision-making process.

Managing soil organic matter in agriculture via plant inputs: recent perspectives and knowledge gaps

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Plants are the main source of soil organic matter in all ecosystems and are thus the main potential lever to increase soil organic matter stocks in agricultural soils in order to improve soil fertility and productivity, adapt to climate change and mitigate climate change. The effect of main cropped species on soil organic carbon (SOC) stocks has been described and incorporated in models for decades and the consequences of returning or not crop residues to soil is widely documented. Beyond this, a range of results show that there is still un-used potential in the management of plant inputs to agricultural soils in order to increase soil organic matter and SOC stocks, and that knowledge gaps are associated.

The magnitude of SOC stocks results from the balance between OC inputs to soil and OC outputs by mineralization or erosion. Several experimental results and meta-analyses show that increases in SOC stocks with changes in management are more related to increased plant inputs than to decreased outputs by mineralization due to no-tillage.

It is well established now that the yield in soil carbon is greater for below-ground OC plant inputs than for above-ground, showing that SOC oriented management should focus on the below-ground compartment. Increasing C belowground inputs to soil could be achieved through cropping deep rooting crop varieties, deep-rooting perennials, and agroforestry. For this, the balance between increased OC inputs at depth by root systems and consequent priming effect needs to be established and the carbon storage potential of sub-soils should be quantified. More generally quantifying rhizodeposition, investigating the role of root systems architecture and that of mycorrhizae in SOC storage and stabilization warrant further research. SOC storage is increased by plant species diversity and by the presence of legumes in the rotation, while these effects need to be confirmed, and the processes behind to be unraveled. Indirect effect of plant OC inputs on SOC storage, by affecting the physiology of soil microorganisms and in particular their carbon use efficiency also need attention.

Managing soil organic matter for better SOC sequestration in agriculture via plant inputs hence involves increasing the crop biomass production and returns to soil as known for long, but also managing complex plant associations in space and time (cover crops, trees, hedges, associated crops..) and better explore the whole soil profile.

Drivers of top- and subsoil root biomass and root-shoot ratios in conventional, no-till, and organic winter wheat

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Root carbon (C) is an important contributor to soil organic C and provides a major part of C inputs to agricultural soils (Keel et al., 2017). Roots respond markedly to their environment; hence, site conditions affect root biomass (RB) considerably, while agricultural management alters biomass allocation below ground (Hirte et al., 2018; Hu et al., 2018). However, little is known about the importance of management- and site-related factors for RB, its vertical distribution, and root-shoot ratios. We determined RB (to 0.75 m depth) and shoot biomass in winter wheat on 24 commercial farms practicing either conventional, no-till, or organic management at eight sites in Switzerland. We further evaluated the relative importance of nitrogen (N) fertilization intensity, weed biomass, sowing density, precipitation, and bulk density, texture, organic C, total N, and available phosphorus in soil for RB, its vertical distribution, and root-shoot ratios. Total RB and root-shoot ratios, respectively, were 1.4- and 1.5-times higher in organic than conventional farming. RB differed in the topsoil (0–0.25 m) only and was strongly related to N fertilization intensity and weed biomass that together explained 35% of the variation. Tillage did not affect RB but no-till contributed to a shift in vertical root distribution towards deeper soil, which was linked to elevated topsoil bulk density. RB below 0.25 m was similar among management practices but negatively related to silt content and positively to precipitation, which together explained 35 and 46% of the variation in 0.25–0.5 and 0.5–0.75 m, respectively. We conclude that organic farming clearly enhances wheat RB in the topsoil but site-related factors have a much stronger impact on subsoil RB, which has profound consequences for C inputs to deep soil and C sequestration.

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Plant-derived organic carbon input into soil in biogas cropping systems

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Energy cropping systems have gained importance due to political targets for increasing the share of renewable energy sources in the energy mix. Little is known about the effect of energy cropping systems on plant-derived organic carbon input into the soil and soil organic carbon content. In energy cropping systems for biogas production the harvestable plant biomass is removed from the field. Plant derived organic carbon (C) input is limited to leaf litter and rhizodeposition during the vegetation period, and above- (stubble) and below-ground (roots) harvest residues. In cropping systems for grain production plants are harvested at grain maturity, whereas in energy cropping systems for biogas production plants are harvested well before full maturity when they are ready for ensiling. This allows cultivation of "new" crop species, and facilitates higher cropping intensity, i.e. increased length of the period with actively growing (green) crops in a field on a yearly basis.

In field experiments in Berlin and Gießen we compared plant-related C fluxes in winter rye for grain production, and a two culture system in which winter rye was harvested at green maturity and followed by either maize or sorghum (*Sorghum bicolor*) or sudan grass (*Sorghum bicolor x sudanense*). We quantified net primary production and directly measured the plant-derived organic C input into the soil. Furthermore, we assessed the transfer of plant-derived C into soil organic C in long-term incubation studies under controlled conditions.

In average of four field experiments, net primary production in the two culture system was about 60% higher than in winter rye (13.4 vs 8.4 t C ha^{-1}), reflecting the longer period with green crops in the field. With winter rye, the amount of plant-derived C input into the soil was 1.8 t C ha^{-1} without straw and 4.6 t C ha^{-1} if straw was incorporated into the soil. In the two culture system, in which the harvestable plant biomass is used for biogas production, the plant-derived C input into the soil was higher, if green rye was followed by sudan grass (4.7 t C ha^{-1}) or sorghum (5.5 t C ha^{-1}) than with maize as catch crop (3.4 t C ha^{-1}). This reflects the higher ratio of non-harvestable to harvestable biomass in sudan grass and sorghum.

The production systems also influenced the ratio of different types of plant residues. For example, in winter rye grain production (without straw) total C input into the soil was composed of 19% leaf litter, 19% stubble, 28% coarse roots and 34% fine roots. In the two culture system for biogas production, C input was composed of 6% leaf litter, 27% stubble, 22% coarse roots and 45% fine roots. This is relevant as our incubation studies indicate that the transfer of plant-derived C into soil organic C ("humification") is substantially larger for fine roots (about 50%) than leaf litter (about 30%) and coarse roots and stubble (about 20%).

In conclusion, our data suggest that in cropping systems for biogas production plant-derived C input into the soil is not necessarily lower than in grain production systems, even if the straw is remaining in the field in the latter systems.

Management of ley grassland introduced into cropping cycle determines its effect on soil carbon storage

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Temporary (ley) grassland introduced into cropping cycles has been advocated as being beneficial for the delivery of ecosystem services by agricultural soils (Lemaire et al., 2015). The management of these temporary grasslands has unknown effects on soil organic matter (SOM) quantity and composition of the cropland soils following the grassland phase. The aim of the study was to investigate this legacy effect for differently managed temporary grasslands. We assessed soil organic carbon (SOC) quantity and quality using a long-term field experiment on Cambisol with temperate climate in western France. Temporary grassland management practices differed in terms of duration (3 or 6 years) and presence or absence of N fertilization. Topsoil (10 cm) samples were collected after a 3-yr crop rotation.

While permanent grassland had increased soil C and N stocks 9 yrs after the beginning of the experiment, continuous agriculture had led to decrease and introduction of temporary grassland had maintained C and N stocks. Our results showed that N fertilization during the grassland phase was necessary to sustain soil C and N stocks beyond three years of crop. Temporary grassland management may impact C input as indicated by contrasting microbial activities, polysaccharide and lignin composition. The biogeochemical signature of SOM was close to continuous grassland only in treatments with 6 yrs of fertilized temporary grassland. We thus, conclude that the legacy effects of a grassland phase on SOC quantity and properties of SOM depend on its management.

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Quantification of root-derived carbon input to soil during the vegetation period by dynamically linking of ^{14}C partitioning with shoot growth

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Precise quantification of root-derived carbon (C) input into soils is critical for understanding and modeling the terrestrial C cycle, especially the soil C dynamics and accumulation. However, the acquisition of reliable data on the root-derived C input to the soil is very difficult for several reasons. Since the C input (essentially roots and rhizodeposition) is not directly observable, very elaborate C isotope approaches must be used to quantify it. Unfortunately, these methods do not per se ensure that the C isotope distribution reflects the absolute C fluxes of plant-derived C in the soil. However, this is a decisive prerequisite for reliable quantification of the presumably high temporal dynamics of the C-input.

To overcome these problems, a modified ^{14}C tracer approach was applied. This included a ^{14}C pulse labeling at different stages during the whole plant development and the analysis of the ^{14}C partitioning in the plant-soil-soil gas system. Finally, absolute C fluxes were derived for the components of the C input by dynamically linking of the shoot C production with ^{14}C partitioning coefficients.

It could be shown in case of the model plant spring rye that the transfer of assimilated C into the root-soil-soil gas system during the plant development is a highly dynamic process, in which the maximum root growth preceded maximum shoot growth by approximately 17 days. Model simulations indicated that 18 ± 2% of all assimilated C that was not respired by shoots was transferred into the subsurface during the vegetation period. This flux split into 9 ± 0.8% C for root growth, 6 ± 0.7% C for belowground respiration, and 3 ± 0.3% C for detectable rhizodeposition. Nearly half of the downward-transferred C went into the subsurface between elongation growth and the last boot stage. Moreover, highly correlated relationships between root growth, rhizodeposition, and belowground respiration were found. In an additional experiment, it could be shown that the combination of the modified ^{14}C pulse labeling approach with soil fractionation can be used to analyze the fate of even very small amounts of freshly assimilated C in the soil.

Our study clearly shows that the dynamic linking of the relative C partitioning with the absolute shoot C production can provide detailed and precise information about the dynamics and the total amount of the downward-transferred C and its further fate.

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Plant residue quality mediate soil organic matter stabilization in an organic rainfed Mediterranean woody cropping system

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The incorporation of plant residues in rainfed Mediterranean agroecosystems can be a powerful strategy to mitigate the current atmospheric CO_2 increase, through soil carbon sequestration and stabilization.

The objective of this study is to assess how the type (green manure *vs* spontaneous native vegetation) and quality (leaves and stems *vs* roots) of plant residue incorporation affect soil aggregation and organic carbon stabilization in an organic rainfed almond (*Prunus dulcis* Mill.) orchard under different improved soil management practices (reduced tillage, RT, reduced tillage plus green manure, RTG, reduced tillage plus organic manure, RTOM, and no tillage, NT) after ten years from implementation.

We set up a full-factorial experiment in the laboratory to evaluate the effect of soil-plant residue mixing after tillage operations on decomposition, soil aggregation and organic carbon physico-chemical stabilization. Soil from the plow layer (0-15 cm depth) and inter-crop plant biomass were collected at each management practice in spring 2016. Soil was immediately homogenized and sieved through a 5-mm mesh sieve to remove stones and large plant residues, and plant biomass was cleaned, separated by above- and below-ground components and cut into 2-3 cm pieces. Three types of homogeneously plant residues (leaves and stems, roots, and the combination of both) from each management practice were mixed with soil at 1:40 litter to soil ratio and incubated under controlled conditions (28 °C, 60% water holding capacity), and CO_2 release was measured regularly over 243 days. One ‘no-plant residue’ (that is, containing only soil) microcosm per treatment x block x replicate combination (n = 36) was also incubated to correct for the soil contribution to CO_2 production. At the end of the incubation, water-stable macroaggregates (>250 µm), free micro-aggregates (53–250 µm), silt plus clay size fractions (<53 µm), as well as the micro-aggregates occluded within macro-aggregates, were isolated by sieving and associated OC content was measured.

Preliminary results show that leaves and stems mineralised faster than roots, and that soil aggregation and OC stabilization increase with higher-quality plant residues.

Strategies for soil carbon sequestration in cropland evaluated in long-term field experiments

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Soil organic carbon (SOC) sequestration can be a win-win strategy, leading to both a reduction in the growth rate of atmospheric CO_2, as well as increased fertility and sustainability of world's soils to ensure sufficient food production. Since annual changes in SOC are small compared to the large amount stored in soil, long-term field experiments and repeated soil inventories are indispensable for quantifying the effect of management practices on SOC stocks. We made a synthesis of literature reviews using paired treatments from long-term field trials assessing the effects of agricultural management practices on SOC stocks. The most prominent SOC sequestration strategies are practices that stimulate photosynthesis and net primary productivity, resulting in higher annual carbon inputs to soil through roots and aboveground crop residues. In that regard, increasing the frequency of perennial plant species is most efficient, where the substitution of annual crops with perennials increased SOC stocks by at least 0.5 Mg ha^{-1} yr^{-1}. Introducing cover crops in rotations has the second largest potential with (0.3 Mg ha^{-1} yr^{-1}), followed by nitrogen fertilization (0.2 Mg ha^{-1} yr^{-1}). The management of aboveground crop residues and tillage showed smaller effects. Considering present plant traits and consumption patterns, in many regions the 4per1000 target using e.g. more perennials or cover crops is only achievable on a limited proportion of the total cropland area. Our analysis highlights the need for further analysis of changes in subsoil carbon stocks. For example, considering whole soil profiles in Northern Europe, where present SOC stocks are high, even a relatively small change in subsoil C for perennial crops could largely outnumber the total effect attributed to no-tillage. More efficient recycling or modifications in processing of animal and other organic waste materials from the food and bioenergy chain can also contribute to SOC sequestration. We discuss conceptual problems when scaling-up results obtained from field studies to regional levels, the finite temporal dimension of these sequestration strategies and eventual drawbacks on the emission of non-CO_2 greenhouse gases.

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Soil carbon saturation – is there a limit?

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As soils can sequester carbon on a long-term basis they can contribute to the mitigation of climate change. Research in the last decades has shown, however, that the carbon storage capacity of soils seems to be limited and that soils become saturated in carbon at a certain point[1,2]. This saturation level was found to be dependent on different factors, including the soils texture or specific surface area, the land-use and the soils mineralogy[3].

Most studies showing the existence of carbon saturations are, however, limited in our view. We analysed data from over 60 long-term experiments, each having at least two different levels of organic fertilizer treatments plus a control without organic fertilizer. We found that the soil carbon storage is not saturating with higher rates of carbon inputs. In most experiments soil carbon storage depends linearly on the carbon inputs and does not seem to be saturatable, even at fertilizer input rates containing more than 20 Mg C ha^{-1} y^{-1}.

The results demonstrate that, in terms of soil carbon saturation it is important to compare different levels of input and not just one level of carbon input over time, as this will always reach a new steady state at a certain point. This does not mean, however, that soils at a new steady state are saturated in carbon. The results also show that it is important to look at individual experiments instead of adding up data from various experiments, with very different starting levels of SOC, and analysing them all together.

The implication of this study is that the concept of soil carbon saturation needs to be reviewed. This is important when considering the soil carbon storage in the future, as soil has got the reputation of being a possible, but severely limited sink for atmospheric carbon. Our results show that this is not true and that the major limitations when sequestering carbon in soils are not the saturation but the mass and origin of the organic amendments as well as the various effects that other nutrients which come along with the carbon in organic fertilizers may have in the soil.

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Biochar as a main solution for C storage in Norwegian soils: current status and needed developments.

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Norway is strongly committed to the Paris Climate Agreement with an ambitious goal of 40% reduction in greenhouse gas emission by 2030. The land sector, including agriculture and forestry, must critically contribute to this national target. Beyond emission reduction, the land sector has the unique capacity to actively removing CO_2 from the atmosphere through biological carbon storage in biomass and in soils. Soils are the largest reservoir of terrestrial carbon, and relatively small changes in soil carbon content can have an amplified mitigation effect on the Earth's climate. Therefore, improved management of soils for carbon storage is receiving a lot of attention, for example through international political initiatives such as the "4-permill" initiative. However, in Norway, many mitigation measures targeting soil carbon might negatively impact food production and economic activity. For example, soil carbon storage can be increased by shifting from cereal crop production to grasslands, but Norway already has abundant grassland and a comparatively small area dedicated to cereals. Another such issue is cultivation on drained peatland, where food is produced at the expense of large losses of soil carbon as CO_2 to the atmosphere. Therefore, there is a need to look for win-win solutions for soil carbon storage, which benefit both food production and climate mitigation. Large-scale conversion of agricultural and forest waste biomass to biochar is such an option, and is considered the activity with the largest potential for soil carbon sequestration in Norway. Biochar has been demonstrated to have a mean residence time exceeding 100 years in Norwegian field conditions (Rasse et al, 2017), and no negative effects on plant and soils has been observed. However, despite the convincing benefits of biochar as a climate mitigation solution, it has not yet advanced much beyond the research stage, notably because its effect on yield are too modest. Here, we will first present the comparative advantage of biochar technology as compared to traditional agronomy methods for large-scale C storage in Norwegian agricultural soils. We will further discuss the need for developing innovations in pyrolysis and nutrient-rich waste recycling leading to biochar-fertilizer products as win-win solution for carbon storage and food production.

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Persistence of organic matter amendments in Finnish agricultural soils

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According to the national soil inventory, the organic matter content of Finnish cultivated soils has decreased almost linearly in 1974-2009. The undesirable trend reflects the imbalance between the organic matter returns to the soils and losses due to decomposition and leaching.

Most effectively the carbon stocks of cultivated soils can be increased by introducing plants with high biomass to cultivation scheme or by applying resistant organic amendments from outside the farming system. In this study, we selected a set of various organic amendments, including cover crops, manures, composts, sewage sludges, digestates, biochars and by-products of paper industry, to find answers to the following questions: how resistant these amendments are in the soil and to what extent they increase the long-term storage of soil carbon to mitigate the climate change.

The persistence of the organic amendments is studied using laboratory incubation, litter bag experiment and chemical fractionation. The experimental results are compared with those obtained by Yasso07- soil carbon model.

Laboratory and data analysis of the study is still ongoing and expected to be completed by spring 2018. Preliminary results show variation in the chemical composition of the studied materials: fresh plant litter has the lowest share of non-soluble fraction, whereas biochars have the highest. This is in line with the incubation experiment indicating a very small resistant fraction of carbon in cover crop (clover and ryegrass) and especially in their above-ground residues. Processed materials such as composts, biochars, digestates and by-products are more persistent. Modelling appears to overestimate the resistant fraction of the organic amendments.

Enhance soil organic carbon stocks by means of the Biogasdoneright system

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The Biogasdoneright™ (BDR) system is an example of multifunctional and sustainable agriculture according to "The Roadmap to a Resource Efficient Europe", based on year-long cultivated soil, efficient recycling of organic matter and nutrients, conservation tillage practices (Valli et al., 2017). The system is being applied in a dairy farm in the Po valley (Palazzetto farm, Cremona, Italy). Before the BDR application the farm reared 220 milking cows, nowadays it has 300 milking cows as well as a biogas plant (1.6 MW electrical power).
The farm is transitioning from a conventional agricultural system, mainly based on maize monocropping (soil covered 6 months per year, total above ground biomass ~20 t_{DM} ha^{-1} yr^{-1}), to a sequential cropping system (two crops per year, up to 30 t_{DM} ha^{-1} yr^{-1}). The additional biomass produced is used to feed the additional cows and also as part of the feedstocks for the biogas plant. Digestate recycling to the farmland results in an increased rate of organic matter input when compared to the conventional system, as has already been verified in other European contexts (Witing et al., 2018). Carbon losses as biogas are compensated by the lower carbon degradation after field application of the digestate (Möller, 2015) and by the additional carbon fixed by the second crop, partly recycled as digestate as well.
Thelen et al. (2010) verified that the use of agricultural manures can raise soil organic carbon (SOC) in bioenergy cropping systems to a level sufficient to overcome the C debt associated with manure production, collection and storage, land application, and post-application field emissions. BDR increases SOC compared to the reference system. A mass balance approach was used to quantify the SOC change: field measurements of soil organic matter show an annual increase of SOC of 0.5 to 1.0 t C ha^{-1} in the first ten years of BDR application, depending on various conditions. We expect that in the medium term (10-20 years) about 20% of the organic carbon from digestate can be converted into stable SOC.
Biogasdoneright has already been defined as a bioenergy with carbon capture and storage (BECCS) system (Valli et al., 2017). Implementing BDR in dairy farms can bring a number of benefits that significantly reduce the Carbon Footprint of farm products. Among these benefits, the increase of SOC may be particularly significant in the short and medium term.

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4‰ yearly soil C storage: How much will verification cost? How to help farmers design soil C storing management within boundaries set out by nutrient legislation?

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Large-scale monitoring will be required to verify effectiveness of policies to sequester organic carbon (OC) in soils. On a regional scale, in Flanders – Belgium we assessed to what extent stratification can raise efficiency of monitoring to detect changes in soil OC. We present how optimization of sampling locations along strata based on land-use and soil texture (and drainage) are able to lower required numbers to minimally detect a certain soil OC stock change. On the basis of previous surveys we also looked at the uncertainty attributed to measurement of soil bulk density along with C concentration and depth extrapolation. We also made predictions of expected temporal auto-correlation and implications for achieved statistical power (i.e. 1 - the chance of committing a type-II error β) in case of pair-wise re-sampling. All calculations were explicitly made for detection of average 4‰ storage of OC over 10 and 20 years. Next to agricultural land we also included forest, nature and residential land-uses as well, partially relying on assumptions. We present calculations of total costs to conduct required planning, field sampling, sample handling and analysis for a first survey.

In a farmer's context, recommendations for OC management will need to consider nutrient fluxes and legislation as well. We present scenario calculations with a user-friendly online decision support tool (DST) that translates insights in sustainable nutrient and soil OC management into practical recommendations for farmers. The DST consists of a nutrient module and a soil OC module and operates on the field scale. The organic matter module calculates the long term (30 years) evolution of organic carbon in the selected field based on the Roth-C model. The inputs for this model are climate data (temperature, rainfall and evapotranspiration), soil characteristics (texture, bulk density, organic carbon content), crop rotation and input of organic materials. In the nutrient module of the DST, a mineral N balance and a P balance are calculated for the selected field. The mineral N balance consists of 7 input parameters (mineral N in the soil, mineralization of soil organic matter, catch crop, crop residues and organic materials, ploughing of permanent grassland and N deposition) and 2 output parameters (N uptake by crops and leaching). The P balance considers the application of organic materials as P input and P uptake by crops as P output. P balances are calculated over a whole crop rotation period.

Routine soil fertility analysis to improve soil organic matter management. A case study from southern Belgium

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An extensive sampling campaign covering the regional scale, long-term experiments and paired sites in farmers' fields revealed that the coarse C fraction separated by wet sieving over 20 µm provides a sensitive indicator for changes in C content after the application of soil conservation techniques such as conservation tillage, increase in residue return and extensification of grassland management. A random forest analysis demonstrated that the coarse C fraction (C>20 µm) is determined by the microbial biomass N and C, the potential respiration rate and the land use (grassland or cropland). Moreover, a positive linear relation between C>20 µm/C and the change in C content over the last 10 years could be determined (r^2=0.55). The threshold between losses and gains of C over the last 10 years was established at a C>20 µm/C ratio of c. 0.45. Routine soil analysis for fertility advice in southern Belgium uses Vis NIR spectroscopy for analysis of C, N, clay content and CEC. This allows extending the range of soil properties analysed using traditional wet chemistry (P, K and pH) at virtually no additional costs. A partial least square regression after log ratio transformation proved to be able to predict the C<20 µm and C>20 µm fractions for a limited data set of 325 samples (RPD = 4.17; RMSE = 2.88 g C kg^{-1}). This dataset will rapidly grow once the fractionation is integrated in the analysis chain. The large amount of samples analysed (c. 25,000 annually) for seven soil properties and the C fractions provides an opportunity to determine the optimal conditions for increasing the C content and defining the limiting conditions that can be addressed through application of nutrients and/or amendments.

Balance of soil organic carbon stock changes on the background of detailed analysis of land cover changes

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Determination of the total soil organic carbon (SOC) storage in the agricultural land and its time changes is conditioned by the knowledge of the spatial and temporal changes in the land cover. This should not only be considered within the agricultural land as such, but also all historical conversions between the agricultural and non-agricultural land cover types should be taken into account. In this study we present results of land cover and land cover change reconstruction for the Hanušovce nad Topľou cadastral area in North-East Slovakia during the time period of 1950 – 2016. Historical military aerial photographs were used for land cover evaluation in 1950, 1955, 1970, 1980,1983, 1987 and 1995. Aerial orthophotos were used for land cover reconstruction after 2000. Land cover information was digitalized from aerial imagery into vector data format using geographic information systems (GIS) software. Change in SOC stock related to land cover change was estimated using results of SOC stock values simulated by RothC model with 10 theoretical scenarios. Reverse changes in land cover that were not addressed by the scenarios were calculated with constant values of average annual increase/decrease of SOC stock (Szemesová, 2016). During the monitored period significant change in the land cover was observed, and this mainly in the agricultural land. Within monitored land cover types decrease of area was observed only for agricultural land, with cropland in particular, which lost more than 57 % of its area. In general, we can see successive transition from cropland to grassland and then to forest ecosystem or urban areas. Therefore, overall budget of the SOC stock was continuously increasing with some fluctuations in individual observed years. We can conclude that trend of conversion of crop land to grassland or forest is reflected in overall SOC stock dynamics.

Acknowledgement: This work was supported by the Slovak Research and Development Agency under contract no. APVV-14-0087.

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Implementation of the 4 per 1000 initiative at the regional scale: A reality check of soil management in Bavaria

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The ambitious 4 per 1000 initiative launched in 2015 aims at increasing world´s soil organic carbon (SOC) stocks in the upper 40 cm by 4 per mill per year in order to offset anthropogenic CO_2 emissions. For practical implementation of the initiative, regional feasibility studies are needed that include a precise analysis of the status quo of SOC stocks, an estimation of the C storage potential of soils, and a comprehensive, spatially explicit development of improved land management scenarios based on an analysis of existing land management practices. In this study, we estimated the potential of SOC increases in Bavaria (Germany) by improved management of agricultural soils. A determination of the SOC saturation level showed that agricultural soils of Bavaria generally have a high C sequestration potential, as a mean SOC saturation level of 50% and 77% was found for cropland and grassland soils, respectively. In order to delineate the specific 4 per mill target for Bavaria, a SOC map was generated for the depth of 0-40 cm on the basis of 786 soil profiles using the Random Forest model. As agricultural soils of Bavaria store around 276 Mt C in the first 40 cm, a total amount of 1.1 Mt C has to be sequestered each year in order to achieve the 4 per mill target. A comprehensive and spatially explicit analysis of management options including cover cropping, improved crop rotations, organic farming, agroforestry and a conversion of cropland to grassland showed that a maximum amount of 0.37 Mt C yr^{-1} could be sequestered. Although the 4 per mill target can hardly be reached in Bavaria, the estimated C sequestration potential would significantly counterbalance regional greenhouse gas emissions from the agricultural sector in Bavaria. Moreover, there are further benefits associated with C sequestration such as improved soil fertility, soil structure and water holding capacity, a reduced risk of soil erosion, eutrophication and water contamination as well as reduced costs for fossil fuel and fertilizers.

Swiss agricultural long-term experiments reveal little potential for soil carbon sequestration

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Soil organic carbon (SOC) stocks in agricultural mineral soils (0-20 cm) of Switzerland amount to 70 Mt (Leifeld et al., 2005), whereof 12 Mt are found under cropland (CL) and 58 Mt under temporary and permanent grassland (GL). Together these extend over an area of 1.49 million hectares. To meet the goal of the "4per1000" Initiative an increase of 0.19 t C ha^{-1} $year^{-1}$ would be required. Is this feasible for Switzerland?

Here, we summarize, for the first time, SOC time series from eleven long-term field experiments (mean duration 25 years). Most sites are located in the temperate Swiss Central Plateau; three are permanent GLs and eight CLs. At each location, different treatments were tested (e.g. various organic or mineral fertilizers, different types of soil tillage). Extreme managements (no or very intense fertilization) and managements typical for Swiss farming systems were included. We estimated the change in SOC for each of 80 treatments by fitting linear regressions to repeated field measurements. A linear mixed effects model was applied to test which factors could explain the SOC change rate.

On average, SOC stocks in topsoil decreased by 0.33 t C ha^{-1} $year^{-1}$. Intensity and type of fertilization (organic vs. mineral), soil cover and clay content were identified as significant factors. Soil tillage, land-use (CL vs. GL) or land-use history (i.e. conversion from GL to CL prior to experiment) had no statistically significant effect on the SOC change rate.

Based on our preliminary results and the current practice, increasing the use of cover crops or ley in crop rotations are most promising options to reduce SOC losses, but with a limited potential. Additions of organic matter through crop residues or organic fertilizer can hardly be increased, since they are already left on the field or returned with manure. Together these results suggest that the potential for SOC sinks in Swiss agricultural topsoils is very limited and the "4per1000" goal cannot be reached with common agricultural practices.

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High-resolution simulations of crop production and agro-ecosystem services for Germany

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Computer power today allows massive parallel simulations of sophisticated mechanistic simulation models. For agro-ecosystem processes, we apply the MONICA simulation model (Nendel et al. 2011) in the context of various climate change and food security assessments in grids of varying size, from 50m to 1km adjustable to the research problem, and produce maps of agricultural yields, long-term soil carbon dynamics, nitrate leaching or N_2O emissions for Germany and its regions. MONICA has been tested against different levels of data, including short- and long-term field data for many different output variables and county-level data for yields. An application at national-scale assesses nitrate leaching on the basis of mono cropping land-use assumptions. Using the crop map of Germany (Griffiths et al. 2018) we furthermore derive crop rotations for each grid cell, which allows designing more elaborated spatially explicit land-use scenarios that reflect policy or market changes, and thus enlarges the exploratory space beyond climate-focused assessments (Nendel et al. 2014). On the basis of a simplified set of crop rotations, another application is demonstrated for a North-Rhine Westphalia case study, focusing on sustainable intensification options for agriculture and testing crop residue management and rotations regarding their effect on yields and long-term soil organic matter development.

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Advancing SOM modeling by the use of measurable proxies for different soil organic matter pools

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In soil organic matter (SOM) models, purely conceptual pools should be replaced by measurable properties representing the chemical composition of SOM in the soil. Doing so makes model pools meaningful and not just a mere result of optimization. Rapid and cost effective Diffuse reflectance infrared Fourier transformation spectroscopy (DRIFTS) as well as pyrolysis coupled with infrared spectroscopy were proposed as tools to monitor SOM quality [1]. They can be used to assess relative abundance of aliphatic and aromatic carbon compounds in SOM. We hypothesized, that using the ratio of aliphatic to aromatic (AL/AR) carbon as proxies for slow and fast turnover carbon pools in SOM models will improve the modeling of SOM dynamics. To test the assumption, we recalibrated the DAISY model [2] with a Bayesian approach, using the AL/AR ratio. Measured temperature responses of enzymatic activities (ß-glucosidase and phenoloxidase) [3] were then used to create pool specific temperature functions to further refine the model. This combination of measurable chemical properties of SOM and modeling of their individual response to temperature should improve prediction accuracy of the DAISY SOM model.

We calibrated the model using a two-step approach and measurements from eight years of field monitoring from the Kraichgau and Swabian Alb in Southwest Germany. First, the turnover times and carbon use efficiencies of SOM within DAISY, without addition of new organic material, were optimized using bare plots data. Then carbon use efficiency and turnover times of new organic matter was optimized using data from cropped plots. An independent evaluation showed, that the new calibration considerably improved the model fit and sensitivity to input and temperature. The posterior distribution of calibrated parameters highlighted however, that there is a wide range of plausible parameters to achieve a reasonable model fit. The reasons for this are the high heterogeneity of soil properties even at field level, as well as a high internal parameter correlation in DAISY.

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Prediction of SOC accumulation for high input rates of organic matter - is there a limit?

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Soil organic carbon (SOC) powers many soil functions. Therefore, the prediction of management impacts as well as the interaction with environmental factors is for a long time in focus and lead to the development of a multitude of models. Currently, most models build on a concept that includes one pool that has no or a very slow, negligible turnover. Following the hypothesis of the CIPS model (Kuka et al. 2007) we implemented within the well validated CCB model (Franko et al, 2011, 2016) a physical protection process in order to study also this slow changing pool of long term stabilized (LTS) organic matter (Franko et al. 2017). Our current hypothesis is the assumption of an exchange between protection in pore space and exposition due to destruction of aggregates that leads on the long run to a steady state with a more or less constant LTS pool.

With the current focus on soils as potential carbon sink the dynamics of the LTS pool is of special interest leading to the question about a limited capacity or saturation of carbon storage. We followed this problem applying the CCB model on a dataset from a long term experiment that started in 1983 in Bad Lauchstädt, Germany on Haplic Chernozem including bare fallow treatments with the application of farm yard manure (FYM) in different rates up to 200 t ha^{-1} a^{-1}. The special advantage was here that the amount of carbon input was very well known and it was not necessary to apply submodels to estimate the amount of organic matter from crop residues and roots. The experimental dataset includes observation for SOC and total nitrogen (N_t) that both were used to validate the CCB model with a hypothetical assumption of a limited LTS pool size. The results confirmed our hypothesis. The model results obviously improved assuming a saturation of the LTS pool. Moreover, the differences between prediction and observation give hints to a shift in microbial community with a widened C/N ration and decreased carbon use efficiency for very high FYM application rates.

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Development of a new *in situ*, time- and cost-effective indicator to assess the impact of land management on soil organic carbon dynamics

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The proposed 4 per mille initiative aims at assessing soil organic carbon dynamics affected by land management in various and numerous ecosystems. However, assessments based on soil organic carbon dynamics face methodological and experimental shortages. First, SOC assessments may not be sensitive enough to rapid land management changes, due to the long term turnover of SOC (Dignac et al., 2017). Indicators based on soil fractions seems more adapted but this method is strenuous and time consuming and not well adapted for land managers. A new framework was proposed by Hurisso et al., (2016) to assess soil carbon dynamics, linking two indicators of soil carbon fractions (POXC and Basal Soil Respiration). This framework proved to be sensitive to land managements, and may be applied with cost-time-effective indicators in the field. Strictly following this framework, this study presents a first *in situ* application of the POxC and SituResp® indicators along a perturbation gradient based on rubber tree cultivation in Thailand. The indicators were applied in five study sites to follow a pedo-climatic gradient and finally resulted in 210 sampling points. A predictive model was then developed to avoid the site-specific calibration step and the model was validated among the literature data. The aggregation of the results at the site-scale proved to provide generalizable conclusions on the soil carbon dynamics, from the conversation of an intensive cash cropping system to various rubber tree stand ages, bounded by natural forest reference. Then, the model, integrating soil properties variables, proved to be robust under the pedo-climatic conditions treated, and validated against literature data. This first *in situ* study and the model developed are promising for the further application of the two indicators in more contrasted contexts. The methods may easily be implemented as a preliminary assessment tool in order to conceptualize new management practices that sustain soil carbon stabilization.

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Thermal analysis based models to quantify centennially persistent soil organic carbon and 20 year soil organic carbon loss in temperate soils

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The organic carbon reservoir of soils is a key component of climate change, calling for an accurate knowledge of the residence time of soil organic carbon (SOC). Existing proxies and models of the size of SOC labile and persistent pools are time consuming and inaccurate. Thermal analyses of bulk soil samples have recently been shown to provide useful and cost-effective information regarding the long-term in-situ decomposition of SOC.

The objective of this study was to build regression models based on Rock-Eval (RE) thermal analysis to quantify the proportion of centennially persistent SOC and 20 year SOC loss in a soil sample with known uncertainty. We used archived soil samples from 4 long-term agronomic experiments in North-Western Europe with bare fallow and associated non bare fallow treatments. We built 2 reference sample sets with observed SOC loss over a 20 year period (CL_{20}; n=38) or estimated size of the centennially persistent SOC (CPsoc; n = 118). CL_{20} in bare fallow treatments ranged from 0.8 to 14.3 gC.kg^{-1}, representing 9 to 51% of total SOC. The size of the CPsoc pool ranged from 14 to 100% of total SOC in bare fallow and associated non bare fallow treatments. Simple linear regression models were used to predict CL_{20} while a random forest multivariate regression model was used to predict the size of the CPsoc pool, using a series of RE parameters. The RE hydrogen index yielded the best simple linear regression model for the prediction of CL_{20} ($R^2 > 0.7$). The random forest multivariate regression model showed an excellent predictive performance for the size of the CPsoc pool with validation $R^2 > 0.9$ and validation error of prediction below 7%. This study demonstrates that the RE thermal analysis method can predict 20 year SOC loss and the size of the centennially persistent SOC pool, as assessed by long-term in-situ decomposition experiments. Rock-Eval appears to be a more accurate and convenient proxy of the size of SOC pools than other existing methodologies. Future developments include the validation of these models based on RE thermal analysis on soils from contrasted pedoclimatic conditions.

Activities in Germany contributing to the 4per1000-Initiative

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The Federal Republic of Germany, through the Federal Ministry of Food and Agriculture, is forum partner and consortium member of the 4per1000-Initiative. The support of the “4 pour 1000” Initiative was delegated to the Federal Office for Agriculture and Food (BLE), Division 323 – International Cooperation and Global Food Security. This includes in particular organizational, technical and coordinating activities of the German contribution to the implementation of the 4per1000-Initiative as well as the support of the activities of the Executive Secretariat. Several ongoing research activities support the 4per1000 goal. Our aim is to create a country profile for the Republic of Germany, in particular an inventory of the relevant projects funded by the Federal Ministry of Food and Agriculture as well as an overview of the institutions and organizations working on the topic of soil carbon sequestration. This will build the basis to identify gaps and future needs in research and strengthen the link to land users and decision makers. Further steps include the exchange with other countries to explore synergies and potential for collaboration. Through the enhanced use of the 4per1000 collaborative platform, project realisation, knowledge sharing and interlinkage will be supported.

Coordination of International Research Cooperation on soil Carbon Sequestration in Agriculture (CIRCASA)

The scientific coordination of CIRCASA project: Arias-Navarro, C.[1], Smith, P.[2], Frelih-Larsen, A.[3], Montanarella, L.[4], Kuikman, P.[5], Soussana, J-F.[1]

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Agricultural soils carry a large potential for carbon sequestration (Paustian et al. 2016), especially degraded soils. On the one hand, world soils contain a total organic carbon stock of about 1,500±230 GtC (Scharlemann et al. 2014), equivalent to twice the amount of carbon as CO_2 in the atmosphere (Le Quéré et al. 2016). On the other hand, close to half of all agricultural soils are estimated to be degraded (FAO and ITPS 2015), which raises threats for food production as climate change is likely to accelerate land degradation. Targeting ambitious changes in agricultural practices that would preserve restore and enhance soil carbon and soil health requires a better-structured international research cooperation. In this context, overarching goal of CIRCASA (Coordination of International Research Cooperation on soil CArbon Sequestration in Agriculture) is to develop international synergies concerning research and knowledge exchange in the field of carbon sequestration in agricultural soils at European Union and global levels. By bringing together the research community, governments, research agencies, international, national and regional institutions and private stakeholders, CIRCASA takes stock of the current understanding of carbon sequestration in agricultural soils, identifies stakeholders' knowledge needs, and fosters the creation of new knowledge. A 2020-2025 Strategic Research Agenda on agricultural SOC sequestration will be co-designed with stakeholders, grounded on scientific evidence and stakeholders' knowledge demands. The project will create significant outcomes for the implementation of the UN Sustainable Development Goals (SDGs) and of the Paris Agreement (COP21, 4 per 1000 voluntary initiative) of the UN Framework Convention on Climate Change (UNFCCC).

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Soil organic carbon monitoring and using of its results in SOC modelling

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In 1993 Slovakia started with regular monitoring of soil properties. The main goal of soil monitoring system in Slovakia is to build knowledge of present state and development of soils with regard to their productive and nonproductive ecological functions. Important soil indicators and parameters are being monitored focused on main threats to soil including also soil organic matter decline (Kobza et al., 2014). Soil monitoring system in Slovakia consist of 3 basic subsystems: a) the basic network of monitoring sites (316) in 5 years repetitions (agricultural, and alpine soils together); b) the key monitoring sites (21) in repetition every year; c) monitoring of peatland (8) in 10 years repetition. On the basis of results received during the soil organic carbon (SOC) monitoring it is possible to evaluate changes in SOC stock in the past period. Nevertheless, the prediction of SOC stock as a consequence of climatic changes and rapid changes in land use and soil management is very important task for future research. Promising tool for SOC estimation is modeling. SOC data from database of soil monitoring were used for testing of RothC model applicability for the SOC prediction in agricultural soils of Slovakia at national scale (Barančíková et al., 2010). More recently (Skalský et al., 2017) SOC data from permanent soil monitoring sites were used for validation of simulated SOC values at regional scale. Reasonable agreement was found between measured and simulated SOC content in *Ondavská Vrchovina* highland region. It can be concluded that SOC data from soil monitoring database can, as a part of SOC modelling, also serve for predicting of future SOC stock.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under contract no. APVV-14-0087. We thank also to Ministry for Agriculture and Rural Development in Bratislava for financial support of Soil monitoring system in Slovakia contract No 471/2014-310/MPRV SR.

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The long-term experiment V140/00 in Müncheberg, Germany: contribution to modern soil fertility research

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The prediction of soil fertility trends in tilled soils under altered climatic conditions or management schemes, necessitates long-term experiments exceeding 20 years. Only in this case a distinction between trends and fluctuations is possible. The V140/00 in Müncheberg, Germany, installed in 1963, provides information about yield development, carbon dynamics and quality of organic matter in sandy soil, fuelled by two types of exogeneous organic matter, straw and manure, combined with 5 levels of mineral N.

The site is characterized by an orthic luvisol, with 5 % clay and 0.56 % soil organic carbon, at 536 mm annual precipitation and 8.8 °C mean annual temperature. The soil is annually plowed to 25 cm. The experimental design (A-R type) consists of 21 treatments with 8 replications; plot size is 5mx6m. Crop rotation is cereal dominated.

Maximum yields were achieved with intermediate N supply. The maintainance of the orginal carbon stock level was achieved with high manure and optimized N input (N4). The unfertilized control and mineral only variant were characterized by decreasing carbon stocks.

A positive N balance of 3040 hg per ha proved necessary for the maintainance of the original carbon stock level. With regard to soil biodiversity, the abandonment of mineral N in the high manure treatment did not lead to increased diversity of soil biota. Modelling SOC dynamics with CANDY Carbon Balance (CCB, Franko et al. 2011), revealed relationships between soil biodiversity and certain carbon pools.

The long-term experiment V140/00 shows that sustainable intensification is no contradiction: high yields and carbon stocks may be achieved on sandy soil with a combination of mineral and organic fertilizer.

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How land conversion from C4 to C3 plants helps in quantitative estimation of C sequestration in soil and approaching 4 per 1000 initiative

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There is a vivid discussion concerning the validity of the proposed 4 per mille initiative in mitigating the impact of greenhouse gases emissions (GHG) (Minasny et al., 2017, Schiefer et al., 2017). Uncertainties in estimates of agricultural GHG emission potential and soil C sequestration are very high. Irrespective of the approach used to connect soil C stabilization mechanisms to dynamics of soil C stocks, the predictions must be compared to field data. We used a long-term field trial and ^{13}C stable isotope analysis to assess the turnover of soil organic matter and C sequestration potential after conversion of sugar cane to rubber plantation in Khon Kaen province, Thailand. This kind of conversion make a considerable contribution to the current land cover changes in South-East Asia (e.g. Yang et al., 2016). Soil samples were taken from 5-, 11- and 22-years-old rubber plantations as well as from a sugar cane field, which was cropped before this experiment. We measured carbon content and ^{13}C enrichment of the soil samples taken from 0-15 and 15-30 cm depth, as well as samples of leaf litter and roots of rubber trees. The differences in ^{13}C abundance for plants with C3 and C4 photosynthetic pathways (i.e. rubber tree and sugar cane, respectively) allowed the calculation of rubber derived C contribution to soil organic matter at the two soil depths. By this means, we compared rates of organic matter formation from leaf and root residues. Conversion of arable field to rubber plantation led to fast and significant increase in soil organic C content at both depths with new C3 – C contributing up to 54% and up to 20% in 22 years old rubber plantations for 0-15 cm and 15-30 cm soil layers, respectively. We conclude that rubber plantations significantly contribute to soil C sequestration in sandy soils thereby strongly exceeding the rate needed for reaching the 4 per mil level. This land conversion, however, has marginal significance in fulfilment of 4 per mil demands at regional and global level as can be seen from land cover change maps.

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Regional sensitivity and uncertainty analysis of a SOM modelling with aggregated cultivation data of Saxony

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Sound statements of modelling of SOM trends on regional scale rely heavily on the quality of the input data. Practically, on these scales it is not feasible to have genuine data for every field, and model inputs partly depend on estimates. Yet, we still have a knowledge gap about which input parameters should be quantified in better quality and which parameters may be roughly estimated.

Here, we will evaluate the sensitivity of the CCB model results about nitrogen mineralization and carbon storage on its input parameters using a comprehensive data set from 1998- 2014 consisting of six time slices which was provided by the Landesamt für Umwelt, Landwirtschaft und Geologie Sachsen (LfULG) (Witing et al. 2016). The agricultural area of Saxony was divided into almost 30.000 grid cells (500x500 m²) with individual soil and climate data.

A subset of 686 plots (so called Dauertestflächen), with original data of the cultivation and various SOC measurements, is used to cross-validate the aggregated data.

Since soil and climate can hardly be altered by man, and the data is available in sufficient high resolution and quality (BK 50 and ReKIS, both provided by the LfULG), the focus of this research is on the cultivation input parameters.

These parameters are (for now):

- intitial SOC content, - yields in general and - yield of cover crops in particular (since this can only be estimated), - amount of mineral fertilizer, - amount and - composition of organic fertilizer, - proportion of retained by-products, - amount of atmospheric nitrogen deposition

In a second step, we build a roadmap for further data improvements based on the uncertainties that are inevitably incorporated when generating such data set for regional scales.

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Controlling factor of carbon dynamics in grassland soils of Bavaria between 1989 and 2016

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The use of Random forest model showed that the complexity of storage of carbon (C) in grassland soils of Bavaria between 1989 and 2016 is affected by tree principal controlling factors: i) climate (such aslength of vegetation period, changes of winter soil moisture, changes of winter/summer precipitation/temperature)), ii) pedogenic and topography variables (soil type, pH and initial C content); and iii) management practices (organic fertilization). We found three different trends for the evolution of SOC stocks in the grassland soils: sites with high initial SOC stocks revealed SOC decreases, whereas sites with low initial SOC stocks revealed an increasing trend and sites without changes. In particular, mountainous grassland soils may become a source of greenhouse gas emissions under global warming due to large amounts of labile C. In this regard, aggregate-occluded and mineral associated C may play a key role in the mitigation of climate change. Nevertheless, few studies have focused on different soil organic matter (SOM) pools and their main controlling factors in mountainous grassland soils. Regard to this, we determined the principal mechanisms involved in the build-up and stabilization of different C pools using a promising physical fractionation method. This method enables the separation of five different SOM fractions by density, ultrasonication and sieving separation: fine particulate organic matter (fPOM), occluded particulate organic matter (oPOM>20µm and oPOM<20µm) and mineral associated organic matter (sand and coarse silt, > 20 µm; medium + fine silt and clay, < 20 µm). The final aim is the determination of a diagnostic fraction that can be used as an indicator for future C changes in mountainous grassland soils.

Carbon sequestration potential of compost application in agricultural soils

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Soil organic carbon (SOC) sequestration has been considered as a possible solution to mitigate climate change. Besides, as SOC content is regarded as a major indicator for soil quality and as its management is crucial for agricultural production, improved SOC management is required. Several strategies haven been identified to increase SOC content by which using organic amendments such as compost is considered to be the most obvious way. As compost can vary widely in composition and decomposability and hence its ability to store carbon, not all composts are of equal value. Therefore, six multiyear field experiments were established on sandy/silt loam soils at Ghent University – Department of Plants and Crops and ILVO to test different types of compost (i.e. vegetable, fruit and garden waste compost, farm compost, biochar-blended compost, municipal solid waste/green waste compost), application rates (i.e. yearly, every three year, one single application) and doses (1,9 – 10,9 Mg carbon ha^{-1} year^{-1}). After a given period of time (2-12 year), SOC stocks were determined in the compost and unamended control treatments of each experiment after which carbon sequestration rates were calculated. Depending on compost dose, type and application rate, carbon sequestration rates varied between 0,5 and 1,8 Mg C ha^{-1} year^{-1}. In addition, changes in SOC-stocks were related to the yearly carbon dose (by means of compost). Results indicate that when 1 Mg of carbon ha^{-1} year^{-1} is added to the soil by means of compost, approximately 0,26 Mg is retained in the soil as stable carbon. Finally, repeated compost application proved to be beneficial for a wide range of chemical, physical and biological soil properties.

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The utopian / illusionary initiatives like 4p1000 org to enforce apparently "permanent" C-, (N-, P-, S-) (im-)mobilisation ≠ sequestration in soil organic matter (SOM) as "negative emissions" to counteract i.e. climate change

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C-, N-, P-, S are both nutrient elements for the biosphere but their reactive compounds cause (in-)directly also as emissions /immissions above their critical levels and loads the environmental damages not only of climate change but also of eutrophication, acidification and decline of biodiversity. Sequestration i.e. of C, N, C, P, S as fossil coal (diamond), oil and gas are the results of former geological / tectonic processes (i.e. before 359 -299 millions of years, also during 60 millions of years in the Carbon) which cannot be managed by humans. – The utopia / illusion to fix C (N, P, S) likewise permanently by SOM (im-)mobilization will fail because:

1. These elements are (im-)mobilized only in (from) the decomposable (labile) SOM fraction (about 25% of total SOM).

2. Only for a short time (here in 4p1000org for 20-30 years) and

3. To sustain immobilization the need of additionally endless and, because of an only about 10% SOM efficiency (a.o. Körschens 2018), utopian amounts of organic primary matter (OPS) according to 0.5 – 4.4 fold actual net primary production (60 Gt C $\cdot$ yr^{-1} = 12.3 t C$\cdot$ ha^{-1} $\cdot yr^{-1}$) and likewise additionally both 1.1 – 10.0 fold higher N and 0.7 – 5.9 higher P input / deliveries (Tab.).

Comparable to CO_2 capture and storage (CCS) in the lithosphere such a C-, N-, P-, S (im-)mobilization functions as chemical time bombs (CTB) in respect to similar additional emissions of reactive C-, N-, P-, S- compounds. Therefore there is no alternative to the needed reductions of the C-, N-, P-, S-emissions, nearly to zero for C (decarbonisation not only of fossil C), and in respect to the emissions / immissions of reactive N, P, S compounds below the critical levels and loads of the nearly natural ecocystems latest before 2050. In respect to climate change as requirement to reach the level not more increase of atmospheric temperature than 1.5° C before the pre-industrial level.

Scenarios (2007-2016) (Agricultural Area = 4.86 $\cdot$ 10^9 ha)	4 p 1000.org (A / B) French Government / IPCC(2015) Compensation Atmospheric Increase: 1.3 (LULUC) / 3.8 Gt C $\cdot$ yr^{-1}	3 p 1000 .org (C) Compensation Atmospheric Increase: 4.7 Gt C $\cdot$ yr^{-1}	(D) Compensation Total human CO_2-Emissions: 10.7 Gt C$\cdot$ yr^{-1}
1. Soil depth [cm]	40 / 40	**100**	**100**
2. Actual SOC [Gt C]	300 / **950**	**1500**	**1500**
3. Additionally needed:			
3.1 Immobilisation [kg C $\cdot$ ha^{-1} $\cdot$ yr^{-1}]	250 / 780	980	2 200
[% actual SOC]	0.4	0.3	0.7
3.2 OPM [t dm $\cdot$ ha^{-1} $\cdot$ yr^{-1}]	6.2 / 19.5	24.2	55.1
[relative: actual = 1]	0.5 / 1.5	2.0	4.4
3.3 Relative Fertilizer Input / Delivery:			
3.3.1 N (actual: 22 kg N $\cdot$ ha^{-1} $\cdot$ yr^{-1}= 1)	1.1 / 3.6	4.5	10.0
3.3.2 P (actual: 3.7 kg P $\cdot$ ha^{-1} $\cdot$ yr^{-1}= 1)	0.7 / 2.1	2.7	5.9

Carbon inputs to agricultural soils in Germany

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Due to several international agreements on climate change abatement (UN Framework Convention on Climate Change, Decision 529/2013/EU of European Parliament and of the Council), Germany is in duty to report greenhouse gas emissions from agricultural soils. Moreover, enhanced carbon storage in soils can be accounted for as greenhouse gas mitigation strategies. For such reports and policy decision making, a harmonized, representative, and reliable database of soil carbon stocks was missing so far. Thus, the German Agricultural Soil Inventory started over in 2011 assessing soil carbon contents and stocks. A 8*8 km grid defined the 3100 sampling points under arable land, grassland and plantation crops. Soil carbon stocks are driven not only by site conditions but as well by agricultural management. The latter is decided by the farmer as crop residues left in the field or organic fertilizers spread. Moreover, the amount of crop residues depends on the yield harvested. Thus, management data and yield information for the sampling points are explored within the Agricultural Soil Inventory. To calculate carbon inputs into arable and grassland soils, several default data and models are known (e. g. Bolinder et al. 2007). However, these data are not specific for growing conditions and varieties used in Central Europe. In this study, we combined knowledge on carbon allocation within crops (Bolinder et al. 2007, Pausch & Kuzyakow 2018, Poeplau et al. submitted) with specific values on carbon content, dry matter content, and harvest indices of a broad literature research. Yearly mean carbon input into arable and grassland soils all over Germany were calculated for 2136 data points available. For 1676 arable soils, carbon input was 3.8 ± 1.2 Mg ha^{-1} a^{-1}, mainly derived from crop residues (83%) as the sum of harvest residues (1.2 ± 0.9 Mg C ha^{-1} a^{-1}), stubble (0.3 ± 0.1 Mg C ha^{-1} a^{-1}), and roots (1.6 ± 0.4 t C ha^{-1} a^{-1}). Organic fertilizers were used on 1057 arable sites and accounted for a carbon input of 0.7 ± 0.7 Mg C ha^{-1} a^{-1}. On 548 arable sites, catch crops were grown and accounted for a carbon input of von 0.8 ± 0.6 Mg C ha^{-1} a^{-1}. On 639 permanent grasslands, yearly mean carbon inputs to the soil was as high as on arable sites with 3.6 ± 1.2 Mg C ha^{-1} a^{-1} mainly (85%) as the sum of aboveground biomass residues including mulch (0.7 ± 0.6 Mg C ha^{-1} a^{-1}) and belowground inputs from roots (2.22 Mg C ha^{-1} a^{-1}). On 460 grassland sites, organic fertilizers or carbon input via grazing animals' excrements accounted for 0.9 ± 0.9 Mg C ha^{-1} a^{-1}. The contribution shall offer a discussion on agricultural management strategies to increase carbon inputs into soils.

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Tracing the origin of the remarkably stable organic Carbon in plaggic Anthrosols

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Until the invention of chemical fertilizers around 1900 AD, stable manure was used for centuries to fertilize poor sandy soils throughout large areas of North-Western Europe. The manure was produced in stables and consisted of a mixture of stable straw, animal (mainly sheep) droppings and sods. In spite of the abandonment of this agricultural practice over a century ago, the elevated organic C in the resulting plaggic Anthrosols still remains. Its remarkable stability is difficult to explain by the reigning paradigm of sorptive preservation and physical occlusion alone, and may be linked to unique combination of straw, heath sods and sheep manure that constituted the manure added to the land each year. Therefore, a key first step to study the dynamics and preservation of soil organic carbon (SOC) in these systems is to reconstruct the SOC input and subsequent (selective) preservation thereof.

Previously we showed that preserved plant derived *n*-alkanes and *n*-alcohols can serve as biomarker indicative of past vegetation cover and C input in soils (1). To study C input and subsequent SOC dynamics in Plaggic Anthrosols (2) we used a combination of such biomarkers and fossil pollen to examine the input of stable fillings used to produce plaggic manure in the plaggic horizon of several Plaggic Anthrosols. Pollen of *Calluna* was observed in all spectra of the plaggic horizons, biomarkers of *Calluna* only in the youngest. This suggests that large scale *Calluna* sod application only took place in last stages of the plaggic agricultural system, while other stable fillings were used before (2). However, even if other fillings than *Calluna* sods were used, sheep grazing occurred at least since the early Middle Ages. This means sheep droppings were always part of stable manure, and input of C, including biomarkers, via digestive tracts of animals must be taken into account. The favorite food of sheep are grasses, but at the end of the season when grasses become scarce, they also consume *Calluna* shoots. The question then arises: where did the *Calluna* biomarkers from the sheep droppings in the older parts of the plaggic horizons go? Did they not survive the digestive tract of sheep? Was *Calluna* derived C preferentially degraded in the soil? And what does this mean for the turnover of SOC in these old manured soils now and under future climate or land-use change?

In our presentation we will discuss these questions and their potential answers using our previously mentioned analyses of the molecular dynamics of SOC in Plaggic Anthrosols (2), combined with the results of on-going research where we analyze biomarker and pollen compositions of present day sheep droppings collected during one annual seasonal cycle.

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Relationship between soil structure and carbon dynamics in differently tilled soils: potential for a farmer`s tool ?

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Soil structure, the spatial arrangement of pores, organic and mineral material in soil, is recently receiving increased interest as main driver of soil processes (e.g. Rabot et al., 2018). Soil structure is one of the main indicators of soil fertility. With non-destructive X-ray computed tomography, methods are available for characterising soil structure qualitatively and quantitatively.

The DIWELA project aims to develop a farmer`s tool, based on soil structure, that will support to increase soil fertility on farmers' fields. Soil fertility is closely linked to soil carbon dynamics.

To develop the tool, as a first step we took undisturbed soil samples (from 12 – 3 cm diameter and height) in differently tilled soils, analysed them with X-ray computed tomography and quantified them with simple measures.

As expected, first results show clear relationships not only to soil management, but also to soil biodiversity (earthworms) and carbon dynamics. If further substantiated on different soils and climates, our approach shall lead to a farmer`s tool for assessing, understanding and hence improving, the soil fertility status of his soils.

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Carbon sink activity of managed grasslands

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In agriculture, a large proportion of GHG emission saving potential may be achieved by means of soil C sequestration. Recent demonstrations of carbon sink activities however, often questioned the existence of C storing grasslands, as uncertainty surrounding estimates are often larger than the sink itself. Besides climate, key components of the carbon sink activity in grasslands are type and intensity of management practices.

Here, we analysed long term data on C flux and soil organic carbon stocks for two long term sites (>13yrs) of a national observatory in France (SOERE-ACBB). These sites comprise a number of grassland fields and managements options (e.g. old vs young grasslands, grazing, mowing, and fertilization) offering an opportunity to study grassland properties (i.e. plant functional types, rooting, litter, …) in relation C sequestration potential, climatic-management interactions and trade-offs.

Carbon sink activity was compared using two methods; repeated soil inventory and estimation of the ecosystem C budget by continuous measurement of CO2 exchange (i.e. eddy covariance, EC Technique) in combination with quantification of C imports and exports. Furthermore to assess the becoming of sequestrated C, soils were analysed in details, i) for their soil organic matter pools (i.e. labile, passive, inert; Zimmermann et al method) and ii) spatial distribution of soil C stocks at field scale.

According to soil inventories and EC technique, grasslands were a net sink of C once established for >3year. Soil inventories provided evidence that C was mostly stored in deeper soil layers (20-60 cm) whereas top soil C stocks were more vulnerable to management practices. Fractionation of soil organic matter revealed temporal changes between soil C pools and soil layers i.e. humidified C pool declined and inert, stable soil C increased between two inventories (5yrs). Moreover, spatial analyses of soil C stocks showed that grazing intensity and grazing *vs* mowing had a significant effect on the spatial distribution of soil carbon stocks.

With regard to CO_2 exchanges, all grasslands were potential sink of C (i.e. net ecosystem exchange, NEE), where grazed sites had lower net exchange compared mown site. However, when it comes to full C balance (e.g. net C storage, NCS), mowing reduced markedly potential sink leading to very low NCS compared to grazed sites. Which underlined the trade-off between intensity of biomass removal (i.e. removal of photosynthetic tissue, litter and root production) and C inputs for C sequestration. Analyses of CO_2 exchanges were in line with soil inventories with measurements, when analysed in the long term (>5yrs measurements).

Effects of tillage practices on net farm returns (profits)

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Various tillage practices are some of the most widespread, costly, and important (in terms of yield) inputs for agricultural systems as well as some of the most promising for managing soil organic carbon (SOC) storage in croplands. While many studies have looked at effects of these agricultural practices on SOC and net return (profits), a comprehensive understanding of how these effects vary across climate and soil variables is lacking. Such understanding would be imperative for achieving greater carbon sequestration in agricultural lands without negatively affecting food production.

We assessed how differences in net farm returns resulting from different tillage practices vary with climate and soil factors. No-till and reduced tillage often resulted in smaller returns to the farm than conventional tillage, though not always. The difference between no-till and conventional tillage were more positive in more humid climates than in drier climates. The studies took place on a narrow range of soil texture types, reflecting the fact that annual crop farming tends to occur on loamy soils. Perhaps for this reason, soil texture had less explanatory power in our model than climate did. Switching to no-till on continuous corn was more costly than other crops. Social variables such as price of fuel and whether the farmer would be a partial adopter of no-till (i.e. the farmer would still keep equipment for tillage for other plots on the farm) also affected the difference in net return between tillage practices.

We combine our meta-analysis on net farm returns with similar efforts on SOC sequestration to identify areas that give the greatest carbon sequestration for the cost of shifting agricultural practices.

Calculation of field SOC stocks based on high-resolution soil texture maps

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Soil texture and soil organic carbon (SOC) are fundamental soil properties relevant for many agricultural applications. Determination of these properties by conventional, laboratory based methods is time-consuming and expensive. Therefore, different soil proximal sensors were tested to measure these properties or relevant co-variables directly in an EU-funded project (*pH-BB,* http://ph-bb.com/).

Here, the focus is on the relation between soil texture and SOC stocks. Soil texture maps were based on the application of the Geophilus soil profile mapper. This measurement system predicts the apparent electrical resistivity (ERa) of six different soil depth levels and the top soil-born gamma activity (Boenecke et al. 2018).

The test site was a 22 ha field in Wilmersdorf in the north east of the federal state of Brandenburg, where this study was conducted on August 1st 2017 within the pH-BB project. Thirty field samples (0-25 cm) were taken and lab-analyzed for soil texture soil organic matter.

We calculated high resolution soil texture maps by applying the co-variables ERa and γ in (multi-) linear regression models for the target variables clay, silt and sand. Results were validated with a leave one out cross validation and results showed an adj. R^2 between 0.65 and 0.83 and a root mean square of 1.6 to 2.5 (weight-%).

To model the SOC stocks, the CANDY submodel CCB SOC was used (Franko et al. 2011). We applied CCB in an inverse way to estimate the carbon input that corresponds with the observed SOC concentrations of the soil samplings. This calibration procedure was supported by repeated cross validations where the 30 observations were randomly split into two groups of 15.

Based on a high resolution map of top soil texture, the result of this calibration (C_{rep}=1048±66 kg/ha) was applied to model SOC concentration and the related bulk density for the whole field. This allowed for an estimation of the total carbon storage in the topsoil (1160±90 t) as wells as the spatial distribution of the SOC concentration (0.5 -1.65). The latter value may be used together with other information as input for further tools.

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Soil Organic Carbon stocks in French mown old grasslands: What are the drivers?

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Grasslands represent the most widespread ecosystems on the surface of the earth and provide many ecosystem services. They are managed by farmers to produce provisioning services through forage production. They provide also regulation services such as carbon (C) storage. P^2C “Plant Pilot Carbon” project aims at understanding the determinism of C stocks in mown permanent grasslands. It aims to identify which of vegetation composition, plant community functioning, climatic and edaphic conditions, management or land cover history drive the Soil Organic Carbon (SOC) stocks.

32 permanent grasslands (aged >40 yr) were selected among over two French Regional Natural Parks (Normandy-Maine / Lorraine) and an experimental farm (ACBB SOERE, Theix, Auvergne). At selected grasslands, a constant land management (mowing and fertilization at different intensities) was applied since 1 to 40 years (i.e survey was conducted among farmers to acquire management and land use history data). In 2016, grasslands were sampled, and soil texture and chemical properties, as well as soil C stocks were analyzed at the top soil (0-10 cm) and deeper soil layer (10-30 cm). Hot Water soluble C (HWC), corresponding to the labile fraction of SOC, was used as an index of C dynamics. Finally, to link vegetation status to soil C stocks, plant community composition and functioning was assessed through leaf functional traits before the first cut. To determined C fluxes and C allocation between atmosphere-plant-soil system, a controlled pulse ^{13}C labelling experiment was carried, using monoliths collected in 6 grasslands (out of the 32) of contrasted clay content (high vs low clay content).

All stations were old mesic temperate grasslands, managed by low-intensity mowing and fertilization. We found a wide range of SOC content (2.3 to 11.6% of the dry mass) and bulk density in the top and lower soil, leading to a large range of SOC stocks (42 to 153 kg C/ha, 0-30cm). Taking into account the floristic, climatic, edaphic and management parameters, SOC stocks were affected by clay content<pH<management. HWC as an index of soil carbon dynamics appeared to be related to SOC. The higher the SOC, the less organic C dynamic is.

The first results of the ^{13}C experiment indicated rapid transfer of C assimilated through photosynthesis to soil, while no obvious effect of clay content on C fluxes was observed. ^{13}C signature of plant and soil fractions of monoliths 1, 3 and 12 weeks after the 5-days labelling are still under investigation.

Assessment of the role of biowaste compost for SOC reproduction in German agricultural soils

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In a project on behalf of two organisations of the German compost and soils substrate industry (VHE – Organisation of Humus and Soil Industry, BGK - Federal Compost Association) we have analysed the role of compost from biowaste in German agriculture. Further, we have investigated patterns of regional and farm-type specific distribution of compost, and impacts of the recent amendment of German fertilizer legislation.

Compost from biowaste contributes currently only 2.2 % to the 'calculatory humus reproduction' in the German agricultural sector, according to the methodology of VDLUFA (2014). Sewage sludge adds another 0.5 %. Compared to this, organic manure from livestock and biogas production as well as crop residues are much more important for humus reproduction. The share of compost and sewage sludge to total nitrogen inputs into German agricultural soils is about 1 %, and for phosphorous 4 %. These figures show that for the maintenance of soil organic carbon and for recycling of nutrients, compost and sewage sludge play only a minor role in German agriculture.

On the other hand, about 80 % of total German biowaste compost is applied in agriculture. For sewage sludge, the share used in agriculture is still at 25 %. However, a phasing-out strategy for agricultural applications of sewage sludge has entered into force in 2017, combined with strengthening P recovery. While for the agriculture sector, N, P and C inputs from compost are of minor importance, for the biowaste industry the compost use in agriculture is essential. Further, a survey of enterprises producing and selling compost showed that biowaste compost is mainly applied in crop and vegetable farms as a means of SOC reproduction. Thus, compost plays a crucial role also under specific farm conditions.

The new fertilizer legislation in Germany sets limits for N inputs per crop and for average N surplus per hectare. As N in compost is not directly available for crop growth, compost inputs tend to crucially increase the farm N surplus. As a consequence, the new legal rules for mineral accounting represent a disincentive for compost use in German agriculture.

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Livestock management regulates soil organic carbon storage in interaction with factors acting at regional to ecosystem scales in grasslands from the Pyrenees

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Pyrenean grasslands are largely affected by climate change and experienced important changes in livestock management in the last decades, with decreasing stocking rates, and cattle replacing sheep (Lasanta *et al.*, 2017). Grazing management affect multiple components and processes on grassland ecosystems, including aboveground biomass or soil organic carbon (SOC). Moreover, grazing effects can change depending on other environmental factors (Zhou *et al.*, 2017). As grasslands are an important soil carbon store (Follett & Reed, 2010), establishing how grassland management affects SOC depending on different conditions is extremely relevant to predict future grassland soil C losses (Liu *et al.*, 2015). We modelled SOC content in mountain grasslands of the Pyrenees. We built general linear models explaining SOC, using a set of 26 predictors. On the other hand, we performed Path Analysis including regional (climatic), landscape (topographical) and ecosystem (soil and herbage productivity and quality) and management predictors. We developed multiple groups according to grazing species and grazing intensity. Management variables showed strong interactions with all other variables, supporting the assumption that management affects grassland ecosystems at multiple scales.

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Deep soil flipping increases carbon stocks of high productive pastures on New Zealand's West Coast

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Sequestration of soil organic carbon (SOC) is recognised to significantly off-set global atmospheric carbon dioxide emissions. Most of published studies focused on topsoil SOC while the subsoil (bellow 30 cm) is mostly not considered. The subsoil, however, has a great potential to sequester large amounts of SOC due to an increased saturation deficit. To create high productive grazing pasture on highly podsolized soils on New Zealand's West Coast, flipping (deep full inversion to 50-300 cm) is widely used to break iron pans to prevent waterlogging constraints. Flipping results in burial of SOC rich topsoil into subsoil regions and the translocation of subsoil material to the top; which were reported to rapidly accumulate SOC within ten years. This study address three hypotheses: (i) flipping increases total SOC stocks through burial of topsoils and SOC accumulation in "newly" formed topsoil; (ii) topsoil SOC stocks re-establish within 20 years since flipping to pre-flipping values; (iii) the burial of topsoil results in preservation and stabilisation of SOC. Soil flipped 3-20 years ago were sampled (0-240 cm) for a chronosequence of SOC stock changes. Furthermore, previously sampled topsoils were re-sampled after 10-12 years. Incubation (72 h) and physio-chemical fractionation was used to determine SOC degradability and stability in recent and buried topsoils. Flipped subsoils contained 73 ± 3 % of total SOC while un-flipped topsoils contained more than two-third in the upper 0-30 cm. Total SOC stocks (0-150 cm) were increased by 69 ± 15 % (179.1 ± 39.7 Mg SOC ha^{-1}) following 20 years of flipping compared to un-flipped soils. Topsoils burial caused an on-time sequestration of 159.9 ± 14.1 Mg SOC ha^{-1} in depth of 30-150 cm and preservation as subsoil SOC stocks did not change significantly with time since flipping. In 0-30 cm depth, the chronosequence revealed sequestration of 3.6 Mg SOC ha^{-1} a^{-1}, resulting in similar stocks of un-flipped soils and soils flipped 20 years ago. However. the chronosequence and re-sampling showed SOC accumulation rates of 1.2-1.8 Mg SOC ha^{-1} a^{-1} in 0-15 cm and a deficit of 36 ± 5 % after 20 years. Indicating further accumulation for ~16-25 years until un-flipped topsoil SOC stocks are reached. Labile SOC fractions were accumulated in 0-15 cm with time since flipping and contributed to 40% of total SOC similar to un-flipped soils. Subsoils after 20 years of flipping contained 32 % labile SOC but basal respiration decreased with time since flipping, indicating a potential preservation of labile SOC with burial. This study confirms that burial of SOC and the exposure of SOC depleted subsoil results in an overall increase of SOC stocks of the whole soil profile and deep soil modification can be considered as a mitigation option of the global climate change by sequestering relevant quantities of atmospheric carbon.

Can the thermal stability of soil organic matter reflect disturbance and resilience in rubber tree-based agrosystems?

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The capacity of soils to mitigate climate change through carbon sequestration depends on the quantitative but also the qualitative changes in soil organic carbon (SOC). In particular, the stability of SOC has to be considered to evaluate the long-term fate of the soil carbon stocks. The aim of this study was to assess the accurateness of thermal analyzes (Rock-Eval pyrolysis) to monitor the evolution of SOC quality and quantity in different land management situations. Using new I/R diagram (Sebag et al., 2016), dynamics of SOC was assessed in rubber tree-based agrosystems in Thailand. This case study allowed analyzing the changes in SOC properties after land use change (cassava to rubber) and over the ageing of the rubber plantation (up to 25 years). Soil from secondary forest plots were included in the study as a reference of an undisturbed system. While I (contribution of fresh OM) and R indices (global thermal stability) were well correlated in forest soils, our results show a higher I value in cassava field, and increasing R values with rubber plantation age. These results indicate that both SOC stocks and SOC stability increased with the age of plantations. However, R-index in the oldest rubber plantations was lower than in forest. Finally, this study highlights the potential of thermal analyses for monitoring SOC quantity and quality with promising application under the 4‰ initiative.

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4 per 1000 – What can we learn from the erosion-carbon nexus?

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The 4per1000 initiative aims to an enhanced C sequestration into soils. A significant and sustainable effect can only be achieved in soils being unsaturated in SOC, hence in soil systems far from equilibrium. Basic principles can be tested in soils affected by erosion since this process brings unsaturated subsoil to the surface (Doetterl et al., 2016). We studied the magnitude, rates and mechanisms of C sequestration at eroded croplands of the field-scale manipulation experiment CarboZALF-D in NE Germany (Sommer et al., 2016). In our manipulation experiment (autumn 2010) with artificial erosion / deposition in a hummocky ground moraine (Deumlich et al., 2017) we study the dynamics of all C fluxes (NEE, C export, DOC/DIC) to derive full C balances (= Δ SOC) for several years (Hoffmann et al., 2017). To unravel the mechanisms of assimilate distribution in topsoils of an eroded and non-eroded site we set up a ^{14}C tracer study (CO_2 pulse labelling, 25 d) with maize (Remus et al., 2018). After 6 years of manipulation the SOC stock increased by 0.9 kg C m^{-2}. We observed very high mean C sequestration rates of 144 g C m^{-2} y^{-1} at the eroded cropland site (Calcic Luvisol) showing a tendency of decreasing rates after 3 years. The lab experiment revealed a very fast and surprisingly high plant C transfer (rhizodeposition) into the most protective SOM fraction (eroded site ~ 2x non-eroded site). Our study on eroded soils proved the concept of a high, fast and (probably) sustainable C sequestration in soils being unsaturated in C. The same effect will be achieved by a controlled admixture of subsoils with a high C saturation deficit into Ap horizons. Dedicated tillage systems will be developed and tested in near future to achieve a sustainable C sequestration without a loss of soil fertility.

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The SOCORT consortium: Does conversion to conservation tillage really increase soil organic carbon stocks in organic arable farming?

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Aggravation of weather extremes increases awareness of climate change consequences. Mitigation options are in demand which aim to reduce the atmospheric concentration of greenhouse gases. Amongst others, the conversion from ploughing to conservation tillage is argued to increase soil organic carbon (SOC) stocks as an accumulation of SOC in topsoil layers is commonly reported. Yet, main findings of reviews and meta-analyses that compare SOC stocks between conservation tillage and ploughing changed over time: from a significant increase of SOC stocks to the question if there is any effect at all (Powlson et al., 2014). The reason for this change is a sampling bias as in many campaigns only topsoil layers were assessed. Apart from sampling depths, there are also other constraints in the assessment of SOC stocks including different methods for SOC and bulk density determination (Walter et al., 2016), and the comparison of SOC stocks based on equivalent soil masses instead of equal sampling depths (Powlson et al., 2014).

In order to address these limitations, we initiated the SOCORT consortium (Soil Organic Carbon in Organic Reduced Tillage) – an international network of nine longterm trials. All trials represent common mixed organic farming systems of the respective region with organic fertilisation and crop rotations including leys. While climatic conditions are similar, soil types vary from sandy to clayey soils. A common sampling campaign (constant staff and methods) was consequently elaborated to answer the question if the combination of conservation tillage and organic farming can really increase SOC stocks. Undisturbed soil cores were taken with driving hammer probes (8 cm in diameter) to a maximum depth of 100 cm. All samples are then analysed in the same laboratory. Bulk density is calculated and corrected for compaction according to Walter et al. (2016). Beside agronomical data, soil texture and pH are determined on pooled samples as covariates and yields are compiled for each trial to assess carbon inputs. The SOCORT consortium in combination with the common sampling campaign has a large potential to entangle the driving factors of carbon sequestration through reduced tillage and add important knowledge on carbon dynamics in agro-ecosystems.

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Cropland soils in China have a large potential for mitigating CO_2 emissions based on literature survey

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The carbon sequestration of soils, has been of key concern, particularly since the 4 per mil initiative was launched in COP21 in Paris. Here, by literature survey we try to understand three important questions: how did soil organic carbon (SOC) stock change in croplands of China during the past decades? What are the agronomic management practices and their potentials to increase the SOC of croplands in China? And how do changes in the SOC affect crop yields? The analyses showed that the SOC stock in Chinese croplands had increased on average by 0.22% yr^{-1} from 1980s to 2000s. The increase was significant in the eastern and northern China, and particularly in the paddy soils in southern China; however the SOC decreased in the northeastern China. The increase of the SOC was attributed to substantial increase in crop yield, the amendments of crop residues and organic manure, the increase in synthetic fertilizer application and the optimal combination of nutrients, as well as adopting no-tillage practice. Increase in the SOC can increase crop yield and reduce yield variability. Additional means to enhance mitigation of climate change by soil carbon sequestration could be application of biochar, and improvement of synthetic nitrogen use efficiency through disseminating formula fertilizer application based on soil testing, optimized application of inorganic and organic fertilizers associated with the extension of conservation tillage. Currently, the straw return ratio has reached 50%, whereas organic fertilization and conservation tillage (about 6.6%) are still at relatively low levels, the recommended management practices can be further extended to the regions with degraded soils and high population pressure. Further implementation of the recommended management practices on Chinese croplands would increase the SOC stock in China by ≥25.0 $TgCyr^{-1}$ or 0.63% yr^{-1}, compensating for Chinese CO_2 emissions by ≥1.0%. In conclusion, Chinese croplands can meet the 4 per mill target and play a crucial role in food security, carbon sequestration and GHG mitigation.

Biofunctool®: a new framework to assess the impact of land management on soil quality

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The assessment of soil quality is a scientific issue that has been widely debated in the literature for the last twenty years. We developed the Biofunctool® framework to assess soil quality based on an integrative approach that accounts for the link between the physico-chemical properties and the biological activity of soils. Biofunctool® consists of a set of twelve in-field, time- and cost- effective indicators to assess three main soil functions: carbon transformation, nutrient cycling and structure maintenance. Firstly, a reliability, redundancy and sensitivity analysis was performed to validate the capacity of the set of indicators to assess the impact of land management on soil quality. The results showed the relevance and consistence of each of the twelve indicators to assess the soil functioning. Secondly, we applied Biofunctool® to assess the impact of various land use contexts and agricultural practices on soil quality. In order to consolidate the information gathered by all the indicators, we aggregated it through a Soil Quality Index. The Biofunctool® index was applied in rubber tree plantations along three study sites in Thailand, as well as in forests and intensive cash crops to cover various land use changes and management practices in various pedo-climatic contexts. The results were analyzed site by site to investigate the impact of land use change, management practices and rubber stand ages on soil quality. The results proved that Biofunctool® index can provide an aggregated synthetic soil functioning score that is sensitive to land management and is robust in various pedo-climatic contexts. First, the index revealed the impact of the conversion from annual crop to rubber plantations and order rubber plantation regarding to a natural forest reference. Then, it showed the positive effect of legume cover-crop on the soil functioning. Finally, it highlighted a similar improvement of the soil quality with the age of rubber plantations in contrasted pedo-climatic contexts. Therefore, the Biofunctool® index is a reliable and relevant descriptor of the soil integrated functioning, i.e., soil quality, and could be included in more global approaches of environmental impact assessment.

Detectability of organic amendments in soil organic matter using thermal decay dynamics

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Sustainable soil management requires a reliable and accurate monitoring of changes in soil organic matter (SOM). However, despite the development of improved analytical techniques during the last decades, there are still limits in detection of small changes in soil organic carbon content and SOM composition. This study focused on the detection of such changes under laboratory conditions by adding different organic amendments to soils. The carried out model experiments consisted of artificial mixing soil samples from non-fertilized plots of three German long-term agricultural experiments in Bad Lauchstädt (silty loam), Grossbeeren (silty sand) and Müncheberg (loamy sand) with straw, farmyard manure, sheep faeces, and charcoal in quantities from 3 to 180 t ha^{-1} each. In these mixtures we determined the organic carbon contents by elemental analysis and using dynamics of thermal mass losses (TML). The results confirmed higher reliability of elemental analysis comparing with TML for organic carbon content determination. The sensitivity of both methods was not sufficient to detect the changes in organic carbon content caused by small quantities of organic amendments (3 t ha^{-1} or 0.1 - 0.4 g C kg^{-1} soil). In the case of elemental analysis, the detectability of changes in carbon content increased with quantities of added amendments. The dynamics of TML allows temperature dependent discrimination of different types and quantities of organic amendments. For example, added charcoal was not visible in TML from 320 to 330 °C, which is used for carbon content determination. However, increasing quantities of charcoal were reflected in a higher TML around 520 °C. Furthermore, differences between measured and predicted mass loss on ignition were confirmed as a suitable indicator of changes in the composition of organic amendments in different soil types. We conclude that thermogravimetry offers sensitive detection of changes in soil organic matter composition in practical land use.

Conservation agriculture can store carbon in soil

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Conservation agriculture (CA) is typically claimed to mitigate climate change, but this system is not common in Europe. CA occupies only 5% of total agricultural area in Europe, and it can be adopted for conventional as well as for low-input and organic farms. CA implies minimum soil disturbance, permanent soil cover, crop rotation and intercropping. Model-based comparative assessments of SOC dynamics in CA and traditional cropping systems were performed by using a dynamic simulation model ARMOSA (Perego et al., 2013). We simulated SOC changes during 20 years under different cropping systems, cultivated in Italy and Finland (Table).

Table. Simulated SOC changes in different cropping systems.

Cropping system[1]	Tillage	Cover crop[2]	ΔSOC (kg ha^{-1}y^{-1}) Silage maize (Italy)	ΔSOC (kg ha^{-1}y^{-1}) Barley (Finland)
Conventional	+	–	-610	28
Conventional with cover	+	+	-150	355
CA 1	Minimum	+	-60/200R	**460**
CA 2	Minimum	–		250
CA 3	–	+	410R	**490**
CA 4	–	–		**510**
Organic	+	–	13R	220
Organic with cover	+	+		**650**

[1] All systems with except for organic received mineral and organic fertilization.
[2]Rye as cover crop for maize; Italian ryegrass was undersown in barley.
R, Rotation with wheat and soybean.
Bold numbers indicate the achievement of the 0.4‰ objective.

For silage maize cultivated in Italy, the model demonstrated a decline in SOC under conventional system, and no-tillage with rotation and cover crop was the most effective measure to increase SOC. In contrast, for Finnish spring barley, conventional system caused no decline in SOC, and any CA systems increased SOC, among which no-tillage with or without cover crops was the best option, reaching the 4‰ objective. In addition, organic barley with cover crop may be a good option to increase SOC in Finland.

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The ‘4 per 1000 : Soils for food security and climate‘ initiative

The international scientific and cooperation program

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The ‘4 per 1000: Soils for Food Security and Climate’ initiative, launched at COP 21 in Paris, aims to increase food security, mitigate and adapt to climate change through carbon sequestration in agricultural and forest soils, based on the results of scientific research. This international multi-stakeholder initiative consists of an action plan and a scientific and cooperation program. The 4 per 1000 action-oriented research program aims to address knowledge gaps to best enhance global SOC stocks, while also ensuring food security; to provide evidence-based options for stakeholders; and to facilitate the development of national policies. This requires a multidisciplinary and integrated approach. This program develops by strengthening complementarities and synergies among the international scientific community. The Scientific and Technical Committee (STC) of the Initiative has recommended research priorities grouped in four pillars: 1) Estimating the soil organic carbon (SOC) storage potential, 2) Developing management practices, 3) Defining the enabling environment and 4) Monitoring, reporting and verification (4 per 1000 STC, 2017). It has been shown recently that the 4 per 1000 target, calculated relative to global top soil SOC stocks, is consistent with literature estimates of the technical potential for SOC sequestration (Soussana et al. 2017). Moreover, recent studies show the link between the increase of SOC sequestration in agricultural land and food security in a 1,5°C scenario (Frank et al. 2017). Socio-economic constraints influencing the adoption rate, the permanence of carbon storage in soil and the duration of improved soil management practices bring uncertainties on the capability to reach the 4 per 1000 target that still have to be assessed.

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Modelling long term effects of different nitrogen fertilization levels in a crop rotation on a light sandy soil

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Process-oriented models provide a useful tool to examine the relation between agricultural management practices and soil organic matter dynamics. We use a long-term field experiment (LTFE) at Müncheberg/Germany running since 1963 to simulate the effects of different levels of organic and mineral fertilizer inputs on interactions between soil organic matter, crop yields and nitrogen balance components. The light sandy soils of the LTFE are characterized by the presence of fine texture components of 7.7% to 19.0% in the upper soil layer. Accordingly, the capacity of the topsoil to bind organic carbon to silt and clay minerals is correspondingly low and is between 6,939 mg kg-1 and 11,120 mg kg-1. The comparative simulations conducted with different process models (HERMES, MONICA) compare different pool-based approaches. It is recognized that models' response to varying site conditions is not initially equal. In addition, the opportunities to calibrate the models are considerably influenced by their complexity and flexibility. Differences in model performance occurred, for instance, in relation to the hydrological sub-model and the carbon and nitrogen approach. While nitrogen dynamics in the MONICA model are strongly related to the defined carbon pools, and hence require intensive calibration to specific site conditions, the more simple approach of the HERMES model allows for a more flexible adaptation. Inter alia HERMES focusses on a net-N-mineralisation approach which is linked to soil organic carbon via the C:N ratio. However, both models provide with satisfactory results after calibration. In this regard, it is interesting to note that the simplified algorithm recently implemented in the HERMES model to derive soil organic carbon reflects the observed trends in the simulation of the long-term field experiment (LTFE). Based on the historical simulations predictions under different projected climate change scenarios were performed to evaluate the potential of carbon sequestration under changing boundary conditions.