EJP SOIL
European Joint Programme

Annual Science Days 2024

BOOK OF ABSTRACTS

Block B

B1 Carbon sequestration and trade-offs

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B1 Carbon sequestration and trade-offs

Session Description

Involved projects: INSURE, TRACE-SOILS, SOMMIT

Conveners: Felipe Bastida, Cristina Aponte, Eugenio Diaz-Pines, Kristiina Lång

The improvement of soil carbon (C) sequestration while reducing GHG emissions is a strategic target to mitigate climate change in agricultural lands. This can be pursued through a large range of management strategies, including minimizing soil disturbance, diversification of crop rotations, use of cover crops, incorporation of crop residues, addition of organic amendments, rewetting of organic soils, etc. Further, the increase of soil organic carbon stocks has a variety of co-benefits, beyond climate change mitigation, including improvement of soil health, fertility and water holding capacity. However, the environmental context, including biotic (biodiversity, microbial activity, crop type, etc.) and abiotic (soil physical and chemical properties, climate, etc.) factors can strongly shape the balance between C sequestration, CO_2, N_2O and CH_4 fluxes, and N leaching. For instance, in cultivated peat soil warming is expected to intensify organic matter degradation and further reduce C-sequestration, while contributing to GHG release. In more arid environments, the application of organic amendments can improve carbon sequestration while impacting the GHG fluxes.

In this session, we welcome contributions that give insights into how soil management influences C sequestration rates and non-CO_2 GHG fluxes in agricultural lands. We welcome experimental, modelling or synthesis approaches addressing the causes and mechanisms of the observed trade-offs and/or synergies between GHG release and soil C sequestration. The session will be convened by scientists participating in projects within the European Joint Programme Cofund on Agricultural Soil Management.

Effectiveness of soil management strategies for mitigation of N_2O emissions in European arable land: A meta-analysis

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Soil management strategies involving the application of organic matter (OM) inputs (crop residues, green and livestock manure, slurry, digestate, compost, and biochar) can increase soil carbon storage but simultaneously lead to an increase in non-CO_2 greenhouse gas (GHG) emissions such as N_2O. Although multiple meta-analyses have been conducted on the topic of OM input impacts on GHG, none has focused specifically on European arable soils. This study plugs this gap and can assist policymakers in steering European agriculture in a more sustainable direction. The objective of this meta-analysis was to quantify how OM inputs of different nature and quality, but also the application strategy, can mitigate soil N_2O emissions in different pedoclimatic conditions in Europe.

We quantitatively synthesised the results of over 50 field experiments conducted in 15 European countries. Diverse arable crops, mainly cereals, were cultivated in monoculture or in crop rotations on mineral soils. Cumulative N_2O emissions were monitored during periods of 30 to 1,070 days in treatments, which received OM inputs, alone or in combination with mineral N fertiliser; and in controls fertilised with mineral N.

The overall effect of OM inputs had a slight tendency to reduce N_2O emissions by 10% (*n*=53). With the increasing carbon-to-nitrogen ratio (C/N ratio) of the OM inputs, this mitigation effect became more pronounced. In particular, compost and biochar significantly reduced N_2O emissions by 25% (*n*=6) and 33% (*n*=8) respectively. However, their effect strongly depended on pedoclimatic characteristics.

Regarding the other types of OM inputs studied, a slight N_2O emission reduction can be achieved by their application alone, without mineral N fertiliser (by 16%, *n*=17). In contrast, their co-application with mineral N fertiliser elevated emissions to some extent compared to the control (by 14%, *n*=22).

We conclude that among the seven OM inputs studied, the application of compost and biochar are the most promising soil management practices, clearly demonstrating N_2O emission reduction compared to mineral N fertiliser. In contrast, other OM inputs had a small tendency to mitigate N_2O emissions only when applied without mineral N fertiliser.

Keywords: climate change mitigation; effect size; nitrous oxide; organic matter inputs; pedoclimatic characteristics

The effect of conservation agriculture interventions on greenhouse gas emissions in European temperate systems

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There is widespread interest in how conservation agriculture (CA) interventions (zero or minimum tillage (ZMT), retention of organic residues, diversification of cropping systems), adapted for local conditions, might increase the sustainability of arable systems. While evidence suggests that CA may increase the resilience of crop yields to climate variations and improve soil health, the impact on greenhouse gas (GHG) budgets remains uncertain.

A consortium of researchers is seeking to contribute substantively to the evidence base on the impact of CA on carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions in systems in Europe and sub-Saharan Africa (EJP SOIL External project: *CropGas*). We present some of our initial findings from temperate systems in Europe, focussing on the tillage aspect of CA.

Using established experiments with contrasting tillage treatments at Rothamsted Research (UK), Lyons Research Farm (Ireland) and Brody Research Station (Poland), we measured GHG emissions, contributing soil properties, crop yields and meteorological data over 12-month monitoring periods. With a particular interest in N_2O emissions, N fertiliser was withheld from small areas of experimental plots for emission factor calculation.

Patterns in GHG emissions were typically variable in space and time, being affected by seasonal weather patterns, fertilisation, and tillage. In the UK, CO_2 and N_2O emissions were increased significantly by fertilisation and non-significantly by tillage compared to ZMT. In Ireland, N_2O and CO_2 emissions were greater under tillage following a first and second fertilisation, respectively, compared with ZMT. Taken as a cumulative flux, however, CO_2 and N_2O emissions were greater under ZMT than tillage in the Ireland experiment. In Poland, greater CO_2 emissions from conventional tillage were observed in autumn, with some suggestion that N_2O emissions were lower under ZMT. In all experiments, CH_4 emissions were negligible and not affected by tillage.

Tillage effects on soil physical properties were observed. In both the UK and Ireland, soil under ZMT had a greater overall porosity, and a smaller water-filled pore space (degree of saturation) compared to conventional. This latter observation is important as it relates to the potential for denitrification and production of N_2O in wetter anaerobic soils. Water retention in unsaturated soil is important, and ZMT was associated with greater water retention in both the UK and Poland experiments. Also in Poland, there was greater C and ammonium-N, but smaller nitrate-N, in soils under ZMT.

Effects of tillage on crop yields were mixed, being little affected in the UK experiment, but greater (and with greater grain N concentration) under conventional tillage in the Ireland experiment. Improvements to the physiological condition of crops under ZMT were observed in the Poland experiment.

Data processing from the UK, Ireland and Poland experiments, and the complementary experiments in sub-Saharan Africa, is on-going and will be supported with further assessment of the effect of CA on soil chemical and physical properties. Modelling will help us to identify the key processes in the management-soil interaction which determine GHG production and will allow us to evaluate the potential role of CA in mitigation strategies with associated trade-offs.

Keywords: zero or minimum tillage; crop rotations; field experiments; nitrous oxide; soil structure

Policy measures effectively reduce soil nitrous oxide emissions with minor trade-offs in crop yield

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Nitrous oxide (N_2O) emissions are closely linked to agricultural fertilisation. European and national policy incentives have been set to reduce greenhouse gas (GHG) emissions; however, only a few evaluations have been conducted. Avoiding such emissions is an important climate change mitigation measure, but it is still uncertain which management measures over a long-term, best out-balance crop yield and GHG balances in agricultural systems. We here used the process-based LandscapeDNDC model to simulate N_2O emissions and trade-offs in yield and soil nitrogen budget for four alternative arable crop- ping systems in three Austrian agricultural production zones belonging to different climatic regions. We evaluated statistical data on crop rotations and management practices, predominant soil types, and 10-year daily weather conditions for four cropping systems: (1) conventional farming receiving the maxi- mum allowed nitrogen fertilisation rate (*Nmax*), (2) conventional farming receiving 15% less fertiliser, (3) conventional farming receiving 25% less fertiliser, and (4) organic farming. Our results showed that soil N_2O emissions could be best reduced in wet, high-yield regions. Reducing nitrogen fertilisation by 15% and 25% mitigated N_2O emissions by, on average, 22% and 39%, respectively, while the yield was reduced by 5% and 9%, respectively. In comparison, the same crops grown in the organic cropping system released 60% less N_2O, but yield declined on average by 23%. Corn, winter barley, and vegetables showed the highest N_2O reduction potential under reduced fertiliser input in conventional farming. In addition to N_2O emissions, reduced fertilisation substantially decreased other nitrogen losses into the water and atmosphere. Generally, the soils under all cropping systems maintained a positive mean nitrogen budget. Our results suggest a significant emission reduction potential in certain production zones which, however, were accompanied by yield reductions. Knowledge of the emission patterns from cropping systems under different environmental conditions is essential to set the appropriate measures. In addition, region-specific measures to reduce soil N_2O emissions have to be in line with farmers' interests in order to facilitate the successful implementation of targeted nitrogen management.

Keywords: crop rotation, cropping systems, fertilisation, LandscapeDNDC, nitrogen balance

No net carbon sequestration by willow on a cultivated peat soil

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Peatlands are a major source of greenhouse gas emissions, on a global scale and locally in Finland. More than half of agricultural emissions come from Finnish peatlands, although their share of cultivated fields is only 12%. Possibilities to decrease emissions are e.g. to raise the water table level and reduce soil disturbance by cultivating a perennial crop. Willow has been found to create a net carbon sink on mineral soils, but this is challenging in peat soils due to high loss of carbon in soil respiration.

We set up an experiment on a cultivated peatland located in southwestern Finland in the summer of 2018, where we monitored the growth of the willow and greenhouse gas emissions for four years starting from 2019. The ground water table was raised gradually from 80 to 30 cm during the experiment.

During the experiment, the willow sequestered about 87 Mg ha^{-1} of carbon in its above and below-ground parts whereas carbon loss in soil respiration was 43 Mg C ha^{-1}. In two harvests, 51 Mg C ha^{-1} of carbon was removed in total, leading to net loss of carbon and net ecosystem carbon balance of 8 Mg C ha^{-1} over the study period of four years. A 10 cm increase in water level reduced annual CO_2 emissions from soil respiration by 1.5 Mg C ha^{-1}.

Annual emissions of N_2O ranged from 2 to 17 kg N_2O-N ha^{-1} with a decreasing trend towards the end of the monitoring period. Flux of CH_4 changed from consumption (-1…-2 kg CH_4-C ha^{-1}) to moderate emissions (4-11 kg CH_4-C ha^{-1}) as the water table rose.

With the mean annual net ecosystem balance and emissions of N_2O and CH_4 from the last year when the water level had settled and willow stand well established, the total greenhouse gas emission balance can be estimated to be about 8 Mg CO_2 equivalent. This indicates that willow cultivation in wet management has potential to reduce greenhouse gas emissions from cultivated peat soils as compared to typical crops but it is difficult to reach net carbon sequestration at least during the first years of cultivation.

Keywords: organic soil, wetland, willow biomass, GHG emissions

Understanding the Role of Phosphorus Fertilisation: Long-Term Effects on Nitrogen Cycling, Carbon Sequestration and Greenhouse Gas Emissions in European Agricultural Soils

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Due to the inappropriate and excessive use of phosphorus (P) fertilisers, we are facing a global P crisis. P is a crucial element for promoting plant growth, but its scarcity can diminish both plant and microbial biomass, thereby influencing the sequestration of soil organic carbon (SOC). Alterations in soil P content have the potential to shape microbial communities, thus affecting pathways within the carbon (C) and nitrogen (N) cycles and subsequently impacting emissions of greenhouse gases. In this laboratory incubation experiment we investigate the impact of different P fertilisation levels in three European long-term experiments (LTE) on N and C transformation processes and greenhouse gas fluxes in agricultural soils using stable isotope techniques (^{15}N and ^{13}C). This study is part of the EJP SOIL project "ICONICA" (Impact of long-term P additions on C sequestration and N cycling in agricultural soils).

The soil samples derived from Johnstown Castle, JC (grassland soil, Ireland), Lanna Skara, LS (arable soil, Sweden) and Jyndevad, JY (arable soil, Denmark). Two P levels were examined from each LTE: low P (0 kg P/ha and year) and high P additions (different P application rates among LTEs). The soils were mixed with ^{13}C- and $^{13}C^{15}N$- labelled maize biomass, respectively, and received ammonium nitrate (NH_4NO_3) in the ^{13}C treatment as $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$, respectively, and unlabelled NH_4NO_3 in the $^{13}C^{15}N$ treatment. Soil and gas samples were taken 0, 1, 3, 7 and 10 days after addition of NH_4NO_3 and were analysed for $^{(15)}NH_4^+$-N, $^{(15)}NO_3^-$-N, organic $^{(15)}N$, organic $^{(13)}C$ contents as well as for nitrous oxide ($^{(15)}N_2O$), carbon dioxide ($^{(13)}CO_2$), and methane (CH_4) fluxes.

Preliminary findings display clear differences among the three LTEs as well as the two P levels. Regarding the impact of P fertilisation history, the JC soil showed increased CO_2 emissions under high P levels compared to low P levels. Significantly, high P levels exhibited higher CH_4 uptake rates in JC and JY soils compared to the respective low P levels. JY exhibited the highest emissions of N_2O, whereas JC displayed the lowest N_2O emissions. Additionally, JC showed higher NH_4-N values compared to LS. The highest concentrations of NO_3-N were measured in JC, and the lowest in JY. Furthermore, within JC samples, higher NO_3-N values were measured under conditions of high P compared to low P levels.

The results so far underscore the complex interactions within the carbon-nitrogen-phosphorus cycles under varying P inputs. Further analyses and interpretations are in progress.

Keywords: Phosphorus, Nitrogen, Carbon Cycle, Stable Isotopes, Agriculture

SUstainable Management of soil Organic Matter to MItigate Trade-offs between C sequestration and nitrous oxide, methane and nitrate losses: The SOMMIT Project

Eugenio Diaz-Pines, Alessandra Lagomarsino and the SOMMIT Team

The SOMMIT project evaluates trade-offs and synergies between soil C sequestration, nitrous oxide, methane and nitrate losses as affected by soil management options aimed at increasing soil C storage. The project involves an integrated and interdisciplinary approach addressing the main pedo-climatic conditions and farming systems in Europe. In this presentation, I will navigate through the main findings of the project, including the effects of organic materials application on the N2O fluxes and discussion on knowledge gaps identified. We will further present results of standardized incubations across selected European long-term experiments investigating different management strategies. Finally, we will present the application of a fuzzy-expert system to identify optimal strategies for mitigation in European agricultural soils.

C-arouNd: Refining Soil Conservation and Regenerative Practices to Enhance Carbon Sequestration and Reduce Greenhouse Gas Emissions

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While the last 60 years have seen significant progress in global food production with inorganic fertilizers, plant breeding, and pesticides, this has come at a cost to soil health. This intensive agriculture has led to a reduction in soil organic carbon (SOC) stocks, increased greenhouse gas (GHG) emissions, and ultimately contributed to global warming. Agriculture and land-use change are responsible for nearly 20% of global GHG emissions, making it a significant source of nitrous oxide (N2O) due to synthetic nitrogen fertilizers and methane (CH4) due to livestock activity and rice cultivation. This project aims to evaluate the influence of conservationist and regenerative agricultural practices on carbon (C), nitrogen (N), and phosphorus (P) cycling, soil biodiversity, and GHG emissions, with a particular focus on long-term SOC stocks and the processes governing carbon persistence. To achieve this, the project has established a consortium of long-term field experiments that assess the impact of different cropping systems and agricultural practices on soil properties. Participants from 12 countries are involved, contributing a total of 37 field sites with varying chronosequences or contrasting agricultural management practices. At 26 sites established for at least 10 years, estimates and scenario models of potential N2O, CO2, and CH4 emissions from cropping, pasture, and forest systems will be generated using the best available IPCC or local emission factors. Additionally, GHG emissions will be directly measured at a subset of these sites. The project is building a global database of C and N stocks, bulk density, soil fertility, and GHG emissions across diverse ecosystems and under different agricultural management practices. This will allow researchers to determine how climatic conditions, net primary production of the cropping systems, and soil type influence C and N stocks, nutrient dynamics, and GHG emissions. The ultimate goal of the project is to recommend best

management practices for food crop production that promote soil carbon accumulation, particularly mineral-associated organic matter (MAOM), without increasing GHG emissions. This will contribute to the long-term sustainability and resilience of agricultural systems. As promised in the project deliverables, the Long-Term Experiment (LTE) metadata has already been organized in a FAIR repository. Additionally, the protocols for soil sampling, laboratory analyses, and site characteristics are being prepared for publication. Furthermore, soil carbon sequestration is being quantified across all fields (or planned for future sampling), and in some experiments, greenhouse gas emissions are also being measured. This includes African dark earths and surrounding ecosystems, where both carbon sequestration and GHG emissions are being quantified. PhD students have also begun field trips to Norway for soil sampling.

Keywords: soil carbon persistence, agriculture intensification, sustainable development, nutrients cycling, carbon storage

Abstracts of Poster Presentations

Long-term crop residue management effects on the greenhouse gas fluxes: an Austrian case study

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Most cropland soils rely on crop residues as their sole source of carbon, especially in cereal production. In the context of climate change mitigation, incorporating these residues into the soil (instead of removing them) is one popular soil management strategy to enhance the carbon input on agricultural land.

Usually, it is observed that crop residue incorporation leads to higher soil organic carbon (SOC) stocks. However, higher carbon in the soil may also modify the N_2O and CH_4 fluxes, since these gases are produced by microbial processes mediated by carbon availability. The effect of residue management

on non-CO_2 GHG fluxes has not been comprehensively assessed, what prevent us from estimating the overall effect of management strategies on the soil greenhouse gas (GHG) balance.

Here, we monitored GHG fluxes from a long-term experiment in the Marchfeld, a productive agricultural area in east Austria. In this experiment, two crop residue management strategies have been compared since 1982: removal of residues vs incorporation.

We used static manual chambers to estimate CO_2, CH_4 and N_2O fluxes between cropland and atmosphere. In parallel, soil environmental conditions and soil nutrients were investigated. We captured flux information between 902 days with a temporal resolution of approximately 21 days between measurements. Within this period the field had a rotation of winter wheat, sorghum, and triticale.

We observed a large interannual variability in N_2O fluxes, from no effect to higher emissions following incorporation of residues. Cumulative N_2O emissions were enhanced by incorporating residues compared to the removal treatment. Nevertheless, this amount is relatively minor compared to the currently higher SOC stocks in the first 25 cm in the residue incorporation scenario. While our case study illustrates a trade-off scenario between GHG fluxes and SOC storage in temperate croplands, the trade-off is only a small fraction of the long-term climate mitigation benefit by incorporating residues.

Keywords: nitrous oxide, long-term field experiment, static chambers, climate change mitigation, soil C and N pools.

Effects of long-term soil organic matter decline on soil nutrient status and organic matter composition in organically managed grass-clover ley and permanent pasture in Norway

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Grasslands are often seen as a beneficial measure to increase soil organic matter (SOM) content in (former) croplands and reduce GHG emissions. In permanent grassland the continuous ground cover and the high root density protect the soil against erosion, leading to an accumulation of organic matter. In cultivated grasslands, such as grass-clover leys, the nutrient cycle encompasses an accumulation phase during the ley period, followed by a rapid decomposition after ley termination. Upon ploughing the grass-clover ley, there is an increased mineralization of nutrients, contributing to the buildup soil fertility. As part of the global C-arouNd project consortium, which aims to investigate how short and long-term agricultural management practices affect SOM persistence in the soil profile, we want to investigate how SOM decline affect the soil nutrient status and organic matter composition in the long term, in a permanent and cultivated grassland in West Norway.

At Tingvoll gård experimental farm, organic milk production was established in 1986, replacing the previous conventional sheep farming. Records of bought additional feed and sold products have been kept, allowing to calculate a farm nutrient budget. Since 1990, soil samples (0-20 cm depth) have been taken every 5–7 year for determination of SOM and soil fertility status. In addition grass-clover yields have been annually measured since 1991. Preliminary analyses of the historical data show a decline on the SOM concentration (ignition loss) in the 0-20 cm top layer over 30-y period. On average in the cultivated grassland, SOM concentration declined from 14.0 % and 7.9 % in 1990 to 7.4 % and 6.4 % in 2021. In the permanent pasture, where the soil is not ploughed every 4 years, the losses of SOM content were smaller, on average SOM decreased from 10.2 % to 8.0 %.

We hypothesize that soil from fields with the largest decline in SOM over the past decades will contain relative more stable carbon components while also being richer for most macronutrients. Analysing the farm nutrient budget, i.e. the in- and output of nutrients from the farm system, will give further insight in potentially deficient nutrients in soil and help establish a more durable soil management. Soil nutrient imbalances can lead to higher SOM turnover and a further decrease in SOM content can be expected. To test these hypotheses, soil samples will be taken in autumn 2024 to study the macronutrients and SOM composition in more detail. C, N and S will be measured by dry combustion, available P by the Bray-1 Method and exchangeable Ca, K and Mg using ammonium acetate extraction. SOM composition will be examined using a thermal fractionation method on the different size fractions (fPOM, oPOM & MAOM) of the soil.

Keywords: Grasslands, SOM decline, Nutrient mining

The impact of long term compost application on soil N_2O emissions

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Application of compost in cropland generally results in enhanced carbon sequestration. However, compost application may stimulate the emission of soil borne nitrous oxide (N_2O), a potent greenhouse gas. This trade-off may offset the climate change mitigation obtained via carbon sequestration. Our study investigates the impact of long-term compost application on soil-borne N_2O emissions.

In the long term BOPACT field trial installed by ILVO, compost has been applied yearly since 2010. The soil organic carbon (SOC) content has been measured every 4 years. Since May 2023, N_2O emissions have been monitored weekly in both the compost and the control treatments. After application of cattle slurry and mineral fertilizer, potatoes were planted. Compost was applied in September after harvesting the potatoes. White mustard was sown as cover crop. Since potatoes are cultivated on rigdes, N_2O was monitored both on the ridges and in the furrows.

After planting the potatoes, higher emissions were observed from the furrows compared to the ridges. This effect was only observed for a limited period, while by the end of the growing season higher emissions from the ridges were measured. The cumulative N_2O emissions measured in the compost treatment were similar to the emissions observed in the control treatment. Combined with the enhanced SOC content observed in the compost treatment, these results suggest the positive impact of compost application on climate change mitigation. Further, our results stress the need to monitor N_2O emissions in winter periods, since significant emissions were measured during this season.

Keywords: N_2O emission; compost, carbon sequestration, climate change mitigation, field experiment

The impact of over a century of different organic fertilization on the properties of soil organic matter and water holding capacity

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The long-term experiment was established in 1921 at the Experimental Station of the Warsaw University of Life Sciences in Skierniewice (central Poland) on sandy loam Luvisol, which received mineral fertilization (Ca, N, P, K). The treatment included: (1) control with arbitrary crop rotation; (2) manure applied every five years at a rate of 30 t ha^{-1}; (3) legumes (*Trifolium pratense* L.); and (4) manure with legumes. Soil samples from A horizon (0-20 cm) were collected during the 2022 mid-growing season and analyzed for total organic carbon (TOC), fractional composition of soil organic matter (SOM) for humic acids (HA), fulvic acids (FA) and humin (HUM), as well as spectroscopic properties of bulk soil (TC-GC/MS) and isolated HUM (UV-Vis and fluorescence). In addition, plant available water, soil moisture, soil temperature, and CO_2 emission were measured in the field during the 2022 and 2023 growing seasons from treatments 1 and 2 only.

The greatest impact on SOM content was observed in plots where manure was applied, which resulted in an increase in TOC by 48% and 68% in variants (2) and (4), respectively. The application of legumes alone caused an increase in TOC by 32%. The analysis of the fractional composition of HS revealed that the transformation of organic matter under fertilization with manure led to a significant increase in HUM amount and decrease in the HA/FA ratio concerning control. Different management caused also changes in the spectroscopic properties of HUM, which indicated an increase in UV-Vis absorbance and fluorescence emission in legume applied soil.

Thermochemolysis and gas chromatography/mass spectrometry showed that HUM was enriched in carbohydrates in almost all pairs of soil and HUM. Manure fertilization and application of legumes resulted in enrichments in carbohydrates in bulk soil and HUM samples as well as in decrease in lipids.

Changes in the amount and properties of SOM were accompanied by changes in the water-holding capacity. Manure fertilization increased plant available water by 20% and 10% in variants 2 and 4, respectively, while legumes alone decreased plant available water by 11%. Based on the two years of monitoring, CO_2 emissions were affected by soil temperature only.

The results confirmed that appropriate cultivation can significantly increase C resources in the soil, contributing to the mitigation of climate change. This is particularly effective when using legumes supported by fertilization with manure. Furthermore, the long-term different soil management not only altered the SOM contents and properties but surprisingly also the chemical composition of HUM which is considered as particularly stable and a long-term sink of atmospheric carbon.

The research was financed by EJP SOIL program (NCBR project EJPSOIL/I/78/SOMPACS/2022 and European Social Fund ESF), and the Ministry of Education, Science and Culture of Mecklenburg-Western Pomerania within the scope of project WETSCAPES (ESF/14-BM-A55-4790029/16-64160025).

Keywords: long-term field experiment; carbon sequestration; SOM spectroscopic properties; humin; plant available water.

Can pore water nutrients and high frequency water table data improve estimation of CO_2 emission from rewetting peatlands?

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Peatlands store approximately 30% of the global soil C pool. Peat drainage causes mineralization and CO_2 emissions. Although water table is a main controlling factor of greenhouse gas emissions from drained peatlands, nutrient status may also affect emissions. Biomass production in paludiculture provides an alternative management of peatlands under wet conditions. This study aimed to (1) quantify the effect of reed canary grass (RCG) management on a rewetted fen peatland in central Denmark, (2) calculate annual CO_2 emissions using high frequency water table data, and (3) relate water chemistry parameters (WCP) to CO_2 emission trends. Four plots established with RCG in 2018 were selected for the study and subdivided into subplots corresponding to three management treatments (0, 2, and 5-cuts per year). The 2-cut and 5-cut treatments received 200 kg N ha^{-1} y^{-1} in equal split doses. CO_2 measurements were conducted biweekly between May 2021 and May 2022 using a transparent manual chamber connected to a GLA131-GGA Los Gatos gas analyser and manipulating light intensities with four shrouding levels. WCP (NO_3, NH_4, total N, total dissolved N, total P, total dissolved P, total organic C, dissolved organic C, and Fe) were measured biweekly in water samples collected from piezometers. Auxiliary measurements (water table depth (WTD), ratio vegetation index (RVI), soil temperature, and photosynthetically active radiation) were taken on each campaign or continually to assist model-based interpolation of measured ecosystem respiration (Reco) and gross primary productivity, the latter calculated as the difference between the NEE and Reco. Reco models using hourly WTD were compared to models using the mean annual or seasonal WTDs. Additional effects of WCP were tested in linear mixed models predicting Reco, GPP, and NEE based on changes in WTD, RVI, PAR and soil temperature. The Reco interpolation model gave the best fit to measured data when both WTD and RVI were included in addition to soil temperature (Nash-Sutcliffe efficiencies between 0.74 and 0.98). The use of an annual mean instead of hourly WTD resulted in a 7% underestimation of Reco. The calculated net ecosystem C balances (NECB) were between 6.0 and 6.9 t C ha^{-1} yr^{-1} for all harvest treatments. Considerable differences in NEE were found between the plot replicates with some plots having as much as 8 times higher NEE than others. Significant differences in WCPs were found between plot replicates, with the plot farthest from the stream having the lowest C, N, P, and Fe concentrations and the plot closest to the stream having the highest nutrient concentrations. Including WCPs in the linear mixed models improved the explanation of Reco as indicated by R^2 and RMSE. The study showed that paludiculture increased photosynthesis (GPP) without increasing Reco leading to no significant difference in NECB despite a biomass resource being obtained from the field. The advantage of paludiculture compared to no harvest relied on the most nutrient rich plot replicates.

Keywords: paludiculture, fen peatland, pore water nutrients, rewetting.

Trade-off analysis of conventional and organic crop rotations under current and future climate scenarios in Finland

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Keywords: crop rotation sustainability; trade-offs analysis; crop modelling; climate change scenarios; organic farming practices.

Balancing agricultural productivity with environmental impacts like soil organic carbon (SOC) loss, greenhouse gas emissions, and groundwater contamination poses a significant challenge for European agriculture. While organic farming practices are expected to enhance soil health and have increased their share of Europe's cultivated lands, the results regarding their effects on soil biogeochemical properties, biodiversity, and nitrogen emissions have been mixed. This study employs the process-based ARMOSA crop model to assess the impacts of conventional and organic farming practices on yield, SOC dynamics, nitrate (NO_3) leaching, and nitrous oxide (N_2O) emissions in both crop and livestock farms.

The research was conducted using simulations under current and projected future climate conditions in the South Savo region of Finland, characterized by a subarctic climate (Köppen-Geiger classification). The soil type used in the simulations was loamy sand (sand 76%, clay 4%, silt 20%), classified as an Aquic Haplocryod according to Finland's Soil Taxonomy, with an SOC content of 3.5%, a carbon-to-nitrogen ratio of 17, and a pH of 6.2 in the top 30 cm of soil.

Five-year crop rotations reflective of prevalent practices in the area were designed for both crop and livestock production systems. Crop production rotations included cereals (with fodder pea in organic management), oilseed rape, and grass. Livestock farm rotations featured two years of cereals followed by a three-year fescue and timothy meadow (including clover in organic management). Nine scenarios were simulated to explore various residue management and fertilization strategies: conventional systems employed mineral fertilizers alone or combined with slurry, while organic systems used slurry, green manure, and a commercial organic fertilizer.

To assess the environmental impact and production efficiency of these crop rotations, a fuzzy logic based trade-off analysis was employed for each climate scenario. This analysis quantifies the trade offs between crop yield, N_2O emissions, NO_3 leaching, and SOC stock changes, resulting in a composite index known as the ∑ommit index. This index rates these trade-offs on a scale from 0 (poor) to 1 (excellent). To accommodate diverse evaluation criteria, alternative versions of this trade-off analysis were implemented, each varying the weightings of the input components to reflect the perspectives and priorities of different representative stakeholder categories.

Using the ∑ommit index to evaluate a five-year rotation rather than analyzing individual cropping cycles offers significant benefits. This approach accounts for the interconnected effects of each cycle and its interactions with preceding and subsequent cycles. By considering these cumulative impacts,

the index provides a more comprehensive view of the dynamics involved in trade-offs during crop transitions. This holistic perspective is crucial for making well-informed decisions about sustainable agricultural practices and long-term rotation strategies.

Thermal and physical soil organic carbon fractions in French topsoil and subsoil monitoring network

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Evaluating soil organic carbon (SOC) biogeochemical stability is key to better predict the impact of SOC on both climate mitigation and soil health. This evaluation can be conducted using SOC partition schemes that allow us to quantify SOC fractions with different biogeochemical stability. However, most of these schemes are costly or time consuming and cannot be implemented on large sample sets. Two exceptions are the widely used physical fractionation protocol allowing to separate particulate organic carbon (POC) and mineral-associated organic carbon (MAOC) and the emerging PARTY$_{SOC}$ thermal fractionation protocol distinguishing active SOC (C_a; MRT ≈30 years) from stable SOC (C_s; stable at a centennial timescale).

Here, we use analyses conducted on samples from the French soil monitoring network (RMQS) to compare the results of PARTY$_{SOC}$ thermal fractionations (C_a/C_s) performed on ca. 2000 topsoil samples, and physical fractionations (POC/MAOC) performed on ca. 1000 topsoil samples. Furthermore, we compare the results of the PARTY$_{SOC}$ thermal fractionations on topsoil and subsoil samples.

Our results show that MAOC and C_s from one side and POC and C_a from the other side have different sizes. The most biogeochemically stable fractions (C_s and MAOC) are mostly influenced by soil characteristics whereas land cover and climate influence more substantially POC and C_a. However, the

more stable fractions provided by both fractionation schemes (respectively the more labile fractions) do not have the exact same environmental drivers. Our results therefore suggest that both fractionation scheme gives complementary results. Regarding the topsoil vs subsoil fractions, the proportion of C_s increases with depth, as the C_a is the compartment that decreases the most with depth. In the deep horizon, the effect of the land cover on the amounts of C_a is also far less visible than in the topsoil.

The relative contribution of these two fractionation schemes to the evaluation of soil functions and SOC stock evolution remains to be evaluated on soil monitoring networks and constitutes a promising research avenue.

Keywords: Soil organic carbon, Biogeochemical stability, Rock-Eval® thermal analysis, Physical fractionation, Mineral-associated organic matter