Soil organic carbon and nitrate leaching loss in organic and conventional farming systems for the current and near future climate

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In Finland, nitrate (N) leaching loss and soil organic carbon (SOC) decrease are current environmental threats. The aim of the study is to simulate soil C dynamic and N leaching loss for conventional (C) and organic (O) farming systems producing either crops (C) or livestock (L) in South Savo (Finland). Simulations were carried out by using the process-based model ARMOSA for both current (1999-2018) and near future climate scenarios (2020-2040, RCP 6.0: annual change + 0.8 °C, -70 mm). Daily meteorological data from Mikkeli station, and the statistical data in the region during the last 20 years served as model inputs.

Five-year crop rotations were simulated on loamy sand soil (C 3.5 %, C/N ratio 17, pH 6.2). In crop farm, rotations included cereals (with fodder pea in the organic farm), oilseed rape and grass, while in the livestock farm, the rotation consisted of two years of cereals followed by a 3-year fescue and timothy meadow (with clover in the organic farm). In the crop farm, we simulated three conventional cropping systems: mineral fertilizer with either crop residues removed (C1-R) or incorporated into soil (C1+R), mineral fertilizer + slurry, residues incorporated (C2+R); and two organic systems: green manure (O1+R) or meat and bone meal-based commercial organic fertilizer, Ecolan Agra® (O2+R). In the livestock farm, we simulated conventional and organic cropping systems: mineral fertilizer + slurry with either residues removed (LC-R) or incorporated into soil (LC+R); slurry with either residues removed (LO-R) or incorporated (LO+R).

The results showed that conventional crop production systems led to relevant SOC decline of 500-750 kg $ha^{-1}yr^{-1}$ at 0-30 cm soil depth, while organic systems showed either less SOC decline (120 kg $ha^{-1}yr^{-1}$) as in O1+R, or slight SOC increase (55 kg $ha^{-1}yr^{-1}$) as in O2+R. Under the future climatic conditions, the model estimated a faster degradation of SOC for all the cropping systems, except for O2+R that still resulted in a negligible SOC increase. Annual N leaching predicted to be about 10 kg NO_3-N ha^{-1} yr^{-1} for conventional crop farms (C1-R/+R; C2+R), while 3 kg NO_3-N ha^{-1} yr^{-1} for organic crop farm with green manure (O1+R). Under the future climate scenario, conventional cropping systems are prone to an increased N leaching loss, up to 20 kg NO_3-N ha^{-1} yr^{-1}, but organic systems do not.

The simulation of livestock farm showed a negligible loss of SOC about 25-160 kg $ha^{-1}yr^{-1}$ in LC-R, LC+R and LO-R, while a small SOC increase of 20 kg $ha^{-1}yr^{-1}$ in LO+R. Annual N leaching loss varied between 6 and 9 kg NO_3-N ha^{-1} yr^{-1} with very little differences between organic and conventional systems due to use of perennial grass in rotation and slurry as N-fertilizer. In the future climate, the model forecasted an overall increase of SOC losses for all systems, and the larger N loss in organic livestock farm, up to 15 kg ha^{-1} yr^{-1}.

In conclusion, the modelling results suggest that using green manure and crop residue incorporation as a source of organic matter allowed to sequester soil C and pose only negligible N leaching loss in organic crop production farms. In contrast, using slurry in organic livestock farms caused trade-offs between soil C sequestration and N leaching loss for the current climate, and loss of both, soil C and N, for the future climate.

Keywords: organic farming, slurry; green manure; residue incorporation; soil organic carbon, nitrate leaching, climate change

Soil carbon sequestration and trade-offs with greenhouse gas emissions and nitrogen leaching: identifying knowledge gaps

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Carbon sequestration in agricultural soils is an important strategy to mitigate climate change. Stimulation of soil organic carbon (SOC) sequestration can be achieved via different soil management strategies. Nevertheless, such strategies may stimulate nitrous oxide (N_2O) and methane (CH_4) emissions and cause nitrogen (N) leaching losses. While these trade-offs can offset the climate change mitigation obtained via SOC sequestration, synergistic effects of certain soil management strategies may positively affect the mitigation potential. Despite the importance of these trade-offs and synergies for the selection of sustainable and climate-proof soil management strategies, knowledge on these effects remains limited.

The ∑OMMIT-project aims to investigate the trade-offs and synergies for the most relevant soil management strategies applied in European agricultural systems. A dedicated literature study was made, summarizing the results of reviews, meta-analyses, reports, and original articles. The most important soil management strategies were identified and grouped into four categories: tillage management, cropping systems, water management, and fertilization and organic matter (OM) inputs (crop residues, cover crop, livestock manure, slurry, compost, biochar, liming). Search criteria including literature and land use type, time-period, and geographic origin resulted in a unique selection of 110 references (31 reviews, 46 meta-analyses, and 33 original papers). Meta-data, extracted knowledge gaps, research recommendations and main conclusions were compiled in a knowledge gap review which provides better insights in existing trade-offs and synergies and acts as guidance to future research.

This review highlights that the increase of both SOC stock change and the microbial biomass C and N, as well as a reduction in N leaching are positively affected by conservation tillage, crop rotation, permanent cropping, more efficient water management as well as using fertilization and OM inputs

(e.g., cover crops, organic amendments, biochar, and liming). The effects on N_2O and CH_4 emission mitigation are dependent on the specific soil management strategy (e.g., water management, fertilization and OM inputs) and require more extensive research before uniform conclusions can be drawn.

In conclusion, future studies should examine the effects of soil management strategies on both SOC stocks, GHG emissions, and N leaching losses. Furthermore, a more concerted use and installation of new long-term field experiments in different pedo-climatic European regions, will be essential to fully elucidate the impact of soil management strategies at the European level. Indeed, we identified a lack of information on the impact of pedoclimatic conditions on trade-offs and synergies, especially on the long-term. Further, since soil management strategies are often combined and their interaction may affect the trade-offs and synergies, the impact of different soil management practices should be assessed simultaneously. Overall, the review provides a unique framework to aid the (re)design of dedicated field experiments and targeted measurements as well as simulations to improve our understanding of the identified knowledge gaps.

Keywords: carbon sequestration, greenhouse gas emissions, nitrate leaching, trade-offs, knowledge gaps

Short-term effects of N fertilization on soil carbon and N_2O emissions in two irrigated maize cropping systems

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In Mediterranean areas, irrigated maize is associated with high-water consumptions and an excessive nitrogen (N) fertilizer use. The direct result of this intensive production model is the high maize yields representative of these irrigated areas. However, this productive model has also negative side effects derived from the high risk of environmental degradation, particularly N leaching and N_2O emissions. Furthermore, the usual cropping system based on maize monocropping with bare tilled fallow in-between maize growing seasons promotes soil organic carbon (SOC) losses. In this context, the intensification of these maize cropping systems with the substitution of the fallow period with a legume crop is a promising strategy which may favour not only the reduction of N fertilization rates and, in turn, the associated soil N_2O emissions, but also the increase in SOC levels. Accordingly, the main aim of this study was to evaluate the impact of N fertilization on SOC changes and soil N_2O emissions in the next two different maize systems: a maize monocropping with bare tilled fallow in between maize seasons and a pea-maize double cropping. To achieve this objective and within the framework of the UE H2020 Diverfarming project, in the two selected cropping systems (maize monocropping and pea-maize double cropping) three mineral N rates (unfertilized; medium rate; and high rate) were evaluated in a field experiment established in NE Spain during two years (2019 and 2020). The layout consisted in a split-block design with each treatment replicated three times. During the studied period, the N rate had a significant effect on soil N_2O emissions particularly immediately after the N application when, in both systems, quick and high increases of soil N_2O fluxes were observed. However, when both cropping systems were compared, the pea phase obtained greater N_2O emissions than the fallow phase but the maize after pea showed similar or even lower N_2O emissions than the maize under fallow. After two years, SOC changes differed among cropping systems and N rates. All three N rates showed SOC losses in the maize monocropping but, in contrast, increases in the pea-maize system. According to all this, the analysis of trade-offs showed differences among cropping systems and N fertilization strategies stressing the impact of these two management practices on the mitigation potential of irrigated maize systems located in Mediterranean conditions.

Keywords: Irrigated maize; SOC sequestration, Soil N_2O emissions; Trade-off analysis; N fertilization

Cover crops affect non-growing season N_2O emissions in boreal cereal cropping

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Keywords: C sequestration; off-season; GHG trade-offs

Use of cover crops under-sown to or in rotation with cereals has been recommended to increase soil carbon (C) stocks. However, producing additional biomass for C sequestration has a nitrogen (N) cost, both in form of increased N fertilizer use and by potentially increasing nitrous oxide (N_2O) emissions after mulching or incorporating cover crops. The presence of N-rich, frost-sensitive aboveground biomass can be a particular problem during wintertime, in which freeze-thaw driven emission pulses drive much of the annual N_2O emission in many temperate and boreal regions. Here we report growing season and over-winter N_2O emissions in a plot experiment in SE Norway, studying seven different cover crops (perennial and Italian ryegrass, oilseed radish, summer and winter vetch, phacelia and a 10-species herb mixture) in a barley cropping system. Cover crops where under-sown in spring or in summer, shortly before barley harvest. We found no significant effect of spring-sown cover crops (perennial and Italian rye grass, 10-species mixture) on barley yields or N_2O emissions, even though emissions tended to be lower in plots with ryegrasses during summer. Additional fertilization in fall (25 kg N ha^{-1}) to selected cover crops had no effect on off-season N_2O emissions. However, when the first night frosts occurred end of October, strongly elevated emissions were recorded from summer-sown oilseed radish, which had developed copiously throughout autumn. Elevated emissions from oil-seed radish persisted throughout early winter and were clearly higher than those from ryegrass or the mixture. Vetches and phacelia developed poorly and did not contribute significantly to N_2O emissions. N_2O emissions peaked in all treatments (including the control without cover crop) during diurnal freeze-thaw cycles in late winter. Notwithstanding, when cumulated for the entire winter, rye grasses and mixture emitted less N_2O than the control. Quantifying N_2O emission dynamics in snow-poor winters with frequent freezing-thawing cycles is challenging but plays an important role in evaluating GHG effect of cover crops. Nonetheless, the first year of our study demonstrates that cover crops should be chosen carefully as to their winter hardiness and ability to reuptake mineralized N during off-season to avoid offsetting potential carbon gains. The study continues through a second annual cycle using the same treatments to assess the effect of interannual variation in weather, notably during winter.

The ∑OMMIT index: a trade-off assessment tool to identify farming practices minimizing greenhouse gas intensity from agricultural systems

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The European Greenhouse Gas (GHG) mitigation policies need quantitative figures on the effect of management strategies on soil carbon sequestration and direct/indirect N_2O emissions, in order to identify ecologically intensive cropping systems that contribute to climate change mitigation. Evidences from scientific literature highlight that the impact of farming strategies (e.g., irrigation, fertilization, tillage) on the overall system sustainability is highly context-dependent, requiring a case-by-case evaluation to assess their interlinkages across pedo-environmental conditions. However, the current IPCC guidelines for national GHG Inventories provide default equations and emission factors for estimating carbon stock changes and N_2O emissions from agricultural soils, without explicitly considering antagonistic and synergetic interactions of farming practices across environments, and mostly disregarding the interdependence among carbon and nitrogen cycles. The ∑OMMIT project aims at filling current gaps of knowledge, thanks to the mobilization of interdisciplinary expertise and multiple research techniques including meta-analysis, long-term field experiments, and process-based simulation models. The unique datasets which will be produced by the project partners need to be harmonised and used to develop a trade-off assessment tool, capable to unravel the complex effects of soil management strategies on carbon sequestration and non-CO_2 GHG emissions. We will present the prototype of the ∑OMMIT index, the tool which will be used to perform trade-off analyses to identify best management strategies contributing to optimize the GHG intensity (emissions and removals) of the crop system, while preserving its productivity. The ∑OMMIT index is trained by an input layer constituted by multiple case scenarios, characterized by specific pedo-environmental conditions and soil management strategies. Each case scenario is associated to the value of four main trade-off components, i.e., carbon sequestration, nitrous oxide emissions, nitrate leaching and crop yield. Machine learning techniques (Variable-Importance Weighted Random Forests) are used to correlate each trade-off component with input layer variables, leading to informative modules where the relationships among soil management strategies are explicitly embedded. Expert opinion is then implemented *via* Multi Objective Decision Analysis to hierarchically aggregate these modules into a synthetic value of the ∑OMMIT index, ranging from 0 (worst trade-off) to 1 (best trade-off). The feasibility of the ∑OMMIT index to perform trade-off analysis has been tested on a dummy input layer, where correlations between management strategies, pedo-environmental conditions, and trade-off components have been superimposed. An online survey among project partners has been carried out to weight the importance of the different trade-off components on the synthetic index value. The results of this proof of concept have been released through an interactive dashboard, where users can test the effect of changing input layer variables on the overall system sustainability.

Keywords: soil carbon sequestration; crop management strategy; greenhouse gas emissions; nitrate leaching; crop yield