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BOOK OF ABSTRACTS

Block A

Session A1

Carbon sequestration at national and European scale

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A1 Carbon sequestration at national and European scale

Session Description

Involved projects: CarboSeq, SIMPLE

Conveners: Sonja Keel (Agroscope), Felix Seidel (Thuenen)

Carbon sequestration in agricultural soils is a strategy that can contribute to climate change mitigation and generates large expectations on ecosystems to take up carbon dioxide from the atmosphere. The key for soil carbon sequestration is reaching a positive balance between carbon inputs and outputs. Enhanced inputs of organic matter to the soil can be achieved by improved management options, such as use of cover crops, increased incorporation of crop residues, addition of organic matter, optimization of varieties with increased root biomass, land use change, or introduction of agroforestry measures. As these measures are affected by bio-physical (e.g. soil type, climate) and technical constraints (e.g. irrigation) a differentiated analysis at national and European scale is necessary in order to assess the true potential of agricultural measures that enhance soil carbon sequestration when implemented on large scale. In this session, we welcome contributions that give insights into the topic of soil carbon sequestration in agricultural lands. A special focus will be given to management practices affecting this process in European countries and at the European scale.

Abstracts of Oral Presentations

A new framework to estimate soil organic carbon targets in European croplands.

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Adopting land management practices that increase the amount of soil organic carbon (SOC) in croplands is widely promoted as a win-win strategy to preserve soil health and mitigate climate change. In this context, the definition of reference SOC content values is needed to provide reliable targets to farmers, policymakers, and stakeholders. In this study, we used the LUCAS dataset to compare different methods for evaluating reference SOC content values in European croplands soils. Methods gave generally consistent estimates although being built on very different assumptions. In the absence of an objective criterion to establish which approach is the most suitable to determine SOC reference values, we propose an ensemble modelling approach that consists in extracting the estimates using different relevant methods and retaining the median value among them. Interestingly, this approach led us to select values from the different approaches in a balanced way. The use of additional methods in the ensemble modelling approach may further refine our framework designed for the estimation of SOC reference values for croplands.

Keywords: Soil organic carbon, carbon storage, climate mitigation, LUCAS dataset, data-driven modelling.

Investigating the reasons behind the choice of funding carbon sequestration initiatives in the European Union

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The present study aims at investigating the reasons behind the choice of funding carbon sequestration projects in different European contexts. The study, first, provides an in-depth analysis of the 2014-2020 RDP funds addressed at improving soil health through participatory initiatives, such as Operational Groups and Innovative projects from across European Union (EU). Funding sources are differentiated with respect to their origin and to three main type of management options: crop management; fertilization management; land use change. Crop management encompasses the introduction of new crop rotations, multiple cropping and cover crops, crop residues management (mowing) and conservative tillage (sod seeding and minimum tillage). Fertilization management includes the use of external organic matter and fertilizers application management. Land use change encompasses all the actions related to the transition from arable crop to agro-forestry, permanent grasslands, and permanent tree crops. This first stage of the investigations provides a rough idea on how differently soil issues are addressed across EU contexts, what type of initiatives are promoted and in what way these initiatives are addressed.

Then, the above information is read in the light of some key agri-environmental indicator connected to soil issues such as: soil cover on arable land during winter, change in share of permanent grassland on the utilized agricultural area (UAA) and change in share of cereal crops on the arable land, available from EUROSTAT; loss of High Nature Value farmlands due to agricultural intensification, available from the European Environmental agency; and, UAA addressed by agri-environment-climate (AEC) measures, available from JRC reports and other official sources.

A Qualitative Comparative Analysis, with fuzzy methods, is carried out to draw possible causalities and to cluster observations based on similar combination of conditions (the above mentioned agri-environmental indicator) in addressing carbon sequestration initiatives (Ragin, 2009). The methodology was developed in the framework of social sciences, but it was rarely applied in agricultural economics and especially never adopted in investigating agricultural soil challenges.

Results might allow to identify whether carbon sequestration projects through participatory initiatives are underfunded and whether there is a difference in the allocation of funds among EU countries. Finally, an expected causality between soil pressures and policy responses is recorded and discussed.

The results thus obtained might bring to several considerations, including possible mismatch of needs and funding sources and barriers to the development of participatory initiatives.

The paper concludes by highlighting the key limits of the study which are to have considered only part of the available funding sources addressed to soil related challenges and to having missing to include in the assessment some relevant indicator because of the limited scope of the investigation and because of missing information.

Keywords: Policy evaluation; Qualitative Comparative Analysis, Land use challenges

Soil Organic Carbon Sequestration Potential National Map of Türkiye

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Soil organic carbon, as an important indicator for the soil fertility, is highly related to the climate change, soil/land degradation and soil ecosystem services. This study was conducted to produce a SOC potential sequestration map of Türkiye through applying the FAO-GSP Technical Specifications and Country Guidelines for Global Sequestration Potential Map v1.0 approach. According to the approach, the SOC stock was estimated in 2040 under the business as usual – BAU (current soil management) and for three different sustainable soil management (SSM) scenarios that implemented SSM practices applied with different organic matter inputs. The SSM scenarios consist of 5% increase, 10% increase and 20% increase of organic matter inputs for SSM1, SSM2 and SSM3, respectively. It is also estimated that differences between SOC stock in 2020 and SOC stocks in 2040 under BAU and SSM scenarios that constitute absolute difference maps and the difference between SOC stocks in 2040 under the BAU and SSM scenarios that constitute relative difference maps. The study results showed that in terms of the average absolute sequestration rates (ASR) and relative sequestration rate (RSR) three projections showed a positive SOC evolution with respect to the BAU situation as 0.05 t C ha^{-1} yr^{-1}, 0.06 t C ha^{-1} yr^{-1} and 0.12 t C ha^{-1} yr^{-1}, for SSM1, SSM2 and SSM3, respectively. The SSM3 scenario showed a highest positive absolute SOC sequestration (0.13 t C ha^{-1} yr^{-1}) in tree crops land use. Besides, the relative SOC sequestration (RSR) results showed also a positive rate for the three scenarios with respect to the BAU situation). In terms of relative SOC sequestration, three projections showed a positive relative SOC sequestration in all land uses with respect to the BAU situation. It means that, SSM practices can increase the current status and similarly the highest SOC sequestration rate was obtained in SSM3 (4.33 Mt C yr^{-11}), followed by SSM2 (2.17 Mt C yr^{-1}) and SSM1 (1.09 Mt C yr^{-1}). These results suggest that three SOC sequestration scenarios which consider applying SSM management practices will generally make a positive effect for achieving SOC neutrality and to avoid CO_2 emissions from SOC losses in Türkiye.

Scenario modelling for assessing impacts of policy changes and socio-economic effects on ecosystem services of soils (SIMPLE)

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The central aim of SIMPLE is to set up a modelling framework that allows us to assess effects of policy changes and socio-economic effects on three ecosystem services of soils: production, soil organic carbon (SOC) storage and greenhouse gas mitigation. We will simulate three different scenarios that potentially reduce nitrogen (N) fertilization. Our main focus will lie on a 20% reduction in N fertilization rates as formulated in the Farm to Fork strategy by the European Commission. In addition, effects on fertilization rates as a result of changes in diets and rising fertilizer prices will be assessed. While we expect reductions in soil-derived nitrous oxide (N_2O) emissions if fertilizer inputs are lower, it is possible that trade-offs arise. Yields could be reduced and also SOC losses could occur as a result of lower plant C inputs to the soil. To quantify these effects, we link several European-scale models with national yield and fertilizer statistics. Based on simple fertilizer-yield response functions, potential yield reductions will be estimated for the most important crop types grown in Europe. With the European-scale agro-economic model AGMEMOD changes in crop areas in EU member states will be simulated. The effect of yield reductions on soil C sequestration will be assessed using the SOC model RothC and the setup provided by the EJP soil project CarboSeq. We will consider whether plant-derived C inputs to soil are affected by lower N fertilization as these are important input data for simulations with RothC. For this purpose, we make use of data gathered within the EJP soil projects CarboSeq and MaxRootC. The European-scale N flow model MITERRA-Europe will be applied to quantify changes in N losses with a focus on N_2O emissions. As a response to yield reductions, cropland might need to be expanded to compensate for lower production, under the assumption that Europe does not increase imports. This could potentially result in land-use changes with effects on SOC storage, that we will determine. Finally, a trade-off analysis will we applied to assess the different aspects of reduced N fertilization on the three ecosystem services of soils we focus on and formulate policy recommendations.

Keywords: soil carbon sequestration, greenhouse gas mitigation, trade-off, fertilization

Estimating the effects of different crop management options on SOC stocks and deriving emission factors – the CarboSeq approach based on European long-term field experiments

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Crop management options, such us, choice of crops in the rotation, residue management, fertilisation, tillage and irrigation, are known to affect the soil organic carbon (SOC) stocks and can be considered as effective mitigation strategies to remove atmospheric CO_2.

This research, as part of the EJP SOIL CarboSeq project, aimed at estimating the effect of seven crop management practices on SOC stocks, considering available data and metadata from European long-term experiments (LTEs). Specifically, the evaluated crop management options were: 1) cultivation of cover crops in comparison with not growing cover crops; 2) increase of crop diversification through an increased part of leguminous crops in comparison with less or no legumes in the crop rotation; 3) incorporation of crop residues compared with their removal; 4) non-inversion tillage compared with inversion tillage; 5) zero tillage compared with inversion tillage; 6) irrigated in comparison with non-

irrigated systems; 7) the comparison of two agroforestry systems (alley-cropping and hedgerows) with croplands or grasslands without these elements.

The available information from published literature, existing databases, meta-analyses, and personal communication with the LTE owners was collected through a structured homogeneous template, checked for data quality both manually and through an automatic error detection tool, and subsequently deposited in the CarboSeq crop and soil management database. The database is coupled with an export module which allows to explore, filter, query and eventually export the data required for the analysis.

For each management option, emission factors (EFs) were calculated as ratio of SOC stocks of the management option to the SOC stock of the respective control option. Different bio-physical variables (e.g., climatic zone, soil type) as well as variables relevant for each management option (e.g., crop type, tillage depth, amendments type) were used to identify significant predictors of the EFs using a mixed effect model approach. The analysis resulted in different EFs for each crop management option based on the moderators that significantly affect these in each case. Considering the identified data gaps and limitations, the derived EFs can be used as a basis for the estimation of the SOC sequestration potential in the European croplands.

Keywords: SOC sequestration, conservation agriculture practices, climate-smart agriculture, EJP Soil

Soil organic carbon sequestration potential of agricultural soils in Europe (CarboSeq)

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Carbon sequestration in soils is a negative emission technology that can contribute to mitigate climate change. However, for European soils, a comprehensive assessment is missing on how much soil organic carbon (SOC) can be sequestered with different management options.

The aim of CarboSeq is thus to identify agricultural management options that increase SOC and subsequently to estimate a feasible SOC sequestration potential considering biophysical, environmental, technical and economic constraints for each identified agricultural measure.

Finally, SOC-sequestration potential maps and data for different management options will guide policy makers regional specific to the most efficient agricultural management options to sequester SOC for climate mitigation.

CarboSeq has reached its midpoint and this project presentation will demonstrate what major steps have already been taken, first results will be shown and a road map on how the project will continue from here will be presented.

Keywords: soil carbon, climate change mitigation, SOC increasing agricultural measures, carbon farming

Refining Soil Conservation and Regenerative Practices to Enhance Carbon Sequestration and Reduce Greenhouse Gas Emissions

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Modern agricultural technology, in all its aspects, has enabled increased agricultural production to meet the growing demand for food and fulfill the Sustainable Development Goals of the UN Agenda 2030. Yet the impact of these achievements on soil degradation and greenhouse gas (GHG) emissions is considerable. Agricultural practices that increase soil carbon stocks and reduce greenhouse gas emissions, as outlined under the international 4per1000 initiative, constitute valuable strategies for mitigating global warming while increasing soil carbon stocks and ensuring soil health. The objective of this proposal is 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 emphasis on long-term SOC stocks, and processes governing C persistence. This project represents an exploratory effort to couple the stoichiometric drivers to microbial populations related to C, N, and P cycling and stocks, and GHG emission under diverse agricultural practices. To this end, we set up a long-term consortium of field experiments that assess the impact of different cropping systems and agricultural practices on soil properties. The participants from twelve different countries represent a total of 37 field sites with different time sequences and/or contrasting agricultural management. Twenty-six sites have been established for at least ten years. At each site, estimates and modelling scenarios of possible N_2O, CO_2 and CH_4 emissions from crop/pasture/forestry systems will be carried out using best available IPCC or local emission factors and GHG emissions will be measured at a subset of sites. To compare the impact of different climatic and edaphic conditions among sites, we propose a standard soil organic matter (OM) physical fractionation procedure resulting in two contrasting soil fractions including particulate organic matter (POM), which consists mainly of partially decomposed plant residues, and the mineral-associated OM (MAOM), principally of microbial origin. This project will build a worldwide database of C and N stocks, bulk density, soil fertility and GHG emissions across different ecosystems and under differential agricultural management. Moreover, the project will determine the extent to which climatic conditions, net primary production of cropping systems and soil type affect carbon and nitrogen stocks, nutrient dynamics and greenhouse gas

emissions. The final product of the project will be to recommend best management practices for production of food crops which would promote soil C accumulation, especially MAOM, without increasing GHG emissions thus contributing to the sustainability and resilience of agriculture.

Keywords: soil carbon persistence, sustainable development, nutrients cycling, carbon storage GHG emissions.

Abstracts of Poster Presentations

Koolstoftool: A carbon calculation tool for the farmer

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The LIFE CarbonCounts project aimed to enable Carbon Farming in Flanders by establishing a geospatial information system. One of the objectives was to develop a high-resolution geospatial information system to monitor carbon storage for agroforestry, woody landscape features and arable mineral soils. This is established by developing a carbon calculation tool, called the 'Koolstoftool', that is accessible for the farmer and connected with carbon calculation models. The Koolstoftool is implemented in the soil passport. The soil passport is an online application that makes all available soil-related data (both public and private) of agricultural parcels easily accessible for farmers. The soil passport has the objectives to group and visualize data and to stimulate the farmer to use the data to perform to carry out sustainable soil management.

The Koolstoftool uses the gathered data in the soil passport as input for the connected carbon calculation models for mineral soils and agroforestry/woody landscape features through API based data connections. The estimated output from the models are visualised in the Koolstoftool, showing the expected evolution of carbon stocks calculated based on the continuation of current crop rotation, i.e. the sequence of crops and cover crops registered in the past six years in the GSAA. Additionally, the interface of the Koolstoftool allows the farmer to simulate the expected evolution of alternative farming practices such as crop rotation and organic fertilizer application. The mineral soil calculation tool is based on the Rothamsted Carbon model that simulates the turnover of organic carbon in the top-layer of mineral soils. The model takes into account different parameters such as soil type, clay content and monthly rainfall. For the agroforestry and woody landscape features woody elements on parcels are detected using orthodetection on aerial images. These elements are divided based on the crown surface, roundness and area into solitary trees, tree rows, groups of trees, forests and hedges. The dataset resulting from this orthodetection is used as input for the agroforestry calculation model by estimating the carbon stock in the elements based on their crown surface and woody element type. This data is then used as input for the calculation model to estimate the carbon stock.

Keywords: carbon sequestration; RothC model, online tool

Scenario modelling for assessing impacts of policy changes and socio-economic effects on ecosystem services of soils (SIMPLE)

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The central aim of SIMPLE is to set up a modelling framework that allows us to assess effects of policy changes and socio-economic effects on three ecosystem services of soils: production, soil organic carbon (SOC) storage and greenhouse gas mitigation. We will simulate three different scenarios that potentially reduce nitrogen (N) fertilization. Our main focus will lie on a 20% reduction in N fertilization rates as formulated in the Farm to Fork strategy by the European Commission. In addition, effects on fertilization rates as a result of changes in diets and rising fertilizer prices will be assessed. While we expect reductions in soil-derived nitrous oxide (N_2O) emissions if fertilizer inputs are lower, it is possible that trade-offs arise. Yields could be reduced and also SOC losses could occur as a result of lower plant C inputs to the soil. To quantify these effects, we link several European-scale models with national yield and fertilizer statistics. Based on simple fertilizer-yield response functions, potential yield reductions will be estimated for the most important crop types grown in Europe. With the European-scale agro-economic model AGMEMOD changes in crop areas in EU member states will be simulated. The effect of yield reductions on soil C sequestration will be assessed using the SOC model RothC and the setup provided by the EJP soil project CarboSeq. We will consider whether plant-derived C inputs to soil are affected by lower N fertilization as these are important input data for simulations with RothC. For this purpose, we make use of data gathered within the EJP soil projects CarboSeq and MaxRootC. The European-scale N flow model MITERRA-Europe will be applied to quantify changes in N losses with a focus on N_2O emissions. As a response to yield reductions, cropland might need to be expanded to compensate for lower production, under the assumption that Europe does not increase imports. This could potentially result in land-use changes with effects on SOC storage, that we will determine. Finally, a trade-off analysis will we applied to assess the different aspects of reduced N fertilization on the three ecosystem services of soils we focus on and formulate policy recommendations.

Keywords: soil carbon sequestration, greenhouse gas mitigation, trade-off, fertilization

Integrated approach of soil carbon sequestration in the Netherlands

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The Dutch government stated in their climate action plan that annually an additional 0.5 Mton CO2-eq must be sequestered in Dutch mineral agricultural soil from 2030 onwards. This was a reason to start the Dutch research programme Smart Land Use in 2018. The aim of the programme is to come up with scientific based actions to reach this goal. This includes not solely insight in the technical potential of soil carbon sequestration, but also insights in factors that stimulate or inhibit farmers to take up carbon measures. The programme looked for example at costs and benefits of measures, and trade-offs and synergies of soil carbon sequestration regarding nitrous oxide emission and other soil health indicators. In theory, an annual potential of 0.9 Mton CO2-eq extra can be sequestered at national level when all carbon measures are implemented optimally. However, the actual carbon sequestration is still far from this potential. Therefore, effort within the programme also goes to the exploration of incentives for farmers to implement carbon measures. For this, but also for other information on carbon sequestration, the Smart Land Use Programme makes use of data, knowledge and insights generated during EJP SOIL and vice versa.

Keywords: soil carbon sequestration; carbon farming, climate mitigation, soil health

Carbon sequestration at international scale: Towards an International Research Consortium on soil carbon.

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Launched in September 2022, ORCaSa is a Horizon Europe project standing for Operationalising the International Research Cooperation on Soil Carbon. Coordinated by the French National Research Institute for Agriculture, Food and the Environment (INRAE), the project aims to establish by 2025 the first International Research Consortium (IRC) on soil carbon, with a first version expected in the fall of 2023.

The idea to create an IRC on soil carbon emerged during the CIRCASA project (2017-2021) together with more than 100 stakeholders and 500 scientists from around the world. The mission of the IRC on Soil Carbon is to support the Paris Agreement on Climate Change by raising both awareness and science-based knowledge on soil carbon. While CIRCASA focused on agricultural soils, ORCaSa goes a step further and considers other types of soils, including forests, pastures, public spaces in urban areas, etc. The IRC's vision is to become an international scientific reference in the domain of soil carbon stock changes. It will also gather public and private funders that will fund multidisciplinary research and innovation still needed to remove the last scientific and technical obstacles that will allow us to go to scale.

The ORCaSa project will :

- Develop KP4SoilCarbon, an online platform where current knowledge on soil carbon will be collected and made accessible by gathering the latest carbon-related publications and practices on the subject, providing maps, aggregating data and facilitating contact with the players in the field,
- Gather the international community on MRV and thus propose co-constructed MRV (Measurement, Reporting and Verification) methodologies that are applicable in different contexts and for different purposes (compliance markets, national incentives, CAP ecoschemes, value chain in-setting or off-setting via voluntary carbon markets),
- IRC will make it possible to go faster and further by aligning Research and Innovation activities and fostering synergies between research efforts at the global level with the strong involvement of all

stakeholders and related initiatives. This will help create breakthroughs, avoid duplication of activities and develop innovation on an international scale.

The poster will focus on two processes : Knowledge Hubs and Thematic Annual Programming for a better alignment, coordination and co-creation of research activities to attract public and private EU&International funders around an enlarged Strategic Research and Innovation Agenda (SRIA). Collaboration with EJP Soil projects are key for these alignement activities.

Keywords: soil carbon, carbon farming, International research consortium, network, research alignment

Where to store additional carbon in European agricultural soils

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In order to estimate soil organic carbon (SOC) sequestration potentials for European agricultural soils, we need to know the area on which *additional* SOC sequestration measures can still be implemented. In October 2023, the EJPSoil CarboSeq project organized three workshops to define harmonized, measurable and impartial criteria that can be used to define this area at the European scale. Here, we will present the outcome of these workshops and the resulting maps for a set of eleven promising and/or popular SOC sequestration measures individually.

Keywords: CarboSeq; soil organic carbon sequestration; area of implementation; continental scale

Full inversion tillage as a strategy of accelerating soil carbon sequestration during the renewing permanent pastures and grasslands in Ireland

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Soil carbon (C) sequestration is currently targeted to offset increases in atmospheric CO_2 emissions. Full inversion tillage or deep ploughing offers a strategy to both protect soil organic carbon stocks that have built up over previous decades, whilst providing the capacity for a 'new C sink' to be established. Deep ploughing to approximately 40 cm, inverts grassland soil depositing the carbon-rich topsoil to lower layers, effectively burying and protecting this carbon stock below the zone where soil biology is most active. Once-off or infrequent deep ploughing can increase soil organic carbon stocks via two processes: (i) burying carbon-rich topsoil and possibly slowing the rate of decomposition, and (ii) transferring carbon-deficient soil to the surface to increase C input by plants. However, key questions remain as to how this renovation may impact soil organic carbon stocks, yield and key components of the ecosystem C cycle. This study aimed to assess the impact of full inversion tillage/deep ploughing by quantifying soil organic carbon conservation at different depths with a ^{13}C labelling approach and assessing the impact on ecosystem CO_2 fluxes. A lysimeter experiment was set at a growth room facility under ambient environmental conditions with the treatments i) Deep ploughed (DP) (40 cm), ii) Conventional ploughed (CP) (25 cm), iii) Minimum tillage (MT) and iv) Unploughed control with monoculture ryegrass and multispecies swards (grass + clover + herbs). This study utilised a C tracer approach in order to attempt to characterise key leverage points by which deep ploughing could enhance the C cycle. Net ecosystem productivity (NEP) and total ecosystem respiration (TER) were measured to calculate the gross primary production (GPP) of the systems. The use of carbon tracers revealed significant differences in net ecosystem productivity between the different tillage methods and sward types. The difference in ^{13}C between root and soil was used to partition the soil respiratory flux into auto- and heterotrophic gross component fluxes. There appears to be a consistent pattern in the autotrophic respiration dominates DP treatments, whilst CP/ MT is equally divided and unploughed grassland is heterotrophic dominated. Deep ploughing impacts C balance, which may positively affect net CO_2 sink activity by increasing GPP and reducing TER and heterotrophic respiration. The tillage methods and sward types affect the C sequestration potential. Deep ploughing with mixed species sward showed the highest dry matter yield compared to other treatments. Within two years of deep ploughing the grass production responded positively and was significantly greater

than the non-renovated pasture. Results of this project show the potential of the full inversion tillage, i.e. deep ploughing to ~40 cm, as a grassland renovation method to increase carbon sequestration. As carbon build-up occurs slowly over many years and decades and the tillage methods and sward types affect the C sequestration potential, this study proposes field trials for further long-term monitoring of carbon sequestration in the permanent pastures and grasslands in Ireland.

Keywords: Soil organic carbon, C tracer approach, Isotope analysis, Deep tillage, Zero tillage