Spatially explicit effects of land use change on organic carbon stocks of agricultural soils in Europe

Schneider Florian*, Poeplau Christopher and Don Axel

Thünen Institute of Climate-Smart Agriculture, Bundesallee 65, 38116 Braunschweig, Germany

** Presenting author: florian.schneider@thuenen.de*

Minor alterations in global soil organic carbon (SOC) stocks can cause major changes in the concentration of atmospheric carbon dioxide. In mineral soils, land-use change typically exhibits the strongest anthropogenic effect on SOC stocks. However, site-specific effects of land-use change on SOC stocks may depend on environmental properties such as climate and soil texture. In the present study, we provide spatially explicit, quantitative estimates for the effect of agricultural land-use change on SOC stocks in Europe. Specifically, we addressed the question of how much atmospheric carbon European agricultural soils could sequester if today's cropland were converted to grassland.

Our predictions were derived by applying novel data-driven reciprocal modelling to 3,770 grassland and 6,155 cropland sites of the LUCAS soil survey. In brief, a Random Forest model was trained to predict the SOC stocks of grassland. This model was then applied to cropland soils, with predictions being restricted to the model's space of applicability.

In the remaining croplands, the model predicted SOC stocks to be 12.1 Mg C ha^{-1} (95 % CI, 11.8 to 12.5) higher on average than measured values (Figure 1). This number illustrates the average SOC accrual if European cropland were converted to grassland. Individual effect sizes differed drastically, but their spatial distribution revealed pronounced regional trends. On a country level, the potential SOC accrual from converting cropland to grassland was predicted to be highest in Belgium (mean 27.2 Mg C ha^{-1}; 95 % CI, 24.7 to 29.3) and lowest in Estonia (mean 5.2 Mg C ha^{-1}; 95 % CI, 0.8 to 8.3). Effects of land-use change on SOC stock were strongly related to climate, mineral N fertilisation, C:N ratios of soils and mean annual NDVI values of the land surface.

These results suggest that data-driven reciprocal modeling may offer a promising alternative to existing process-based, mechanistic modeling approaches that still struggle to accurately describe the site-specific effects of land use change on SOC. Data-driven reciprocal modeling allows effect size to be estimated by analyzing associations alone, without understanding causality. They provide the best possible quantitative estimate of the effects of land use change on SOC without understanding every detail of their cause, while achieving a maximum of representativeness.

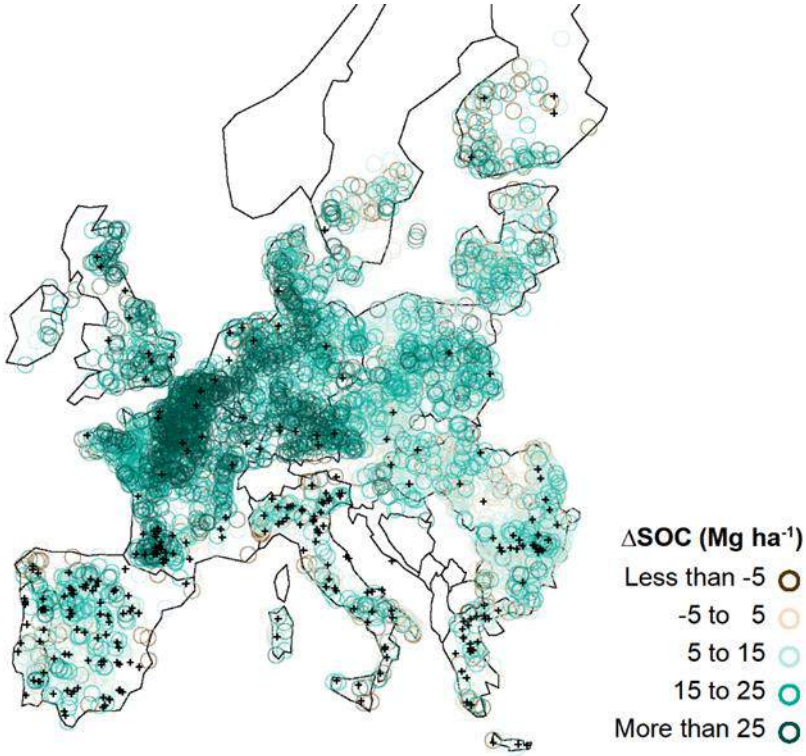

Figure 1. Estimated change in soil organic carbon (SOC) stocks by converting European cropland to grassland. Positive values denote SOC accrual (green colours), negative values SOC losses (brown colours). Crosses represent cropland sites with environmental properties for which no reliable estimate could be made since they were located outside the model's space of applicability. Modified after Schneider et al. (2021) GCB 27, 5670– 5679 (https://doi.org/10.1111/gcb.15817).

Keywords: Soil organic carbon; carbon farming; climate mitigation; machine learning; data-driven reciprocal modelling

Impact of agricultural management on topsoil structure, aggregates and associated organic carbon fractions: Analysis of long-term experiments in Europe

[1,2*]Ioanna S. Panagea, [3]Antonios Apostolakis, [4]Antonio Berti, [5] Pavel Čermak, [1]Jan Diels, [6]Annemie Elsen, [5]Helena Kusá, [4]Ilaria Piccoli, [1,7] Jean Poesen, [8]Chris Stoate, [8]Jenny Bussell, [6]Mia Tits, [9]Zoltan Toth, [1]Guido Wyseure

[1] Department of Earth and Environmental Sciences, KU Leuven, Belgium
[2] Plant Sciences Unit, Flanders research institute for agriculture, fisheries and food (ILVO), Belgium
[3] Max-Planck-Institute for Biogeochemistry, Germany
[4] DAFNAE Department, University of Padova, Italy
[5] Crop Research Institute, Czech Republic
[6] Soil Service of Belgium (BDB), Belgium
[7] Institute of Earth and Environmental Sciences, Poland
[8] Game & Wildlife Conservation Trust, Allerton Project, UK
[9] Institute of Agronomy, Georgikon Campus, Keszthely, Hungarian University of Agriculture and Life Sciences, Hungary

Inversion tillage is a commonly applied soil cultivation practice in Europe, which has been blamed though, for deteriorating topsoil structure and organic carbon (OC) content. This has subsequent negative effects on SOC storage as it increases the outputs through mineralization and leads towards a negative balance between the inputs and outputs. In this study, the potential to reverse these negative effects in the topsoil by alternative agricultural management practices, was evaluated in five long-term experiments in Europe, run by the partners of the Horizon 2020 SoilCare project. Topsoil samples (0 –15 cm) were collected and analyzed to evaluate the effects of conservation tillage (reduced and no-tillage) or increased organic inputs of different origin (farmyard manure, compost, crop residues) combined with inversion tillage on topsoil water retention (SWR), stability, aggregate distribution and within these aggregates fractions, OC distribution. Effects from the treatments on the two main components of organic matter i.e., particulate (POM) and mineral associated (MAOM), were also evaluated. Reduced and no-tillage practices, as well as the additions of manure or compost, increased the aggregates mean weight diameter (MWD) and topsoil OC, as well as the OC corresponding to the different aggregate size fractions. The incorporation of crop residues had a positive impact on the MWD but a less profound effect on OC content both on total OC and on OC associated with the different aggregates. A negative relationship between the mass and the OC content of the microaggregates (53 – 250 μm) was identified in all experiments. There was no effect on the mass of the macroaggregates and the occluded microaggregates (mM) within these, while the corresponding OC contents increased with less tillage and more organic inputs. Inversion tillage led to less particulate organic matter (POM) within the mM, whereas the different organic inputs did not affect it. In all experiment where the total POM increased, the total soil organic carbon (SOC) was also affected positively. The direct impact of the SOC increase on SWR was consistent but negligible, whereas the indirect impact of SOC in the higher matric potentials, which are mainly affected by soil structure and aggregate composition, prevailed. We concluded that the negligible effect of SOC under different management practices during drier conditions, and the increased effect in wetter conditions, implies that the indirect effects of SOC increase in the soil structure, are more important and should be considered and that the negative effects of inversion tillage on topsoil structure and OC content can be mitigated by reducing the tillage intensity or by adding organic materials combined with non-inversion tillage methods, in order to increase the SOC stocks and diminish the decomposition of old OC.

Keywords: soil structure; organic matter fractionation; aggregate distribution; water retention

Why a project on soil organic carbon dynamics in inorganic carbon-rich soils?

Chevallier Tiphaine[1*], Cournac Laurent[1], Sebag David[2], Kowalewski Isabelle[2], Hannam Kirsten[3], Ellert Benjamin[4], Gorzelak Monika[4], Dóra Zacháry[5], Zoltán Szalai[5], Gergely Jakab[5], Tibor Filep[5], Marianna Ringer[5], Lucas Trombino[6], Anna Masseroli[6], Eric Verrechia[7]

[1] *UMR Eco&Sols, IRD, Montpellier, France*

[2] *IFPEN, Rueil-Malmaison, France*

[3] *Agriculture & Agri-Food Canada, Summerland, Canada*

[4] *Agriculture & Agri-Food Canada, Lethbridge, Canada*

[5] *Geographical Institute, Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*

[6] *Università degli Studi di Milano, Milano, Italy*

[7] *Institute of Earth Surface Dynamics - Faculty of Geosciences and the Environment, Lausanne, Switzerland*

** Presenting author: tiphaine.chevallier@ird.fr*

Keywords: Biogeochemistry**,** Carbonates, Organic carbon stabilisation, soil C analysis issues [max 5]

Soil is the largest continental carbon (C) sink and contributes to the global C cycle. Two-thirds of soil C is organic (soil organic carbon, SOC). SOC accumulation or loss results from the balance between the capture of atmospheric CO_2 by plants, the incorporation of C-rich plant litter into the soil, and the re-release of this C as CO_2, via root respiration and microbial activity. SOC plays a well-known role in the physical, chemical, and biological properties of soils and the challenge of maintaining soil fertility while promoting soil C storage is widely recognised. The third of soil C is inorganic (soil inorganic carbon, SIC). SIC consists of lithogenic, or petrogenic (primary) carbonates inherited from the bedrock, and pedogenic (secondary) carbonates precipitated in the soil *in situ*. Because SIC pools are generally considered more stable and less sensitive to human activities than SOC pools in the short term, SIC dynamics have received less research interest. Moreover, analytical difficulties in studying SOC and SIC separately have impeded knowledge on the dynamics of SOC in SIC-rich (i.e., carbonate-containing or calcareous) soils. Consequently, the contribution of calcareous soils to the global C balance are given little consideration, even though they cover one third of the Earth's surface.

Although interactions between SIC and SOC pools have been described in the short-term, they are poorly understood. Isotopic analyses have shown that SIC-rich soils emit CO_2 from both the organic and inorganic C pools. Furthermore, soil biota (bacteria, roots, fungi) have the ability to precipitate bio-minerals (SIC) during the metabolic transformation of SOC (inherited or neoformed origin of SIC). Our project proposes the simultaneous study of SOC and SIC content, composition and dynamics. The unique processes of SOC stabilization in soil containing SIC will be also studied. The main objectives are to propose innovative analytical tools for quantifying and describing SOC and SIC, and to acquire knowledge on C interactions and C balance in calcareous soils, according to the use and management of the soils.

The project is based on 3 scientific work packages: **(1)** Integrated methodology to study SOC and SIC forms: protocols to analyse SOC and SIC pools will be compared and developed **(2)** Processes of SOC stabilisation in carbonate soils: thermal, physical (size), chemical and morphological analysis of SOC in different calcareous contexts will be used to explore the relationships between SOC and SIC. And **(3)** contributions of SIC and SOC to C fluxes between the soil and atmosphere: relationships between soil properties, SIC and SOC forms, and C dynamics will be studied through soil incubation studies; data will be used to develop a model that can be used to explore interactions between SOC and SIC pools in situ. Research will mainly focus on the solid phases of SOC and SIC in a collection of soils with varying SOC and SIC contents. Finally, our ambition is to build a scientific community studying the C cycle in calcareous soils.

[max 500 words]

Retrieving SOC content from space at the detailed scales of small regions: purposes and first results of the EJP-STEROPES project

Emmanuelle Vaudour[1*], Johanna Wetterlind[2], Luboš Borůvka[3], James Biney[1, 3], Diego Urbina-Salazar [1, 5], Asa Gholizadeh[3], Fabio Castaldi[4], Dominique Arrouays[5], Anne C. Richer-de-Forges[5], Mohammadmehdi Saberioon[6, 7], Pasquale Nino[8], Silvia Vanino[8], Fenny van Egmond[9], Renaldas Žydelis [10], Didier Michot[11], Youssef Fouad[11], Artur Lopatka[12], Jose L. Gabriel[13], Nádia Castanheira[14], Ana Marta Paz[14], Muhammed Halil Koparan[15], Cantekin Kivrak[15], Frank Liebisch[16], Raimonds Kasparinkis[17], Mogens H. Greve[18]

[1] *Université Paris-Saclay, INRAE, AgroParisTech, ECOlogie fonctionnelle et écotoxicologie des agroécoSYStèmes, 78850 Thiverval-Grignon, France.*

[2] *Swedish University of Agricultural Science (SLU), PO Box 234, SE-532 23 Skara, Sweden*

[3] *Department of Soil Science and Soil Protection, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague (CZU), Kamýcká 129, Prague-Suchdol, 16500, Czech Republic*

[4] *Institute of BioEconomy, National Research Council of Italy (CNR), Via Giovanni Caproni 8, 50145 Firenze, Italy.*

[5] *INRAE, Infosol, 45075 Orléans, France*

[6] *ILVO, Flanders Research Institute for Agriculture, Fisheries and Food, Technology and Food Science-Agricultural Engineering, 9820, Merelbeke, Belgium*

[7] *Section 1.4 Remote sensing and Geoinformatics, German Research Centre in Geosciences, Telegrafenberg, 14473 Potsdam, Germany*

[8] *Council for Agricultural Research and Economics (CREA) Via Po 14, - 00198 Roma*

[9] *Wageningen Environmental Research, Droevendaalsesteeg 3, Wageningen, the Netherlands*

[10] *Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry (LAMMC), Instituto al. 1, Akademija, LT-58344 Kėdainiai, Lithuania*

[11] *UMR SAS, Institut Agro, INRAE, 35000, Rennes, 65, rue de Saint Brieuc, France.*

[12] *Institute of Soil Science and Plant Cultivation – National Research Institute (IUNG), Czartoryskich 8, 24-100 Puławy, Poland*

[13] *INIA-CSIC, Ctra. de la Coruña km 7,5, 28040 Madrid, Spain.*

[14] *National Institute for Agricultural and Veterinary Research (INIAV), Av. da República, Quinta do Marquês, 2780-157 Oeiras, Portugal.*

[15] *Republic of Turkey Ministry of Agriculture And Forestry General Directorate of Agricultural Research And Policies (TAGEM), Çankaya/Ankara 06800 Turkey*

[16] *Agroscope, Research Division Agroecology and Environment, Reckenholzstrasse 191, CH-8046 Zürich, Switzerland*

[17] *Department of Agroecology, Aarhus University (AU), Blichers Allé20, 8830 Tjele, Denmark*

[18] *Faculty of Geography and Earth Sciences, University of Latvia (UL), 19 Raiņa Blvd., Riga, Latvia*

Conventional high-detail soil maps are static and often based on obsolete data in relation to the time of use. In the framework of the European Joint Programme (EJP) SOIL, the EJP-STEROPES project initiated in February 2021 gathers 14 countries (https://ejpsoil.eu/soil-research/steropes/). As multispectral satellite series such as Sentinel-2 time series are now freely available with a weekly frequency, STEROPES aims to assess the potential to predict cropland soil organic carbon content from such satellite data over various pedoclimatic conditions and cropping systems across Europe. While encouraging performances were recently obtained from Sentinel-2 (S2) for temperate soils of Europe and annual crop systems, little is known about the S2 capabilities for many other soil types and agroecosystems across Europe. Therefore, the focus lays on a detailed mapping that could serve as key information in decision making for farmers, governmental institutions and agricultural advisers, or other stake-holders involved in land planning.

Several datasets have been collected focusing on small regions of some hundreds of km^2 or on detailed scales of farms or catchments of some km^2, for which soil organic carbon samples were already available with an areal density higher than 1-3 samples/km^2. Spectral models were constructed from the reflectance image spectra of optical satellite series, using several commonly used algorithms including partial least squares regression (PLSR), support vector machine regression (SVM) and random forest (RF).

Overall encouraging performances have been obtained (RPIQ >1.7), but vary in time and geographical space according to several factors especially soil moisture, texture, dry vegetation due to management practices, and salinity. The following stages of the STEROPES project include the analysis of each of these disturbing or influencing factors and their joint effect.

The project is closely linked with the achievement of task 6.4 within WP6 in the EJP Soil, which aims at developing methods for accounting, monitoring and mapping agricultural soil carbon, fertility and degradation changes, with particular focus on using innovative inventory techniques such as proximal sensing integrated with current and upcoming satellite products.

Keywords: satellite remote sensing; Sentinel-series, soil organic carbon content; croplands

THE EFFECT OF TWO DIFFERENT ROTATION SYSTEMS ON SOIL ORGANIC MATTER IN ORGANIC FORAGE CULTIVATION

Ulfet ERDAL[1*], Ahmet Esen CELEN[2]

[1]International Agricultural Research and Training Center, Menemen, Izmir, Turkey
[2]Department of Field Crops, Faculty of Agriculture, Ege University, Bornova, Izmir, Turkey
*Corresponding author: ulfeterdal@yahoo.com

Abstract

Crop rotation has a key role in improving the soil and increasing the yield. Crop rotation with legumes, recycling of crop residues and the application of organic manure must form the basis of nutrient management in organic farming. Presence of legumes in rotation may serve as the primary source of nitrogen for subsequent crops. Most deficiencies in the soil are directly linked to low organic matter content. Organic matter has a very crucial significance for soil fertility improvement. The aim of this study was to determine the effects of some plants used in animal feeding on soil organic matter (SOM). For this purpose some certain plants have been selected and tested in two different rotation systems. This study was carried out in Menemen Plain, in Aegean Region, Izmir, Turkey during a period of 5 years between 2012 and 2016. Trial was set up in a randomized block design with four replications. According to the results of soil analysis, organic fertilizer containing 2 % N, 2.5 % P2O5, 2.5 % K2O, 60 % organic matter and 9/12 C/N was given to the plots. Fertilization was carried out so as not to exceed 170 kg / ha nitrogen as stated in the organic farming law. In the study, the fertilizer applications required by the plants were made considering the residual nitrogen from the plant roots. In the first rotation system Persian clover - silage maize, vetch/triticale mixture– cotton, Persian clover - silage maize, vetch/triticale mixture – cotton, in the second rotation system Persian clover - silage maize, triticale (grain) – second crop soybean, Persian clover - silage maize, triticale (grain) – second crop soybean were consecutively cultivated for five years. Soil organic matter (SOM) in soil samples taken from 0-20 and 20-40 cm in rotation system mentioned above was analyzed. According to analysis results, plant in the first rotation system affected SOM better than those of the second rotation system. It can also be stated that selected crops play an important role in SOM.

Keywords: *Crop rotation, Organic forage crop, Soil organic matter* (SOM).

Synergies and trade-offs of carbon sequestration in agricultural soils: a global literature synthesis

Sánchez-Moreno Sara[1], Petersen Søren O.[2], Velthof Gerard[3], Munkholm Lars[2], Ros Mart[3], Feizene Dalia[4], Gómez-Gallego Tamara[5], Jeanbille Mathilde[6], Dammie Nompumelelo[7], Juhanson Jaanis[8], Peixoto Leanne[2], Feiza Virginijus[4], Aponte Cristina[1], Parasotas Irmantas[4], Kochiieru Mykola[4], Amaleviciute-Volunge Kristina[4], Pulido-Moncada Mansonia[2], Walder Florian[7], Ramos Juan Luis[5], Philippot Laurent[6], van der Heijden Marcel[7], Hallin Sara[8] and Goberna Marta[1*].

[1] *Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA-CSIC), Madrid, Spain*

[2] *Aarhus University, Aarhus, Denmark*

[3] *Wageningen Enviromental Research, Wageningen University & Research, Wageningen, Netherlands*

[4] *Lietuvos Agrariniu Ir Misku Mokslu Centras (LAMMC), Akademija, Kedainiai, Lithuania*

[5] *Estación Experimental del Zaidín (EEZ-CSIC), Granada, Spain*

[6] *Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAe), Dijon, France*

[7] *Agroscope, Zürich, Switzerland*

[8] *Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden*

** Presenting author: marta.goberna@inia.es*

Agricultural management practices aimed at minimising soil disturbance, diversifying cropping systems and increasing organic matter inputs, often referred to as conservation agriculture, promote carbon (C) sequestration in soils. Enhanced C storage can have synergies with many agroecosystem services, but may come at the cost of climate regulation services depending on the environmental context. To review the trade-offs and synergies of C sequestration in agricultural soils, we performed a global systematic literature synthesis to address: 1. What are the synergies of C sequestration practices with soil structure and soil biota?, 2. What are the associated trade-offs with respect to greenhouse gas (GHG) emissions and nutrient losses?, and 3. How does the magnitude of synergies and trade-offs vary across pedoclimatic regions and change over time since adoption of conservation agricultural practices?

We defined search terms and performed systematic literature searches in the Web of Science for articles that: 1. experimentally assay the effect of conservation agriculture, and 2. include measurements of C sequestration and at least one other response variable related to synergies or trade-offs with nutrient losses or climate regulation services. We retrieved 771 publications, 565 of which were excluded based on i) the type of article (review, opinion papers), ii) a focus on non-soil habitats, forests or organic soils, or iii) experimental designs not matching our criteria. We included 206 studies that report 502 effects of conservation practices on 215 sites located in 34 countries. Experiments averaged 9.6 years of monitoring and the majority reported effects of increasing organic matter inputs and minimising soil disturbance (89%) in temperate and continental climates (80%). Considering all management practices together confirmed that soil organic C increased, without compromising crop yields. Synergistic effects were found for soil biota, i.e. positive effects of conservation versus standard practices on soil biota biomass were more frequent than expected by chance. There were no clear effects on biodiversity. However, in terms of soil structure and physical properties equal numbers of positive and neutral effects were detected. Negative effects of C inputs were significant when considering GHG emissions and nutrient losses, and similar numbers of negative and neutral effects were found for CO_2 and N_2O emissions, and nitrogen and phosphorus losses. We examine how these effects vary across management practices, time and space, and discuss implications for mitigation strategies. Furthermore, we review the main knowledge gaps detected in the literature and the present analysis that should be covered in future research.

Keywords: agricultural management, soil biota, soil structure, greenhouse gas emissions, nutrient losses

Soil carbon sequestration is possible without trade-offs

Keel Sonja G.[1*], Bretscher Daniel[1], Leifeld Jens[1], von Ow Albert[2] and Wüst-Galley Chloé[1]

[1] *Agroscope, Climate and Agriculture Group, Zurich, Switzerland*

[2] *Agroscope, Economic Modelling and Policy Analysis Group, Tänikon, Switzerland*

** Presenting author: sonja.keel@agroscope.admin.ch*

After the 4p1000 initiative was launched, it received mixed critique in the literature. The initiative highlighted that an annual increase of 4 ‰ soil organic carbon per year in the upper 30 to 40 cm of soil, would significantly reduce atmospheric carbon dioxide concentrations. Potentials to sequester carbon were said to be strongly overestimated because limiting factors such as the availability of nutrients were ignored. Furthermore, increasing fertilization rates to enhance carbon inputs through higher biomass was criticized, as it may result in negative trade-offs such as enhanced ammonia and nitrous oxide (N_2O) emissions as well as nitrate leaching.

Using Switzerland as an example, we show that significant rates of soil carbon sequestration can be achieved without causing trade-offs for greenhouse gas emissions. We study the potential of cropland that can be allocated to biochar production instead of food production, while assuming no further increase of food and feed imports. Since plant-based food production is more efficient than animal food production, feed production on cropland soils, which currently occupies 60 % of the arable area is strongly reduced and creates free land. The resulting diets become healthier by decreasing the consumption of oil, sugar and alcohol and a moderate decrease in meat intake. These reductions are compensated by increases in the intake of starch and dairy products. Under this scenario it is possible to maintain methane (CH_4) and N_2O emissions, despite a projected increase in the Swiss population of 43 % until the year 2100 and an associated increase in food demand. In contrast, CH_4 and N_2O emissions would increase by 25 % and 14 % in the baseline scenario, which only accounts for an increasing population, but minimizes changes in diets. The resulting free land, which we suggest can be turned into agroforestry, is used to produce woody biomass. We assume a planting of short rotation coppice (fast growing trees) in rows along fields, which do not require fertilization and are regularly harvested to produce biochar. This biochar is then applied as a soil amendment on remaining cropland soils. On average a sequestration rate of 0.53 t C ha^{-1} yr^{-1} or 10 ‰ for 0-30 cm depth could be achieved for the years 2020-2100. However, without an increase in food imports, the area available for agroforestry rapidly declines towards the end of the 21st century because the land is needed for food production due to an increasing population. Yet, because of the longevity of biochar in soil, increased SOC stocks are maintained in the longer run.

In summary, we show that even in a densely populated country considerable rates of soil carbon sequestration can be achieved with benefits for the environment. The biggest challenge however, is how to reach the projected dietary changes. An opportunity might be the involvement of health organizations, because the changes described in this study are likely to have health benefits.

Keywords: greenhouse gas emissions, diet, food security, population growth, 4p1000