

Soil Organic Matter

IN A STRESSED WORLD

SYMPOSIUM ORAL ABSTRACTS

Sorted alphabetically
by Family Name

Minimal soil disturbance and increased residue retention increase soil carbon in rice-based cropping systems on the Eastern Gangetic plain

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Little is known about the impact of conservation agriculture (CA) practices on soil carbon dynamics in the intensive triple-cropping, rice-based systems of the Eastern Gangetic Plain (EGP). Our aim was to determine whether CA in these systems involving non-puddled transplanting (NP) of wetland rice and strip planting of dryland crops plus increased residue retention would increase the C storage in soils relative to conventional crop establishment practices. Long-term field experiments were studied in two locations of northwestern Bangladesh to determine C turnover as well as examining C cycling under three soil disturbance levels (conventional tillage-CT, strip planting-SP and bed planting-BP) in combination with low residue (straw) retention(LR) and increased residue retention (HR) in Calcareous Brown Floodplain (Alipur) and Grey Terrace soil (Digram). The total nitrogen(N), organic C(SOC), microbial biomass C (MBC) and water-soluble C(WSC) values were measured in soil samples collected at different stages during the growth of the 13th and 14th crops at Alipur and the 12th and 13th crops at Digram since treatments commenced. At each location, SP and BP with LR or HR retained more SOC from C inputs than CTHR and CTRL. In general, the CO₂ emissions under SPLR and SPHR were 13 to 59 % lower than those under CT and BP with LR and HR. The higher levels of C mineralization were associated with higher WSC contents in the soil. Similarly, in SPLR and SPHR, the potentially mineralizable C was higher, while decay rate constant was lower. The HR with SP and NP after 14 crops at Alipur and 13 crops at Digram modified the C cycle by decreasing C emissions and increasing the levels of total organic C in the soil. The application of both minimal soil disturbance and HR enhanced SOC concentrations in the soils under rice-based cropping systems on the EGP.

Quality of soil organic matter in high-latitude environments: From bulk to water-extractable soil organic matter

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Soil organic matter in Arctic and Subarctic regions plays a key role for the global carbon cycling. The objective of this study was to evaluate the structure and fate of soil organic matter in the high latitudes by jointly quantifying and characterizing both bulk and water-extractable organic matter in surface soil samples. We compared two study sites with similar tussock tundra ecosystems and distinct mean annual air temperature and permafrost conditions: Abisko, Sweden ($-1\text{ }^{\circ}\text{C}$, discontinuous permafrost) and Toolik, Alaska, USA ($<-8\text{ }^{\circ}\text{C}$, continuous permafrost). Both sites presented different bulk soil organic matter compositions: higher C/N and alkyl C/O-alkyl C ratios were reported at Abisko (27.1 ± 8.6 and 0.57 ± 0.17 , respectively) compared to Toolik (17.4 ± 2.3 and 0.44 ± 0.11 , respectively). These patterns are attributed to either distinct decomposition stages linked to climate conditions or distinct organic matter inputs with local vegetation influences. Extractable fractions indicated higher water-extractable organic matter concentrations in the colder site (i.e., at Toolik with $4.38\text{ mg gsoil}^{-1}$ of water-extractable organic carbon and $0.25\text{ mg gsoil}^{-1}$ of water-extractable total nitrogen) that we attribute to a higher pool of potentially mobilizable matter from a more preserved soil organic matter. Overall, the most significant result is that the intra-site heterogeneity of the soil organic matter quality was higher than the inter-site heterogeneity, in the bulk as well as in the water-extractable fractions. Finally, the qualities of both bulk and extractable fractions were not directly linked together: some specific patterns observed in the bulk fraction (e.g., locally lower alkyl C/O-alkyl C ratios) were not observed in the extractable one, and reciprocally (e.g., singular fluorescence signature).

Effect of the conversion to irrigation on mid-term soil organic C dynamics in a semiarid Mediterranean agrosystem. An approach using C natural isotopes

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The conversion of rainfed agricultural land to irrigation is a widespread strategy for increasing yields and the variety of crops cultivated. It can also have other repercussions in the agroecosystems. From the soil functioning perspective, changes in soil organic carbon (SOC) can be expected, as not only inputs from crop residues can change, but also the conditions for incorporation and mineralization of these inputs can be affected. The objective of this study was to identify and quantify the changes induced by this land-use change in SOC dynamics in a semi-arid Mediterranean region.

A 7-years C3-C4 chronosequence on a calcareous Mediterranean soil was used for this study. Maize and wheat are grown under two different management conditions: irrigated and rainfed. The dataset includes data on SOC stock (0-30 cm), crop residues inputs and $\delta^{13}\text{C}$ signatures of total SOC and the particulate organic carbon fraction (POC, $>53\mu\text{m}$). A two-compartment model (fast and slow cycling pools) was fit on the data to provide quantitative estimates of the turnover rates of SOC in the irrigated and non-irrigated maize plots

Results show that irrigation increases SOC stocks, both total and POC fraction. This increase is related to a raise by $72\pm 9\%$ of plant productivity and a faster turnover rate in the fast cycling pool. Contrary to what is commonly acknowledged for acidic or neutral soil, POC is not a good proxy for the fast-cycling C pool in the studied calcareous soil. This questions the suitability of analytical methodologies to isolate POC, and calls for a revision of POC correspondence with the soil labile C pool under certain conditions.

Comparison of constituents of dissolved organic matter in soil and lake water by two-dimensional HPLC

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Dissolved organic matter (DOM) is a major form of organic matter in the hydrosphere and plays an important role in the transport of trace metals such as iron. A significant portion of the hydrosphere DOM is considered to be leached from the soil. The purpose of this study was to clarify what kind of DOM constituent is leached from soil to hydrosphere by comparing the constituents of soil and lake water DOM samples. Lake DOM samples were prepared from the upstream and downstream lakes of the Iwaki River in the northern part of the Honshu island, Japan, and soil DOM samples were from representative soils of the river basin. For HPLC analysis, the hydrophobic fractions of DOM prepared by adsorption of acidified samples onto DAX-8 resin were used. For comparison, DAX-8 adsorbed fulvic acids were obtained by alkali extraction from the same soils. The constituents of DAX-8 adsorbed DOM fractions and fulvic acids were analyzed by two-dimensional HPLC using hydrophilic interaction chromatography (HILIC) followed by reverse phase chromatography (RP-HPLC). For the DAX-8 adsorbed fractions of soil and lake water DOM, the proportion of the constituents eluting in the most hydrophobic region upon HILIC was smaller than for soil fulvic acids. Upon RP-HPLC, sharp peaks exhibiting only UV absorption and broad peaks exhibiting featureless spectra with the absorbance decreasing gradually from the UV region to the visible region were eluted for the soil DOM and fulvic acids. In contrast, the lake water DOM mainly had broad peaks, and the number of sharp peaks was smaller than the soil DOM and fulvic acids. It was concluded that the main constituents of the DOM that leached from soil to the hydrosphere were dark-colored organic substances having absorption in the UV and visible regions and were more hydrophobic than soil fulvic acids.

Investigating the relationship between soil organic carbon and age in temperate blue carbon ecosystems.

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Blue carbon ecosystems such as mangrove forests, tidal marshes and seagrass meadows account for almost 50% of total soil carbon stores, globally. Their exceptionally high carbon burial rates are attributed to the retention of organic matter by extensive root systems that encourage deposition and prevent erosion of rich organic material. High carbon burial rates coupled with slow decomposition of the soil organic matter (SOM) results in long term carbon storage. However, the chemical nature of blue carbon through the soil profile and its potential vulnerability to decomposition, particularly with changes in environmental conditions, is largely unknown. The objective of this study was to investigate the relationship between chemical structure of the SOM in the blue carbon environment and its age. Specifically, we characterised the chemical structure of the soil organic carbon (SOC) in mangrove soils through the depth profile with solid-state ¹³C nuclear magnetic resonance (NMR) spectroscopy. Samples were collected from an undisturbed temperate mangrove forest in South Australia to a depth of 1 m. All samples were analysed for elemental carbon content and aged by ²¹⁰Pb and ¹⁴C (radiocarbon) dating methods prior to being selected for ¹³C NMR. Samples were selected to reflect a continuum in age based on short term (²¹⁰Pb) and long-term (¹⁴C) dating data. The relationship between age and chemistry was then assessed using a partial least squares regression (PLSR) analysis. Radiocarbon age tends to increase with depth and is assumed to reflect the mean residence time of the SOM and in turn its stability. Characterising the chemical structure of SOM through the depth profile will contribute to a better understanding of carbon cycling and long-term stability of SOC in the blue carbon environment. An in-depth analysis of the chemical structure of the blue carbon SOM and the PLSR analysis will be discussed.

Characterization of six different biochar-compost mixtures and the effect of a physical alteration on their kinetics of mineralization

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Application of Biochar, a solid product produced from biomass pyrolysis under low oxygen conditions, has been suggested as a low emission technology capable of increasing soil C sequestration to mitigate climate change. Due to its low reactivity and nutrient value in the first years after its deposition, the combined application of biochar with compost may be a promising avenue to ameliorate soil quality while increasing C sequestration. We hypothesize that synergistic effects of both materials have positive effects on organic matter protection. This study aims to compare the stability of six biochar-compost mixtures differentiated by biochar type, at a short time scale. Biochars were produced from different feedstocks at 650°C for 10 minutes. Our conceptual approach included incubation of fresh and artificially aged biochar-compost mixtures. Physical ageing of the mixtures was performed with successive cycles of humidification/drying and freezing/thawing. We evaluated microbial biomass, the elemental composition and stability of the fresh and aged mixtures after incubation with a soil inoculum for 15 weeks. We monitored biochar decomposition when produced from C4 feedstock by determination of the ¹³C signature of emitted CO₂. Mineralization kinetics of the biochar-compost mixtures depended on the nature of biochar, with mixtures containing biochar produced from maize biomass showing faster mineralization than mixtures containing biochar from miscanthus. C:N ratio, also depending on the nature of the biochar, were directly correlated with mineralization kinetics; a growing C:N ratio induced a lower mineralization rate. C:N ratios from biochar from miscanthus biomass had a different connection with mineralization rate. Results showed that biochar ageing influenced its interaction with compost by reducing the mixtures' decomposition rate. However, aged biochar from miscanthus feedstock more than doubled mineralization rate of the compost. We therefore conclude that biochar feedstock determines the capacity of biochars to interact with compost after ageing.

Gaseous emissions from lignite amended manure composting process

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Emissions of ammonia and greenhouse gases from agricultural systems results in the loss of valuable nitrogen (N), and has negative environmental impacts. Composting manure is a typical management practice on livestock farms, used to increase the content and availability of nutrients. We hypothesize that the addition of lignite, readily available in Australia, can retain N during manure composting. To test our hypothesis, a study was conducted at a commercial feedlot during the summer season. Prior to cattle entering a feedlot pen, we applied 6.48 tonnes of dry lignite to the pen surface, while no lignite was applied to a control pen. After 90 days, the cattle were removed, and manure from each pen was collected to form separate manure windrows, with and without lignite amendments. We quantified gaseous emissions of NH₃, nitrous oxide (N₂O), carbon dioxide (CO₂), and methane (CH₄) from both windrows with a micrometeorological technique using open-path Fourier transform infrared spectroscopy (OP-FTIR). Over the 87 days measurement period, the accumulative gas fluxes showed that the addition of lignite reduced NH₃ emissions by 54% during composting, but increased greenhouse gas (GHG) emissions (CO₂ equivalent, CO₂-e). The N lost as N-NH₃ was 9.7% and 24.4% of the total initial N in the lignite and non-lignite windrows, respectively, and the N lost as N-N₂O was 0.8% and 0.3% of the total N in the lignite and non-lignite windrows, respectively. To estimate the economic and environmental benefits of reducing gas emissions, we applied a cost-benefit analysis and found that lignite addition to cattle pens cost-effectively improved the nutrient value in final compost product, and could justify trade-off increased GHG emissions.

Predicting the carbon and nitrogen contents in soil from blue carbon environments using infrared spectroscopy

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Coastal blue carbon environments (mangroves, tidal marshes and seagrass meadows) can contain significant stocks of soil organic carbon and can accumulate additional organic carbon through the capture and retention of organic materials derived from autochthonous and allochthonous sources. Assessing soil organic carbon stocks present in these environments requires quantification of soil organic carbon concentration. Developments in the combined use of infrared spectroscopy and partial least squares regression analyses (IR/PLSR) have demonstrated an ability to provide cost effective measurement of organic carbon concentration in agricultural soils and additionally provide values for the concentrations of inorganic carbon and total nitrogen from one analysis. The objective of this study was to assess the capability of IR/PLSR analyses to provide accurate values for total (TC), organic (OC) and inorganic (IC) carbon and total nitrogen (TN) concentrations in soil samples derived from blue carbon environments. A total 1201 samples were used. All TC, OC, IC and TN analytical data were acquired using automated dry combustion analysers (LECO TruMac, C-144 or CNS-2000) with the application of acid pretreatment to soils containing carbonate. Independent sets of 300 and 901 samples were used respectively to develop and then validate IR/PLSR predictive algorithms. Robust IR/PLSR models were obtained for TC, OC, IC and TN concentrations given the values derived for the coefficient of determination ($R^2=0.91-0.96$), ratio of performance to deviation (RPD = 4.8-5.6) and ratio of performance to interquartile range (RPIQ = 2.5-3.8). After calibration, the concentrations of TC, OC, IC and TN of the blue carbon soils could be robustly predicted using a single IR scan. The IR/PLSR approach therefore provides a cost-effective alternative approach to quantifying the concentration of carbon and nitrogen in blue carbon soils.

Using organic and inorganic soil amendments to improve soil quality and plant recruitment for mine rehabilitation in arid landscapes

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In the arid Pilbara region in the north-west of Western Australia the disturbance footprint caused by large-scale mining practices exceeds 230,000 ha and has contributed to the loss of soil quality and functional ecosystems. Soils used in mine site rehabilitation are physically, chemically and biologically different to natural topsoil and lack the soil nutrients, organic matter and biological life necessary to support plant life and sustainable ecosystems. As such, the rehabilitation of these landscapes is challenging. Here, we present case studies based on the Pilbara region that examines the effect of organic and inorganic soil amendments (gypsum, urea, mulches and biochar) on plant establishment and soil quality in the context of mine site rehabilitation in an arid landscape. In addition, we discuss the role of native plant communities to improve soil quality. This research sought to test the effectiveness of soil amendments to promote soil recovery and the recruitment of plants used in dryland rehabilitation. Our results showed that although the use of inorganic amendments increased plant growth, the effects on soil quality is limited. However, the use of mulches as an amendment in rehabilitation increased soil organic matter and soil microbial activity. The soil quality of mine soils increased through the successful establishment of a diverse native plant community that increased litter quality and quantity. However, water was the predominant driver for determining the effectiveness of the soil amendments with changes in soil and plant indicators significantly decreasing as water became scarce. These studies contribute to understanding how soil amendments effect soil quality and plant recruitment in post-mining rehabilitation in arid regions and their role in reinstating functioning ecosystems.

Resistance and resilience of soil microbial communities to drought and heat stress in a Mediterranean agroforestry system

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Agroforestry systems are of growing interest and viewed as possible alternative to conventional cropping systems in the context of climate change. Our aim was to evaluate the resistance and resilience of soil microbial communities against drought with or without heat stress at different distances from the tree row in an agroforestry system as compared to a conventional cropping system. We simulated two cycles of drying-rewetting under controlled conditions and applied three distinct treatments: control (without stress), drought and drought combined with heat stress. We monitored microbial respiration over the incubation period. The inorganic N and microbial biomass C, N and P contents (MBC, MBN and MBP) were assessed during the drying period (resistance), just after rewetting and at the end of the experiment (resilience), while bacterial and fungal abundances were measured at the end of the resistance period. We demonstrated that an agroforestry system can induce spatial heterogeneity in soil microbial biomass and functions under control conditions. Microbial biomass and activity, soil organic matter (SOM) and mineral N levels increased on the tree row. This spatial heterogeneity pattern was preserved for soil microbial response to drought combined or not with heat. Microorganisms sampled in the middle of the interrow or in the conventional crop exhibited highest biomass resistance and lowest resilience when facing combined drought and heat stress. Our findings suggested that despite higher SOM content, microbial biomass and activity at and near the tree row, the legacy effect of the tree row did not lead to higher ecological stability under stressful climatic conditions. We also demonstrated that soil microorganisms can considerably change their stoichiometry depending on the stress treatment. A high stoichiometric flexibility of microorganisms was observed when exposed to drought stress only, while stoichiometric changes were irreversible when exposed to combined drought and heat stress.

Temporal dynamics of litter quality, soil types and microorganisms as main drivers of the priming effect

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Soil C priming effect (PE) describes the change in the rate of soil organic matter (SOM) mineralization due to the addition of fresh organic matter (FOM), and is thus central to our evaluation of carbon (C) fluxes in terrestrial ecosystems. Towards a more mechanistic understanding of the terrestrial C cycle, our main objective was to evaluate dynamically the regulatory mechanisms that control PE. To do so, we followed the kinetics of C fluxes over 202 days and 23 dates after additions of two ¹³C-labeled plant litters varying in their initial quality from nutrient-rich and relatively accessible litter (non-mature wheat) to nutrient-poor and recalcitrant litter (flax stem) using four soil types originating from a land-use gradient (forest, plantation, grassland and cropland). We analyzed at three time points (at 27, 97, and 202 days) the mass loss rates for the main sugars within the cell wall, nutrient mineralization, hydrolytic and oxidative enzymes and the fate of the labeled ¹³C litters within the microbial biomass, the atmosphere and the SOM. We addressed for the first time the temporal dynamic in the main factors controlling PE by employing an a priori structural equation modelling (SEM) that allowed us to simultaneously test the effects of litter, soil and microbial parameters during FOM and SOM decomposition. Our results showed that FOM additions can rapidly stimulate a PE at the day-scale, with N availability playing a primordial role in the balance between FOM and SOM mineralization at the month-scale. However, C incorporation in the soil can counterbalance C losses via PE. Considering the temporal dynamic in the main drivers influencing PE can increase the predictive power of decomposition models that are currently limited by a lack of understanding in the regulatory mechanisms that control soil C fluxes from short- to long-term.

Co-composting solid biowastes with alkaline materials to enhance carbon stabilization and revegetation potential

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Co-composting biowastes such as manures and biosolids can be used to stabilize carbon (C) without impacting the quality of these biowastes. This study investigated the effect of co-composting biowastes with alkaline materials on C stabilization, and monitored the fertilization and revegetation values of these co-composts. The stabilization of C in biowastes (poultry manure and biosolids) was examined by their composting in the presence of various alkaline amendments (lime, fluidized bed boiler ash, flue gas desulphurization gypsum, and red mud) for 6 months in a controlled environment. The effects of co-composting on the biowastes' properties were assessed for different physical C fractions, microbial biomass C, priming effect, potentially mineralizable nitrogen, bioavailable phosphorus, and revegetation of an urban landfill soil. Co-composting biowastes with alkaline materials increased C stabilization, which is attributed to interaction with alkaline materials, thereby protecting it from microbial decomposition. The co-composted biowastes also increased the fertility of the landfill soil, thereby enhancing its revegetation potential. Stabilization of biowastes using alkaline materials through co-composting maintains their fertilization value in terms of improving plant growth. The co-composted biowastes also contribute to long-term soil C sequestration and reduction of bioavailability of heavy metals. Furthermore, of the materials used in this study, the co-composted biosolids with lime were found to be the most suitable for SOM storage due to its low priming effect. Although the addition of industrial byproducts such as coal combustion products improves the value of composts in relation to increasing revegetation potential, reducing heavy metal bioavailability and enhancing C sequestration, cost, and availability of these materials must be taken into consideration in field scale applications.

A quest for microbial wisdom: elucidating the ecology of oxidative decomposition using nitrogen addition to boreal forests

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The addition of nitrogen (N) to forest soils tends to inhibit oxidative enzyme expression by soil microbes and, likely as a consequence, reduces decomposition rates. Accordingly, soil organic matter (SOM) tends to increase following long-term N enrichment, which is typically seen chiefly as a consequence of inhibited decomposition. The mechanism for oxidative enzyme inhibition by N is unknown. It has been speculated that N-demanding microbes outcompete oxidase-synthesising microbes, or N abiotically couples with aromatic compounds to produce substrates more resistant to decomposition. The latter hypothesis is inconsistent with observed chemistry of accumulated SOM, and the former is challenged by i) the general condition of carbon limitation of soil saprotrophs, and ii) the evolutionary argument that N limited microbes would have strong selective pressure towards oxidative enzyme expression for SOM decomposition. We propose a hypothesis that includes elements kindred to both of the prior explanations, but falls more cleanly in line with empirical observation and evolutionary prediction. We suggest that high rates of N addition do indeed suppress oxidative enzyme expression through altering competitive balance, and that coupling of N with aromatics is the driver. However, the shift in competition is not between genotypes with contrasting N needs, but between phenotypes with contrasting strategies for carbon acquisition, and the products formed by coupling of N with aromatics are easily degraded and short-lived. Our hypothesis is consistent with metatranscriptomic, chemical assay, and SOM compositional results from two boreal forest fertilisation trials in northern Sweden. We discuss clear predictions that arise from the hypothesis about interactive effects of N enrichment, temperature increase, and elevated atmospheric carbon dioxide on decomposition and SOM.

Nutrient enrichment induces a shift in dissolved organic carbon (DOC) metabolism in oligotrophic freshwater sediments

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Dissolved organic matter (DOC) turnover in aquatic environments is modulated by the presence of other key macronutrients, including nitrogen (N) and phosphorus (P). The ratio of these nutrients directly affects the rates of microbial growth and nutrient processing in the natural environment. The aim of this study was to investigate how labile DOC metabolism responds to changes in nutrient stoichiometry using ¹⁴C tracers in conjunction with untargeted analysis of the primary metabolome in upland peat river sediments. N addition led to an increase in ¹⁴C-glucose uptake, indicating that the sediments were likely to be primarily N limited. The mineralization of glucose to ¹⁴CO₂ reduced following N addition, indicating that nutrient addition induced shifts in internal C partitioning and microbial C use efficiency. This is directly supported by the metabolomic profile data which identified significant differences in 22 known metabolites (34% of the total) and 30 unknown metabolites (16 % of the total) upon the addition of either N or P. ¹⁴C-glucose addition increased the production of organic acids known to be involved in mineral P dissolution (e.g. gluconic acid, malic acid). Conversely, when N was not added, the addition of glucose led to the production of the sugar alcohols, mannitol and sorbitol, which are well known microbial C storage compounds. P addition resulted in increased levels of several amino acids (e.g. alanine, glycine) which may reflect greater rates of microbial growth or the P requirement for coenzymes required for amino acid synthesis. We conclude that inorganic nutrient enrichment in addition to labile C inputs has the potential to dramatically alter in-stream biogeochemical cycling in oligotrophic freshwaters.

Forest conversion effects on SOM composition: Disentangling effects of parent material and litter input chemistry

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Increasing forest carbon stocks through forest conversion is being considered in Western-Europe as potential climate change mitigation measure. Edaphic factors, such as soil pH, as well as tree species affect forest carbon cycles, but are difficult to disentangle. We studied how conversion of deciduous stands to mono-culture spruce plantations affected the soil organic matter (SOM) composition along a lithological gradient in the Mullerthal (Luxembourg) and Gaume (south-east Belgium) regions. Parent materials in these regions range from decalcified sands to calcareous marls. We used a twin plot setup of adjacent deciduous and coniferous stands on the same parent material to evaluate the effect of edaphic factors versus litter input chemistry on SOM composition and soil organic carbon (SOC) stocks. Lignin and cutin/suberin molecular proxies were identified with thermally assisted hydrolysis and methylation (THM), to distinguish litter sources (coniferous vs. deciduous and leaf litter vs. roots) in the studied stands. In this study, SOC stocks were influenced more by parent material than by forest type. Lignin yield, composition and degradation state were influenced both by litter input chemistry as by the edaphic context. Moreover, there appear to be important interaction effects between the two, as the relative importance of parent material and litter quality was site specific. These conclusions seem also valid for cutin yield, as tree type effects were absent from the Mullerthal loamy plots with more favourable pH values. We suggest that models used to estimate carbon stocks should always combine data on vegetation history and edaphic context. For forest management this study shows that if forest conversion is applied to increase forest SOM stocks, as climate change mitigation measure, this can only be a success when substrate differences are taken into account, including relatively minor substrate-directed differences in soil properties such as pH and texture.

Organic matter input determines structure development and aggregate formation in artificial soils

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Aggregates are formed by clustering and cohesion of mineral particles and organic matter. Up to now, little is known about the role of different organic matter types within this process complex. We developed an experimental set-up to study the influence of organic carbon (OC) derived from particulate organic matter (POM) and from dissolved organic matter (DOM) for aggregate formation under controlled laboratory conditions. We designed artificial soil microcosms with loamy texture, mimicking an arable Cambisol, and performed an incubation for 30 days under constant water tension. The microcosms received either POM as milled hay litter, DOM as solution derived from hay or no additional OC input. We analyzed aggregate size distribution and their OC content. By means of X-Ray CT, we analyzed the water retention characteristic and pore features of the recent structured soil.

We observed the formation of mostly large, water-stable macroaggregates (3000-630 μm) and some small microaggregates (<63 μm) in all treatments with OC input. Organic matter input as solid, particulate OM as well as dissolved OM solution induced aggregate formation as effect of microbial processing of the added OM. The addition and microbial decay of litter pieces led to physical occlusion of the particles into mainly large (3000-630 μm), OC-rich macroaggregates with low porosity. The addition of DOM solution also induced the formation of large macroaggregates besides small microaggregates, although the OC input was much lower. Here, we considered microbial processing of locally accumulated OC as the main process, which leads to alteration of the microbial microenvironment.

Our experimental design allows to specifically investigate selected process complexes initiated by the addition of OM in soil structure formation. It allows to differentiate between the emergent processes working together in aggregate formation and self-organization of soil structure.

Microdialysis as an in situ technique for sampling soil enzymes

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Soil extracellular enzyme activity (EEA) represents a critical bottleneck in the release of bioavailable nutrients from organic materials. However, quantifying spatial and temporal dynamics of EEA remains challenging. Techniques which measure the activity of, or directly sample free enzymes in situ may assist in understanding the short-term exoproteomic responses of microbes and roots to substrates, but few tools exist to explore EEA with minimal disturbance. We explore the potential of in situ microdialysis sampling to directly sample soil enzymes, and we hypothesize that the technique's bias towards free solutes will also allow differentiation of free and stabilised enzyme pools. As little is known about the efficiency of microdialysis to sample enzymes from soil, recovery of a protease standard was quantified from solution and soil, finding that enzyme recovery is hindered at lower soil moisture contents. We further measured the response of native protease activity after the addition of soybean litter to clay and sandy soils, finding microdialysis observed greater EEA in litter-amended treatments than controls in both soil types. In comparison, EEA as measured by conventional extraction-incubation methods was only greater in amended clay soils. In a final experiment, hydrolytic enzyme activity of free and stabilised clay soil fractions were estimated using microdialysis. Free enzymes contributed 9% of total hydrolytic activity in soil without litter, increasing to 46% in litter-amended soil, suggesting fresh litter promoted a transient increase in the production of free exoenzymes by soil microbes. Despite many challenges involved in applying microdialysis as a method for soil protein sampling, this method offers new possibilities for investigating challenging spatial and temporal aspects of enzyme dynamics and protein availability in soils.

Greenhouse gas production, diffusion and consumption is depth dependent

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Successfully meeting mitigation targets of climate agreements can be achieved with help of specific strategies, such as enhanced soil carbon (C) sequestration. While topsoils have been the major focus of sequestration research, subsoils have characteristics (e.g. old and stable C, low microbial activity, low disturbance) that offer substantial potential to sequester C. However, due to limited research, crucial aspects of subsoil C dynamics remain unknown.

For the development of effective sequestration methods, it is important to understand how the dynamics of greenhouse gases (GHGs), produced by soil organic matter mineralisation, differs throughout the soil profile. Few studies that research soil GHG dynamics venture below the soil surface and indeed none have monitored and experimentally tested GHG production, consumption and diffusion in a vertical soil profile.

In this 12-month study, we investigate the dynamics of nitrous oxide (N₂O), methane (CH₄) and carbon dioxide (CO₂) in an arable soil by sampling from gas collectors inserted into a maize field at 10, 20, 30 and 50 cm depths. In addition, laboratory experiments were conducted to a) determine soil CO₂ production rates and N₂O and CH₄ consumption rates at different depths, and b) test how these GHGs diffuse through the soil profile using sterilised soil and a conservative tracer gas.

Our results from the field gas collectors show a significant increase in GHG concentrations with soil depth. Laboratory experiments suggest that the higher concentrations of GHGs observed in deeper soil layers are due to reduced gas diffusion, greater production of N₂O and CH₄ at depth and consumption of N₂O and CH₄ by microbial processes closer to the surface.

The dynamics of subsoil GHGs are crucial in determining C balances, and a soil's ability to offset GHGs via long-term C sequestration in the subsoil.

Rapid spectral-reflectance-based assessment of soil carbon stratification following full inversion tillage pasture renewal

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Sequestration of soil organic carbon (SOC) is one strategy to reduce atmospheric CO₂ concentrations and limit climate change. Permanently grazed pastures, such as those in New Zealand, accumulate large amounts of SOC because pastures allocate a high proportion of plant-fixed C to root turnover and rhizodeposition. Consequently, these soils show a strong vertical stratification of roots and SOC that limits the topsoil's ability to sequester any additional carbon. Full inversion tillage at pasture renewal (FIT-renewal) has been proposed as a farm management practice suitable to accelerate SOC storage in pastoral soils showing a high degree of SOC stratification. Using a modified mouldboard plough, a one-off soil inversion event transfers carbon-rich topsoil into the subsoil while low-carbon mineral subsoil is brought to the surface where it is exposed to higher carbon inputs from the new pasture. The potential of increasing SOC stocks after FIT-renewal is under investigation at the field scale in New Zealand. In the North Island, two field trial sites were established, one on an Alfisol and the other on an Andosol. Pasture renewal via FIT involved full cultivation of a summer brassica crop followed by autumn re-grassing by direct drilling compared to other pasture renewal treatments by direct drill and shallow till. The sites were sampled through coring before renewal and after 5 months of crop growth to assess changes in SOC stocks and stratification using either (1) laboratory-based analytical methods or (2) diffuse reflectance spectroscopy. The one-time deep ploughing event redistributed large quantities of soil and soil C into depth (below 10 cm), altering its SOC stratification at varying degrees. The rapid reflectance scanning of the cores allows soil carbon content and stratification to be estimated with greater depth resolution helping researchers to make rapid decisions about the plough settings needed prior to FIT-renewal.

How elevated CO₂ impacts the dynamics of different soil carbon pools: stable isotope approaches to isolate pools and understand nutrient regulation

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Atmospheric CO₂ continues to increase. There is a high degree of uncertainty on the mechanisms by which elevated CO₂ will impact SOM. Elevated CO₂ is expected to increase plant carbon inputs to soil, contingent on nutrient availability. While carbon input is an important factor of SOM dynamics, it is the use of this carbon by soil microbes that ultimately determines if inputs are retained in the ecosystem, lost to the atmosphere and/or if they alter the existing SOM pool. Microbial use of new plant inputs and existing soil carbon is also dependent on nutrient availability. Recent work points at contrasting responses of different C pools to CO₂, but mechanisms are not clear. In conventional assessments these different pools are not distinguished, likely masking underlying mechanisms.

Our objective is a high resolution, multi-element investigation of the role of elevated CO₂ on the dynamics of different carbon pools as mediated by nutrients. We have been conducting field and laboratory studies utilising stable isotopes to isolate impacts on the new C inputs and existing organic C in intact plant-soil systems. Field studies took place at the EucFACE facility, a temperate, mature Eucalypt woodland in Eastern Australia exposed to Free-air CO₂ enrichment. So far, under field conditions elevated CO₂ caused a greater loss of existing soil carbon, and greater gross nitrogen mineralization which, together, are consistent with SOM priming. In controlled environments, the impact of CO₂ on existing C, but not on new C inputs, was highly dependent on nitrogen availability. Elevated CO₂ suppressed C loss but only when nitrogen level was low. We are currently investigating impacts of phosphorus availability and SOM phosphorus mineralisation.

Separating nutrient and non-nutrient effects of organic amendments on crop yield

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Organic amendments such as manures, composts and plant residues are often used in crop production systems as alternatives to inorganic fertilisers, to restore degraded soils or to ameliorate soil physicochemical constraints. These organic amendments can indirectly affect crop yields by increasing soil organic matter content and thereby improving soil biological activity, cation exchange capacity, structural integrity and so on. However, organic amendments can also provide large amounts of nutrients to the plant which can directly affect crop yields via fertilisation. Therefore, crop yield responses to the application of organic amendments could be due to an 'organic matter' effect, to the plant nutrients contained in the amendment, or some combination of both factors. Because of the way in which many of these experiments are conducted these factors can be confounded, leading to difficulties in accurately ascribing yield responses to nutrient and non-nutrient effects. Using subsoil manuring on poorly-structured clay soils in south-eastern Australia as a case study, we demonstrate how to use properly designed and assessed field experiments to separate the effects of fertilisation from other non-nutrient effects of the organic amendment on crop yield. We discuss: how to identify genuine soil constraints to plant growth; the selection of proper control treatments; the use of appropriate sampling protocols to assess treatment differences; and, additional measurements that can be used to elucidate the drivers of crop yield responses.

Stabilization – destabilization of soil organic matter in the long term: insights from long term bare fallows

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A fraction of soil organic matter has long residence times, from decades to millenia. Investigating the processes responsible for its persistence is however hampered by the presence of organic matter pools having shorter residence times and by the multiplicity of interacting processes. We proposed to use bare fallows plots, kept free of plants for decades, in which almost all C inputs have been stopped to investigate soil organic matter stabilization processes. Long term bare fallows provide an unexpected and unique opportunity to monitor the decay of soil organic C (SOC) by mineralization under natural conditions and to quantify and isolate stable soil C.

We discuss the advantages and limits of these long-term experiments to study soil organic matter dynamics and address two processes: physical protection and priming effect. By comparing SOC dynamics over 80 years in plots which had contrasted structures, thanks to repeated mineral amendments, we quantified the contribution of physical protection to SOC persistence. To investigate the long-term impact of priming effect on SOC stocks, we used two approaches (i) we compared SOC stocks after repeated additions over 50 years of organic matter that was more or less susceptible to induce priming effects and (ii) we compared the decay of SOC in a long term bare fallow and in an adjacent field in which ¹³C natural abundance. Both analyses suggest that priming has limited impact on SOC stocks over decades.

The role of clays and different clay minerals on carbon uptake, retention and sequestration

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Dissolved organic carbon (DOC) from wheat straw was adsorbed on clay fractions rich in both kaolinite and illite, in smectite, and in allophane that were each extracted from their soils by a physical method. Sorbed DOC was also desorbed from the resulting products. Wheat residues were incubated with the 3 types of clay fractions and ¹⁴C-labelled malic acid was added to each of the 3 soils to study carbon priming effects. The order of both extent of adsorption and of stabilisation of organic C was allophane>smectite>kaolinite-illite, reflecting surface area (SSA). Ease of desorption showed the reverse order. Adsorption was decreased and desorption increased by removal of high SSA sesquioxides. Rate of decomposition on incubation was greatest in kaolinite-illite clay fraction, similar in the smectite and allophane fractions, and increased by removal of sesquioxides. After addition of malic acid, substantially more native C was lost from the smectitic soil than from both the allophanic soil, and the kaolinitic-illitic soil, which sustained similar losses. This latter soil shows strong microaggregation.

Regarding prospects for sequestration of C, the results from priming suggest that simple addition of labile organic matter to soils may result in a decrease, rather than an increase, in the content of organic C. In any case, added C can be easily desorbed and decomposed.

Addition of (mainly kaolinitic) clay to sandy soils, carried out to cure non-wetting, led to an increase in organic C. Addition of bentonite clay to other sandy soils led to greatly increased crop growth, but addition of compost had no effect.

Only limited areas of mineral surfaces of soils are available for the uptake of organic matter and only C adsorbed initially may be retained for a long time. World-wide, sequestration of C may be most promising on sandy soils amended by clay additions.

A molecular-level perspective of soil water repellency in sand and clay

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Soil water repellency is estimated to affect over two million hectares of southern Australia,¹ resulting in approximately \$100 million in production losses.² The cause is associated with soil organic matter, which can form a coating on the mineral grains.³ However, while speculative theories have been proposed to explain experimental data, little has been done to justify the theory at the molecular level. Thus, in this study, molecular dynamics simulations were carried out using mineral surface models of amorphous silica (weathered sand surface), kaolinite (Al-OH and Si-O) and quartz. The organo-mineral interactions between hexadecanoic acid on these surfaces was calculated using radial distribution functions, mean square displacements, torsion distributions, concentration profiles, equilibrium snapshots and interaction energies. Initial models were based on previous studies by Walden et al.,⁴ Uddin et al.,⁵ and Daniel et. al.,⁶ which excluded the presence of water; however, the current models now include the addition of water and charge effects. These more complex models show that both the organo-mineral interactions and structure/layering of the acid molecules on the weathered sand and kaolinite (Al-OH) surfaces differ, resulting in models that more accurately reflect experimental observations.

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Is paddy-rice system a better niche for carbon sequestration?

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Rice (*Oryza sativa* L) is the foundation of global food security particularly in Asian countries. In India only, about 43 million ha of land is under rice cultivation as a mono-crop, rice double crop, and other rice-based cropping systems. Among these, submerged puddled rice is the most common. For maintenance of soil health and curbing global warming, it is important to unveil the processes of accumulation or depletion of organic carbon in soils (SOC) under different management practices of paddy-rice. An attempt is, therefore, made to study the impact of long-term intensive paddy-rice systems with different management practices on the SOC stock in a few long-term fertility experiments under subtropical climate. The mechanistic pathway of stabilization of the SOC into different pools with a tentative C budgeting was also established. Biochemical composition of the organic residues involved, SOC pools of different oxidizability and carbon accumulation from other sources were estimated for the experiments raised with different organic and inorganic sources of nutrients. Cultivation over the years caused a net decrease in SOC stocks, but with balanced fertilization it increased. With increasing depth, the stock decreased on average, to the extent of 50%, 26% and 24% of the total at 0-0.2, 0.2-0.4 and 0.4-0.6 m, respectively. About 4.0% of the crop residues C incorporated into the soil were stabilized into SOC. This was further enhanced (~1.5 times) by the application of organics. Again, a good part (~15%) of the carbon added through organics was stabilized into SOC mostly in the recalcitrant pools; the amount, however, varied among the sources used maximum with farm yard manure. Results thus indicated that paddy-rice system is a good sink for SOC sequestration besides its role in maintaining soil health and providing food security.

Keywords: Rice–rice ecology, carbon stabilization, crop residues, soil C-pools

Bacterial 3-hydroxy fatty acids: Applicability as environmental markers in soils from the French Alps

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The composition of microbial membrane lipids has been shown to vary with environmental parameters in order to maintain an appropriate fluidity and permeability of the membrane. This is particularly the case for glycerol dialkyl tetraethers (GDGT), used for temperature and pH reconstructions in terrestrial settings, although other environmental parameters might also influence the GDGT distribution. Another family of lipids, 3-hydroxy fatty acids (3-OH FAs) was recently proposed as an alternative to GDGTs. To investigate the applicability of 3-OH FAs as temperature and pH proxies and understand the influence of environmental parameters on these lipids, 49 soils were collected between 200 and 3,000 m altitude in the French Alps. These soils cover a wide range of temperature (0°C to 15°C) and pH (3 to 8) and are representative of the diversity of soil vegetation and pedological covers along the mountain gradients. In agreement with previous studies, a significant correlation is observed between 3-OH FAs and pH. In contrast, no correlation could be shown with mean annual air temperature. Similarly, GDGTs are only poorly correlated with temperature in this sample set. This suggests that other parameters, such as vegetation, soil type or humidity are the main drivers of the variability of 3-OH FA and GDGT distribution. The influence of vegetation type and soil classification was tested on 3-OH FA relative abundances as the sampling allows differentiating 10 types of vegetation and 10 types of soil. Both parameters were shown to have a significant impact on the 3-OH FA distribution. This led us to build a model based on Artificial Neural Network, which allowed the reconstruction of soil types and vegetation with an accuracy of 89 %. This promising approach, developed on soils from the French Alps, will be further applied to a larger number of soil samples and also tested on GDGTs.

Molecular dynamics of soil humeome as a function of crop system

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Soil organic carbon (SOC) mineralization signifies reduction in soil fertility and release of greenhouse gases¹. An effective technology for soil carbon stabilization requires an extended knowledge of SOC turnover dynamics at a molecular level. To reach this goal, we applied the humeomics methodology on a soil cropped with maize or wheat after 1 and 3 years of conventional tillage and characterized the molecular development of soil humeome².

Humeomics used advanced analytical techniques, such as ESI-Orbitrap- and GC-MS, to identify both organosoluble and hydrosoluble molecules³ solvated from the supramolecular SOC structure².

Therefore, humeomics provided a measure of the degree of organic matter chemical protection, such as the ratio of OC in the organosoluble/hydrosoluble material.

This ratio was 0.75 in the case of maize crop⁴, and it dropped to 0.49 for the wheat crop. GC-MS analysis revealed that fatty acids were the main compounds contributing to the hydrophobic character in all organosoluble fractions. The unbound organosoluble fraction under maize comprised also of alkanes, which were oxidized to alcohols under wheat, while sugars dominated the bound fraction for both crops, although for wheat they were 50% lesser than in maize. The major difference in the organomineral compounds was due to the amides which were absent under wheat but stabilized under maize.

Our findings revealed that the complex supramolecular arrangement of the soil humeome is extremely dynamic and humeomics can identify the molecular changes induced by the different agricultural management in just 2 years period.

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Conversion from Native Forest to Managed Ecosystems Alters Thermal Stability of Organic Matter in Soil Fractions in the Karst Region of Southwest China

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Understanding the stability of soil organic matter (SOM) after land-use changes is of critical importance to C sequestration. The present study was to evaluate the thermal stability of SOM in different soil fractions after converting from the native forest (NF) to eucalyptus forest (EF), unused grassland (UG) and corn field (CF) in the Karst region of southwest China using thermogravimetry (TG) and differential scanning calorimetry (DSC) techniques. Soil samples were collected from the 0- to 10-cm layer and physically separated into four classes (i.e., >53, 53-20, 20-2 and <2 μm). The results showed that the derivatives of thermogravimetry curves (DTG) and DSC curves had two peaks, near 300 and 500°C for both bulk soil and fractions. The percentage of thermal labile SOM (weight loss in 200–400°C accounting for that in 200–550°C, %Exo1) and energy densities (ED) of SOM (energy release per unit SOM) declined with decreasing particle sizes. The TG-T50 (the temperature leading to half of total SOM loss) increased with decreasing particle sizes, and the DSC-T50 (the temperature at which half of energy released resulting from SOM combustion) was insensitive to the land-use type. Conversion from NF to UG and CF reduced the quantity but increased thermal stability of SOM in bulk soil, indicating by less weight loss at combustion, lower %Exo1 ratio, lower ED and higher TG-T50. Compared with NF, EF and CF significantly decreased thermal stability of SOM within the 53-20 μm and <2 μm fractions, reflecting by the higher weight loss, %Exo1 ratio and ED and lower TG-T50. We concluded that the human-disturbed altered thermal stability of SOM in bulk soil and fractions. Our findings highlight the importance of land-use managements on SOM stability and thus terrestrial C cycle.

Restoring the carbon sequestration capacity of NW-European peat lands

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Peatlands play an important role in carbon balances and climate change. Covering 3% of the earth's surface, estimates are that global peat lands store over 1.4 trillion tons of carbon. However, mismanagement of peatlands causes carbon emission to the atmosphere. At present, mismanaged peatlands emit double the amount of CO₂ emissions compared to aviation. On the global scale, Indonesia is no1 in CO₂ emission by peatlands because of transforming tropical forests into palm oil plantations. However, Europe is no2 on this ranking list!! This is caused by continuous draining of peat lands by traditional agricultural practices such as dairy farming and urban expansion.

There are four running European funded research projects (c. 4-5 million Euro each) that aim at reversing this process: Carbon Connects¹, Care Peat², Canape³ and Peat Restore⁴. Each project has its own focal point but they all aim at developing and applying new business models that no longer require the drainage of peatlands and/or restore peatlands resulting in a substantial reduction of carbon to the atmosphere.

Examples of these innovative business models comprise low carbon construction materials (e.g. cattail, reed), green fuel, meat production (water buffalo) and cranberry production.

Apart from these new wetland commodities some of these projects also explore the use of the Carbon Credit system⁵ and development of a new Blue Credit system (financial incentives to retain water) to subsidise the farmers/landowners in this land use transformation process.

Apart from developing and applying technological innovations directed at new business models and GHG monitoring techniques this European consortium experiments also with new co-creation techniques such as Living Labs in order to involve public and private organisations and jointly to identify tailor made solutions for each region.

In this article/conference contribution we will describe the latest insights and preliminary results of this European endeavour.

Carbon cycling under dryland wheat as influenced by crop residues and nitrogen fertilizer

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Agroecosystem carbon stocks are dictated by the balance between inputs from net photosynthesis and outputs from harvested commodities and decomposition. In dryland grain and oilseed cropping systems of western Canada, typically the grain is harvested and exported from the system, and the residues or non-grain portions of the plants are returned to the land where they decompose, for the most part, back to CO₂. Increasingly, we are asking more of our cropping systems by increasing harvest intensity and exporting the above-ground residues for other uses. We established an experiment in 1999 with three levels of crop residues (returned, removed, or supplemented) and two levels of nitrogen fertilization (with and without). The supplemented residue treatment was imposed to assess the extent to which agroecosystem C stocks might be enhanced by increasing C inputs. The cumulative influence of these treatments on C and N cycling will be discussed. The residue and especially N fertilizer treatments influenced crop yields and the amounts of residue returned to the land each year. Yields were also influenced by interannual variability in precipitation and crop water use efficiency. Soil and residue samples were collected to assess the amounts and locations of organic C and total N accumulated in the system. Inorganic soil C also was measured, but stocks were too variable to discern temporal changes. Temporal changes in soil C and N stocks will be compared with long-term cumulative residue inputs. The implications of the results for managing soil organic matter in annual cropland will be discussed.

Soil organic carbon stocks as an indicator of land degradation for Sustainable Development Goal 15

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Since 2010 there have been several global and regional targets and initiatives to halt and reverse land degradation and restore degraded land; the most recent being the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). SDG indicator 15.3.1, the proportion of land that is degraded over total land area, is assessed in terms of change in three sub-indicators: land cover, land productivity and carbon stocks. Each of these sub-indicators represents a unique perspective on the manifestation and assessment of land degradation. Soil organic carbon (C) is the current metric for assessing the carbon stocks sub-indicator. Good practice guidance (GPG) has recently been developed to assist countries to report on SDG indicator 15.3.1, and support countries to achieve their targets for reducing degradation. Without being prescriptive about the sources of data, the GPG aims to ensure technical soundness and consistency in estimation methods as well as comparability of results across countries and over time. The approach used to quantify change in soil organic C stocks will vary depending on the availability of country-specific data and capability. Key challenges include the establishment of appropriate baselines and methods for determination of significant change in soil organic C stocks. The latter is further complicated by the typically slow rate of change in soil organic C in relation to indicator reporting periods. This paper presents some of the key methodological details of the GPG for assessing soil organic C stocks and describes considerations that may assist in national scale monitoring of soil organic C in order to implement national reporting against SDG indicator 15.3.1.

Quantity, distribution and source of DOC in the soil profile in fresh and dried samples

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The role of dissolved organic carbon (DOC) in soil carbon (C) cycling has recently become the focus of considerable international research attention. DOC is a labile fraction of soil organic matter and plays an important role in soil C dynamics contributing to soil C movement and storage following stabilization in the soil. Soil microbial biomass is considered to be a potential source of DOC and microbial metabolites constitute a significant proportion of DOC. Fluctuations in soil moisture create drying-rewetting events that affect microbial biomass as well as DOC quantity in the soil. We examined the quantity and distribution of DOC under different land-use systems (woodland, improved pasture and cultivated) in northern NSW, Australia. To determine the source of DOC under different soil conditions, DOC was extracted from fresh soils and from 40°C oven dry soils. DOC concentrations were higher in surface soils under woodland followed by improved pasture and cultivated soils and DOC diminished with depth in all soil profiles. DOC concentrations were significantly higher in 40°C oven dry soils than fresh soil samples in every land-use system and site studied. DOC samples were further analysed using ¹H-nuclear magnetic resonance (NMR) spectroscopy to determine the source of DOC in soils. Peaks consistent with carbohydrates and aliphatic biomolecules were detected in ¹H-NMR spectra of DOC samples extracted from 40°C oven dried soils. However, in DOC samples derived from fresh soil samples, peaks for these organic compounds were undetectable. This result suggests that drying of soils causes a liberation of organic compounds of microbial origin contributing significantly to DOC generation in the soil. Potential mechanisms and implications of these results are discussed.

The interactive effects of organic amendments, fertilizer and gypsum on the formation of soil aggregates and storage of carbon in a dispersive sodic-subsoil

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The deep placement of amendments such as the integrated inputs of crop residues, fertilizer nutrients (i.e., nitrogen and phosphorus) and gypsum to ameliorate physicochemical constraints in sodic subsoils have received much attention. Organic and inorganic amendments affect soil structure (e.g., aggregation), as well as soil carbon (C) storage. However, there are knowledge gaps on the impacts of amendments on formation and stability of soil aggregates in sodic subsoils, the linkages between soil aggregation and decomposition process of organic amendments (OAs), as well as the role of resources' C-nutrient stoichiometry on the C distribution and storage within aggregates. To address these knowledge gaps, we conducted a 270-day laboratory incubation experiment (20°C). A sodic subsoil collected from under C3-vegetation ($\delta^{13}\text{C-SOC}$: -24‰; soil organic C content: 5.8 g C kg⁻¹ soil) was uniformly mixed with C4-vegetation derived OAs ($\delta^{13}\text{C}$: -14‰; including sorghum stubble and bagasse at application rate of 6.2 g C kg⁻¹ soil), with or without gypsum (7.2 g kg⁻¹ soil) and nutrients. A wet-aggregate sieving procedure was used on days 31, 90 and 270 to obtain four soil fractions: large macro-aggregates (2–6.5 mm), small macro-aggregates (0.25–2 mm), micro-aggregates (0.053–0.25 mm), and silt-clay (< 0.053 mm). Total C and OA-derived C in the aggregate-sizes have been analyzed. After 90 days, the input of OAs (with or without exogenous nutrients and gypsum) increased soil aggregation (of both macro- and micro-aggregates), with the greatest increase (6–7 folds) when a combination of OAs, gypsum and exogenous nutrients was applied. The preliminary results showed that the increased microbial biomass and activities might have enhanced the association of OAs with soil minerals, leading to the improvement of soil aggregation. The dissolution of Ca²⁺ from gypsum has also further enhanced the formation and stability of macro-aggregates. Our study provides insights on the role of decomposition process of OAs on soil aggregate formation, including aggregate-associated C storage, in a dispersive sodic-soil.

Keywords: gypsum, carbon isotope, soil constraints, soil amelioration, microbial biomass

From spectra to decision support and back again: a roadmap to impact for soil spectroscopy

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Infrared (IR) spectroscopy can provide estimates of the quantities of organic carbon in soil as well as its allocation to fractions isolated and measured by physical and chemical means. Rapid and cost-effective estimates of a range of soil properties by IR spectroscopy allow more samples to be analysed, making the acquisition of large data sets feasible, as exemplified by the national soil carbon dataset collected by the Australian Soil Carbon Research Program. These data sets open up a number of opportunities for spatial modelling at a range of scales and for monitoring of soil condition, with applications in greenhouse gas accounting and mitigation, and management of resources in agricultural enterprises, for example. Here we present a roadmap to take this technology out of the research domain and make it available to a range of users. By combining measurement, prediction and modelling, and creating a system where information flow is circular, synergistic benefits to both end users and technology developers will be realised. For example, analysis of spectra in real time might identify samples for which current prediction algorithms are unreliable, which can then be further analysed and added to calibration sets, potentially providing the end user with more reliable results. Land managers make multiple decisions that balance a number of objectives, including productivity, sustainability and profitability. In the soil organic matter space, we recognise that carbon fractions are just one of many pieces of information that need to be brought together into a decision support framework. To do so will require a concerted effort involving a range of players including researchers, analytical laboratories, data scientists, software engineers, government departments, advisory bodies, agronomists, grower groups, industry and funding bodies. We hope that by articulating a roadmap we can bring these players together and expedite the path to impact for soil spectroscopy.

Effects of nutrient enrichment on soil priming effect: a global meta-analysis

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The inputs of fresh carbon will alter the decomposition of soil organic matter (SOM), which is known as priming effect (PE). Priming effect plays an important role in regulating SOM decomposition and soil carbon storage. Increasing nitrogen (N) and phosphorus (P) inputs and deposition induced by anthropogenic activities have largely increased the availability of soil nutrients, and thus should affect PE. Although many studies have investigated the effects of nutrient enrichment on PE, the general patterns at global scale remain unclear. Here, we compiled available data on PE under nutrient enrichment from primary literatures to examine how nutrient enrichment regulates PE. Results showed that, across all studies, N enrichment and combined N and P enrichment significantly decreased PE ($p < 0.05$), whereas P enrichment had minor effect on PE ($p > 0.05$). Specifically, N enrichment effects on PE varied among ecosystem types, with significant negative effect occurring in grassland, boreal, temperate and tropical forest ($p < 0.05$). Meanwhile, the effects of nutrient enrichment on PE generally decreased with initial soil nutrient status (organic carbon, total nitrogen and phosphorus), indicating that these factors potentially regulate nutrient effects on PE. In addition, the effects of N and combined N and P enrichment on PE were regulated by substrate type, with significant negative nutrient effects in substrates not containing the mineral nutrient added. Combinations of microbial nutrient mining hypothesis and microbial stoichiometric decomposition hypothesis can explain the observed relationships across all ecosystems. Collectively, our findings imply that N deposition might be beneficial to soil carbon storage via suppressing PE, and highlight the need for further field in situ studies investigating nutrient enrichment effects on PE.

Warming alters soil organic carbon dynamics at depth in Qinghai-Tibetan alpine grassland

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Subsoil contains >50% of soil organic carbon (SOC) stocks globally and is conventionally assumed to be unresponsive to warming compared to the topsoil. Recent theoretical and laboratory studies suggest that deep SOC may not be as inert as previously thought. However, field-based evidence is still lacking to prove subsoil's response to warming and its underlying mechanisms. Here utilizing a long-term warming experiment on the Qinghai-Tibetan Plateau, we demonstrate that warming induced substantial changes in carbon dynamics for the subsoil but not topsoil in an alpine grassland. Driven by elevated root distribution at depth, newly synthesized carbon accumulated in the silt-clay fraction of subsoils under warming, accompanied by increased concentrations of lipids, sugars and water-soluble peptides of both microbial and plant origins. However, lignin degradation increased in the subsoil (especially in macroaggregates) with shortening of soil freezing period and labile carbon-fueled microbial co-metabolism. These changes stand in sharp contrast to the unaltered carbon characteristics in the topsoil, suggesting that the warming response of topsoil may not reflect shifting soil carbon processes at depth. More importantly, as warming is accompanied by deepening roots in a wide range of ecosystems, root-driven priming of native SOC versus new carbon accrual needs to be evaluated beyond alpine systems to determine the future patterns and magnitude of soil carbon stock changes in a warmer world. Overall, our study delivers a mechanistic understanding for the high sensitivity of subsoil carbon dynamics to warming, which has significant implications for improving soil carbon models and predictions.

Soil organic matter mineralization by earthworms: A meta-analysis

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In most of soil organic matter models, the action of macroorganisms such as earthworms (EWs) is not represented. In order to build a model simulating the effect of EWs on the mineralization of soil organic matter (SOM), we used a statistical model based on a meta-analysis approach that allows taking into account the main experimental results of the selected literature. First, a database was built using the following steps: literature review, selection of references, data extraction, build a table of the input variables and finally choice of the response variable. Second, several statistical models (programmed in R-language) were tested with the experimental data set between the carbon mineralization response variable and the various explanatory variables selected. The results of the database show that there is an increase in carbon mineralization with the presence of earthworms and also that the effect of earthworms varies greatly between studies. To describe the effect of time, random-effect models are better than fixed-effect models and therefore this indicates that inter-study variability must be taken into account. The cubic model is better than the linear and quadratic models. Among the explanatory variables other than time, only the density makes it possible to improve the model. Thus an equation is proposed to calculate the effect of earthworms on soil carbon mineralization using a cubic model for time and linear for the density.

C:N:P stoichiometry regulates soil organic carbon mineralization and concomitant shift of microbial community in paddy soil

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Soil carbon (C) and nutrient status, e.g., of nitrogen (N), and phosphorous (P), and their stoichiometric ratios play crucial roles in modifying the microbial metabolism of C in terrestrial ecosystems. However, the mechanisms by which microorganisms regulate soil C mineralization in response to resource C:N:P stoichiometry in paddy soils are not well understood. In this study, stoichiometric control on added substrate-C (glucose) and soil organic carbon (SOC) mineralization was assessed by a manipulation experiment based on N only, P only and N plus P fertilization in a 100-days incubation experiment using flooded paddy soil. Glucose-C mineralization was stimulated by nutrient addition, and increased by up to 11.6% with combined N and P application compared with that upon exclusive glucose addition. During the incubation period, about 4.5% of SOC was mineralized in all five treatments, being enhanced by glucose application and reduced by P fertilization. Glucose-C and SOC mineralization increased exponentially with the dissolved organic carbon (DOC):NH₄⁺-N, DOC:Olsen P, and microbial biomass (MB):C:MBN ratios, whereas glucose-C mineralization was negatively associated with the MBC:MBP ratio. This suggests that the P addition relieved the microbial P limitation and increased microbial activities of metabolizing labile C. The bacterial community structure shifted in response to treatments and time, and was significantly affected by the soil and microbial biomass C:N:P stoichiometries. The decrease of negative associations between bacterial taxa in the P-added treatments indicates that microbial competition for nutrients was alleviated. Through 16S rRNA amplicon sequencing, we found that labile C and available nutrients stimulated copiotrophs (Clostridia and β -Proteobacteria) and increased the activities of β -glucosidase and β -acetylglucosaminidase. In contrast, at later stages of the incubation, when the available substrate was exhausted, Syntrophus was found as the keystone species. Hence, soil microbial communities shifted their keystone species to utilize available C or metabolize recalcitrant soil C to acquire necessary elements to maintain the microbial C:N:P stoichiometric balance in response to the change of resource C:N:P stoichiometry.

The global mineralogical capacity of soils to store carbon

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Soil – the largest terrestrial pool of actively-cycling carbon – has the potential to sequester vast amounts of carbon globally. Chemical- and physical-associations of organic matter with mineral surfaces are known to play a critical role in this storage and preservation. However, the maximum capacity of soils to store carbon globally, and the role of mineralogy in driving this limit and its spatial variation, is still unknown. Here we present a comprehensive analysis of mineral-associated carbon and auxiliary variables from sites that span diverse biomes and soil types. We find that soil mineralogical properties dictate the maximum capacity of soils to stabilize organic matter associated with minerals, and that this mineral-associated organic matter accounts for the majority of carbon and nitrogen in soil organic matter. Explicit representations of mineral-organic associations are still lacking in Earth system models, and our findings are essential for informing and parameterizing model formulations at global scales. Our results suggest that most soils contain substantially less carbon than their mineral-associated carbon capacity (i.e., they are below carbon saturation), and that this is particularly evident in deeper soils and in poorly-managed and degraded lands. We calculate the mineralogical limit of low- and high-activity mineral soils to stabilize carbon, and use these empirically-derived limits to estimate the global potential for soil minerals to stabilize carbon. This estimate, and the underlying spatial distribution, provides crucial insights and motivation for targeted soil management and conservation efforts. Increasing soil carbon storage through restoration is a promising avenue for mitigating global emissions with lasting co-benefits.

Soil Organic Carbon Stability at the Large Catchment and Centennial Scales: Field and Modelled Insights

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Soil Organic Carbon (SOC) represents the largest terrestrial store within the carbon cycle at 1550 Gt. SOC fluxes and quantification within global climate models is generally poor and adds uncertainty due to the large amount of carbon it accounts for. The ability to constrain the estimates of the response of such a large amount of carbon to global changes is pertinent to projections of the future global carbon budget. High resolution, continental-scale modelling and field methods are ways to better constrain this uncertainty. This study presents findings on SOC stability for a large (585 km²), agricultural catchment in eastern Australia over the past 115 years using the BIOS2 model recently developed by CSIRO to study the carbon and water cycles in the Australian landscape. Independent field observations (not previously used in the validation of BIOS2) from 2004 and 2014 were compared with modelled outputs for the study catchment, with coefficients of determination ranging from 0.14 to 0.30. The spatial variation of the modelled inputs was also compared with the field observations to determine the sensitivity of the model to topographically influenced climatic variations. The field observations from 2005 to 2015 captured SOC dynamics during and post a significant drought event and were found to be stable. This finding was supported by the modelled outputs which also showed SOC stability from 1900-2015, during multiple dry and wet periods. Spatially, SOC was shown to vary with elevation both within the field and modelled data in response to increased rainfall. Collectively, these results indicate that SOC is resistant to climatic variations under consistent land use at the large catchment scale within a temperate agricultural region. Therefore, SOC flux under land use change may present greater uncertainty to quantify for projected carbon budgets rather than the influence of climate in stable areas.

Biomarker and spectroscopic evidence for microbially stabilized organic matter in an eroded landscape

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Tillage and water erosion are fundamental soil forming factors in hummocky landscapes. Soil organic matter (SOM) is redistributed horizontally and vertically, thereby exposing subsoil carbon at erosional positions and preserving C by burial in depositional positions. Here we explore the links between microbial communities and organic matter chemistry across an erosion/deposition-affected prairie catena. Original A-horizon material at this site has been buried for ca. 70 y, is >55 cm below the current surface, and contains ca. 6% organic C. Total lignin phenol contributions to total soil C were lowest in the buried A horizons compared to surface soils. Microbial alteration of lignins also was highest in buried A horizons. Amino sugar residues were greatest in the buried C-rich soil layers due to selective enrichment of glucosamine. Analysis by XANES (NEXAFS) of the bulk SOM indicated that buried soil layers contained a high proportion of functional groups such as ketones and pyridines, indicative of repeated microbial C and N turnover. High-level microbial taxonomy (Phyla) was strongly correlated with the relative abundance of SOM functional groups associated with substrates or products of metabolism. Lignin alteration, amino sugar content, and spectroscopic evidence of microbially-degraded organic matter suggests that the microbial community altered the SOM in response to available resources and environmental conditions in this spatially and temporally complex landscape. Environmental conditions deep in the soil profile exert selective pressures on the microbial communities in buried C-rich layers, resulting in an enhanced prominence of microbial by-products as stabilized C. Study of this unusual C-rich environment provides a unique insight into the microbial controls on soil C cycling which may be occurring at small spatial scales within microsites and aggregates, or over a long time scales (decades).

Organic matter content, quality and microbial functioning in soils under grazing versus mowing: what is the difference?

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Despite the need for the adoption of soil organic C (SOC) sequestering management practices to improve soil quality and contribute to climate change mitigation, little is known about the effect of grazing versus mowing on properties of grassland soils. Here, we sampled soil from two depths at an experimental site in Western France, which had been since 14 years under grazing or mowing regimes. We aimed to assess the effect of the two management practices on soil organic matter (SOM) quantity, quality and microbial functioning. To this end we analysed for elemental concentrations, specific SOM compounds (lignin and non-cellulosic polysaccharides) and microbial biomass, microbial growth kinetics and 9 extracellular enzymes activities.

We found nearly two times higher SOC under grazing compared to mowing. The chemical composition of SOM in topsoil differed between treatments with lower contribution of lignin and higher contribution of microbial biomass under grazing treatment. Lignin content was higher under mowing while both treatments showed similar non-cellulosic polysaccharides contents. Difference in enzymes activities between treatments were only observed after normalisation by microbial C, indicating more efficient enzyme production under grazing. We conclude, that the presence of animals under grazing most probably caused relative domination of r-strategists in microbial community leading to SOC accrual via enhanced substrate availability and high microbial use efficiency, whereas under mowing poor nutrient conditions favoured K-strategists and led to lower microbial activities.

Organic materials flow and nutrient balance analyses at different landscapes of a watershed in Tigray, Northern Ethiopian highlands

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Abstract

Soil fertility depletion is the major cause for declining per capita food production in Ethiopia. We evaluated a material and associated nutrient flows at different landscapes (lower, middle and upper) and household wealth groups (poor, medium and rich) at Maileba watershed in Tigray, northern Ethiopia. Comparison of the domestic organic material inputs and processed outputs indicated an annual total organic material balance of about -12.09 t/ha for upper, -8.04 t/ha for middle, and -5.41 t/ha for lower landscapes. The associated annual total organic C, N and K depletion for the rich household groups was about 598kg C/ha, 38 kg N/ha and 16kg K/ha in the upper, 621kg C/ha, 42kg N/ha and 22kg K/ha in the middle and 603kg C/ha, 44kg N/ha and 14kg K/ha/yr in the lower landscapes. The poor household group extract about 438kg C/ha, 36kg N/ha and 11kg K/ha in the upper; 293kg C/ha/yr, 22kg N/ha and 9kg K/ha in the middle, and 368kg C/ha/yr, 30kg N/ha and 12kg K/ha in the lower landscapes. Product harvest, crop residue removal and run-off associated material outflows were the major causes for nutrient depletion in the watershed. The organic material and soil nutrient stocks of the various landscapes are rapidly declining particularly in the upper landscape position of catchments. The rich (better of) households are the potential target groups to contribute more to conservation of watersheds than the poor. A properly planned nutritional management and integrated upland organic farming should receive due attention on the mountainous areas of Ethiopia and east Africa.

Keywords: Material balance, organic carbon, nutrient flux, landscape position, Ethiopia

Microbial uptake kinetics of dissolved organic carbon (DOC) compound groups from river water and sediments

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Dissolved organic matter (DOM) represents a key component of carbon cycling in freshwater ecosystems. While the behaviour of bulk DOC in aquatic ecosystems is well studied, comparatively little is known about the turnover of specific dissolved organic carbon (DOC) compounds. The aim of this study was to investigate the persistence of ¹⁴C-labelled low molecular weight (LMW) DOC at a wide range of concentrations (0.1 μ M to 10 mM), in sediments and waters from oligotrophic and mesotrophic rivers within the same catchment. Overall, rates of DOC loss varied between compound groups (amino acids > sugars = organic acids > phenolics). Sediment-based microbial communities contributed to higher DOC loss from river waters, which was attributed, in part, to its greater microbial biomass. At higher DOC compound concentrations, DOC loss was greater in mesotrophic rivers in comparison to oligotrophic headwaters. A lag-phase in substrate use within sediments provided evidence of microbial growth and adaptation, ascribed here to the lack of inorganic nutrient limitation on microbial C processing in mesotrophic communities. We conclude that the higher microbial biomass and available inorganic nutrients in sediments enables the rapid processing of LMW DOC, particularly during high C enrichment events and in N and P-rich mesotrophic environments.

SOM, SDG, BRG, ACIAR, PCI, NDC, BOSF: communicating across disciplines, cultures and jurisdictions to realise the potential of Soil Organic Matter research to achieving the Sustainable Development Goals

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Soil scientists across the world recognise the importance of soil organic matter in achieving many of the UN's Sustainable Development Goals. Want to double agricultural productivity of small scale farmers (2.3)? Consider the soil. Want to restore degraded land (15.3)? Consider the soil. Want to increase capacity to mitigate and adapt to climate change (13.3)? Consider the soil. However, the importance of soil organic matter in sustainable development is not well appreciated by a wider audience. This paper presents a case study of research design and implementation whereby cutting edge soil organic matter research is nested within a multidisciplinary, international "Research for Development" project: "Community fire management and peatland restoration in Indonesia" that attends to the integration of soil science research in a broader, social and ecological context. Indonesia has committed to implement the SDGs, with the Ministry of Environment and Forestry (FOERDIA) becoming the main actor to implement Goals 12, 13 and 15. The focus of action towards achieving these goals in Indonesia is centred around reducing peatland fires. As such, there is potentially a strong relationship between this international research project and fulfilment of SDG goals in Indonesia. The narrative of this paper grows outwards from the Nuclear Magnetic Resonance and Mid Infra Red spectroscopy and hydrology investigations of degraded tropical peatlands to explore the processes and challenges of communicating this SOM research such that it can effectively inform sustainable peatland management. Internal and external communications, disciplinary, institutional and cultural barriers, assumptions and norms: a good graph is simply not good enough to inform this change. Lessons learnt and current challenges will be shared from this ongoing research.

Seeking deeper for future: potential of subsoils management for the storage of organic matter in agricultural fields

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While the demographic pressure for food demand is continuously rising, global environmental changes are threatening the productivity of agroecosystems. Climatic events like floods or droughts, and long-term decrease in soil organic matter stocks due to intensive agriculture are examples pointing to the necessity to find solutions for sustainable performance of agroecosystems.

Significant amounts of water and nutrients are stored in deep soil horizons, and thus subsoil management is being considered as an alternative to sustain high demand in crop productivity. Moreover, despite low concentrations in organic matter, subsoils correspond to larger volume of soil and thus contain a high proportion of SOM. For these reasons, the dynamics of SOM in deep horizons is logically receiving more focus and their potential for the stabilisation of organic carbon need to be determined.

We used samples from a field experiment in Germany where the agricultural management was adapted to investigate the potential benefits of deep ploughing with OM incorporation. We recorded hyperspectral images of soil cores (depth = 1 m) using Vis-NIR spectroscopy and the C distribution within the soil was modelled at a very high spatial resolution (53×53 μm). The SOC mapping revealed an increase in SOC stocks resulting from deep ploughing, and the high resolution images generated allows the observation of OM distribution in the subsoil and the response in SOM stocks to different types of organic matter incorporation (compost vs green manure).

Hyperspectral imaging of soil cores allows the quantification of OM stocks and changes in deeper horizons, and visualisation of heterogeneity in the spatial distribution of soil organic matter is helping to understand and quantify the processes related to changes in soil C stocks in subsoils.

The effects of long-term nitrogen addition on the composition and sequestration of SOM in a boreal forest

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Boreal forests are responsible for large terrestrial carbon (C) stores. They are typically nitrogen (N)-limited, such that the intense use of fertilisers for forest management in this biome has drawn great attention to the long-term impacts of N additions on biogeochemical processes, especially, decomposition and sequestration of SOMs. We investigated the impacts of N addition on SOMs both qualitatively and quantitatively in a mature Scots pine forest located in Northern Sweden. Two experimental plots were established: reference and fertilised plots. The latter has received the total amount of 950 kg N/ha over the past 13 years (c. 50-100 kg N/ha/yr), resulting in an N gradient in the soil adjacent to this plot. We established soil sampling transects along the gradient and assessed the relationships between the N level and SOMs.

Soils were collected from the litter and humus layers and assessed for 1) the composition of C compounds using solid-state carbon-13 nuclear magnetic resonance (NMR) spectroscopy and pyrolysis-GC/MS and 2) total C mass. NMR demonstrated decreases in O-alkyl relative to N-alkyl/methoxyl C with the N levels. These compounds were derived from carbohydrate and lignin components, respectively. This shift in C compounds was consistent with pyrolysis-GC/MS showing that carbohydrate:lignin ratios were negatively correlated with N. The total C mass was 2.09 ± 0.43 and 1.7 ± 0.30 kg C/m² (Mean \pm 95% confidence interval) in the fertilised and reference plots, respectively. This treatment difference corresponded to C sequestration of 30 g C/m²/yr. Furthermore, C mass in humus was positively related to the N level. Thus, our study suggests that an N addition in this pine forest alters the composition of C compounds by decreasing carbohydrate-derived compounds relative to lignin and also may increase C sequestration in the organic layer. Our results may help us to disentangle the potential mechanisms of C decomposition/sequestration in N-limited boreal forests.

Responses of soil carbon pool and soil aggregates associated organic carbon to the addition of rapeseed straw and/or straw-derived biochar in a rapeseed/maize cropping system

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How to link soil carbon (C) sequestration or restoration with straw utilization is an enormous challenge for agriculture. The addition of straw-based organic matters including fresh straw, decomposed straw or straw-derived biochar to soil can alter soil C pools. To understand the potential of soil C sequestration and dynamics after the addition of straw and/or straw-derived biochar, an in situ mesocosm experiment in purple soil (Eutric Regosol) was performed under five treatments: (1) no straw/biochar control (CT), (2) straw only (ST), (3) straw with a straw-decay bacterium (STDB), (4) biochar only (BC) and (5) straw plus biochar (STBC). Carbon dioxide (CO₂) flux from soil, soil organic C (SOC), labile organic C (LOC), and soil aggregate associated OC were analyzed within a dryland rapeseed/maize cropping system. Results showed that soil CO₂ flux increased with the addition of straws (ST, STBC and STDB), but decreased under BC because its lower LOC, particularly the microbial biomass C fraction in LOC. The combined application of STDB increased percentage of macro-aggregates (>2mm and 0.25-2mm). Meanwhile, both the decomposition of organic matter and the CO₂ flux were increased. The 0.053-0.25mm aggregates under BC had the highest fine intra-aggregate particulate organic C (iPOC), which promoted C sequestration. However, the higher coarse-iPOC in >2mm and 0.25-2mm aggregates under ST and STDB promoted SOC decomposition and also CO₂ flux. Compared with all three straw treatments (ST, STBC and STDB), the sole biochar addition improved the physical protections for SOC from soil aggregates, but reduced CO₂ flux, while increased net C sequestration without significant decreases of crop yields and net primary productivity. Our results demonstrated differential responses of soil C pool and aggregates associated organic C to straw and/or straw-derived biochar addition while providing insights into the potential for soil C sequestration or restoration by using agriculture based organic materials.

Degradation of SOM in cultivated peat soils, why is there no stabilization?

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Drainage of peatlands for cultivation leads to oxidation of organic material and subsequent soil subsidence and increased carbon emissions. Development of counteracting or mitigating strategies for these negative effects require improved understanding of oxidation dynamics in drained peatlands. While initial dynamics are well-known, it is less clear what happens after peat has been transformed to secondary organic compounds through initial oxygen exposure.

It is often assumed that drainage leads to a short peak in CO₂ emissions, our experiments however show that these high emission rates are maintained throughout the entire conversion of organic peat to its inorganic constituents, indicating that no organic matter stabilization takes place during peat decomposition. This high degradation rate of degraded peat samples deviates from the general pattern of organic matter dynamics where decay rates reduce with degradation. The apparent lack of SOM stabilization in peat soils can be explained with two scientifically interesting concepts: 1) the turnover of microbial biomass is low in peat soils, increasing the proportion of maintenance respiration and decreasing the relative production of secondary compounds and 2) the absence of mineral material organo-mineral complexation. Understanding these differences in SOM dynamics between peat soils and mineral soils can result in a crucial guideline for peat oxidation reduction and assessment of peat oxidation risks.

Crop rotation diversity changes soil organic matter composition and microbial function in corn- and wheat-based systems

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Sustainable cropping systems rely on diverse crop rotations to maintain balanced fertility and critical soil functions, including organic matter turnover. We evaluated soils from two long-term field experiments comparing continuous cereals with cereals in diverse crop rotations. The first is a humid corn-based system (Ontario, Canada) and the second is a semi-arid wheat-based system (Saskatchewan, Canada), both of which have exhibited a yield boost of at least 20% in the cereals grown in diverse rotations. Using multiple indicators of soil function and DNA amplicon-based microbial community profiling we found significant differences in soil organic matter composition and microbial community structure and activity. Effects of diverse crop rotations were greater in the corn vs. wheat system, with bigger changes in the relative abundances of different bacterial and fungal taxa, extracellular enzyme activities and available nutrient concentrations. Soil organic matter characterization showed an accumulation of lignin, increased syringyl:vanillin ratio and greater mineralizable C in continuous wheat and corn but no difference in amino sugar content, indicating that there was faster turnover of recent plant C inputs in the diverse rotations but no differences in microbial necromass accumulation. A soil incubation study using ¹³C labelled corn and wheat residues to track the microbial decomposition of residue C revealed differences in active decomposers between rotation treatments. Similar to our field survey, these rotation-induced differences were greater in the corn compared to the wheat system. We hypothesize that this is due to moisture stress being a stronger determinant of microbial decomposer community structure and function than residue quality in the semi-arid climate. Our work demonstrates that changes in residue quality, realized through crop rotation, impact soil organic matter composition and soil function and explicitly considers microbial functions as both causative and indicative of changing soil fertility and organic matter dynamics.

Mycorrhizal nitrogen acquisition from organic matter enhanced by multipartite interactions

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Arbuscular mycorrhizal (AM) fungi are ubiquitous plant symbionts that can improve plant nitrogen (N) acquisition from organic sources, with implications for soil organic matter (SOM) cycling and soil-climate feedbacks. Recent work shows that interactions with other soil biota mediate AM N acquisition from SOM. We used the stable isotopes ¹⁵N and ¹³C, controlled mesocosms, and soil microbial communities from a N gradient experiment to investigate these complex relationships and their response to long-term N enrichment. Multipartite interactions between plants, AM fungi, and soil microbial communities greatly enhanced total plant biomass and resulted in up to a tenfold increase in plant N acquisition from organic matter. This far exceeded the expected increase in plant N acquisition based on the sum of N taken up when plants were grown alone, grown only with AM fungi, or grown only with soil microbial communities. Like plants, AM fungi acquired more N from organic matter in the presence of soil microbial communities. These synergistic interactions also resulted in a significant increase in microbial utilization of plant-derived carbon, demonstrating an important link between SOM mineralization, AM N utilization, and plant carbon allocation belowground. Long-term N enrichment disrupted these synergies, resulting in diminished plant and fungal N acquisition from organic matter. Taken together, these results shed light upon multipartite biotic interactions involved in SOM cycling and their response to environmental change.

Subsoil amelioration with organic matter amendment in western Victoria, Australia: leaf physiological and root morphological response

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A range of subsoil physicochemical constraints limit root penetration, nutrient and water uptake and crop yields throughout large areas of cropping soils in western Victoria. Adding large quantities of nutrient enriched organic matter (also known as subsoil manuring) has been shown to ameliorate such constraints, but the mechanisms underpinning this crop response are not well understood. Two field trials were established at Tatyoon (high-rainfall zone; 550 mm annual rainfall) and Kiata (medium-rainfall zone; 400 mm annual rainfall) in Victoria in 2018 with four treatments: (1) Control; (2) gypsum, deep-banded at a depth of 30 cm in the subsoil (Gypsum-subsoil) (3) chicken manure pellets, top-dressed on the soil surface (Manure-topsoil) and (4) chicken manure pellets, deep-banded in the subsoil (Manure-subsoil). The effect of these amendments on photosynthesis, leaf chlorophyll, leaf area and biomass, and root morphology of wheat were investigated. Rainfall at both sites was below average (Decile 1-2) and significant treatment effects occurred only at the high-rainfall Tatyoon site. At the Tatyoon site, the manure-subsoil resulted in a 22.5% increase in grain yield (8.12 t/ha), followed by manure-topsoil (7.53 t/ha), gypsum-subsoil (6.64 t/ha) and control (6.63 t/ha). At Kiata, however, there was no treatment effect on grain yield, with an average of 2.72 t/ha. At Tatyoon, gypsum-subsoil and manure-subsoil tended to increase root length in the 28-42 cm section of the soil profile at anthesis. The photosynthetic function of leaves continued for a longer period after anthesis with the manured treatments compared to the control. Greater leaf N concentrations recorded in these treatments suggest that greater N uptake facilitates C assimilation and yield formation by enhancing leaf photosynthesis and prolonging leaf greenness. Future investigations on the association between SOM, soil structure and soil moisture dynamics, and water-use efficiency should provide more insights into the efficacy of these treatments.

Effects of increased temperature and precipitation on soil biogeochemical processes in Cambridge Bay, Canada

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Increasing atmospheric temperature is preferentially higher in the Arctic than the mid or low latitude over the last few decades. Pattern of precipitation is also changing with warming but more unpredictable. We conducted an experiment to examine the effects of increased temperature and precipitation on CO₂ flux and soil and microbial properties in the high Arctic Canada since 2012. The study site was Cambridge Bay on the southeast coast of Victoria Island, Nunavut (69° 07' 48" N, 105° 03' 35" W). *Carex* spp. and *Dryas integrifolia* are dominant vegetation types in this dry tundra. A full factorial design was used in this warming and wetting experiment. Warming was implemented with a hexagon type of open top chambers (OTCs) with a 2-m diameter, and we added 0.5 mm of water every week throughout summer. The atmospheric and soil temperature increased about 0.48 and 0.65 °C in non-warming plots compared to OTCs, respectively. The relative humidity in OTCs was about 1 % lower than that in non-warming plots. Net ecosystem exchange (NEE) and ecosystem respiration were measured by a manual chamber method. NEE was negative (CO₂ uptake > production) during mid July to mid August, and CO₂ fluxes during a growing season did not show significant differences among treatments. Inorganic N and water extractable C contents were not significantly different among treatments either. Additionally, we measured the extracellular enzyme activities associated with C and N dynamics at the same time, however, no apparent relationship was found with CO₂ fluxes, inorganic N content, and water extractable C. Currently, we are analyzing microbial biomass through extracting microbial phospholipid fatty acids and dissolved organic matter composition using 15T FT-ICR/MS. We expect to understand the effects of warming and wetting on soil biogeochemical processes and DOM compositions through integrating all results produced in 2018 and 2019.

Improved methodologies for SOC measurement, estimation and reporting its density changes in agricultural soils

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Reduction of greenhouse gas (GHG) assessment uncertainties and improvement in the quantification of sinks and offsetting mechanisms are required to develop appropriate mitigation measures aimed at keeping global temperature <2°C. The key factors that are needed to fulfil these objectives are a precise, verifiable estimation of soil organic carbon (SOC) and its variation at field scales. For SOC measurements, land use (LU)/soil type-specific and consistent sampling protocols (e.g., method and timing of samplings) together with a consideration of other factors (e.g., soil moisture and carbon) that influence soil mass and volume, are required. For accurate estimations, the determination of SOC by 'mass by volume' on an equal soil mass basis, in a defined but adjustable soil layer and reporting is essential. The Intergovernmental Panel on Climate Change proposes proportional (%) approach, as a SOC density (here)/stock change factor (DCF), for application across key agricultural LUs, managements and inputs. Methodologies developed with higher spatial resolution databases, coupled with two-phase modelling and GIS approaches, could provide robust estimates. However, the DCF factors overestimated the SOC density changes for organo-mineral (12-19%) and organo-mineral plus organic soils (33-81%) compared to mineral soils. This resulted in a corresponding increase in national SOC stock estimates by, on average, 14 and 20%. The corrected estimates showed a sequestration rate of 0.04, 0.12 and 0.42 t C ha⁻¹ yr⁻¹ in Irish agricultural soils, and a potential GHG offsetting of 1.20, 2.93 and 5.41 Tg C yr⁻¹ for the 0-10, 0-30 and 0-100 cm soil layers, respectively. These findings suggest the replacement of the apportioning approach, including 4‰ concept, by a 'mass by area' (depth-specific) one for more precise estimations. This will include the disaggregation of soil types, and the calculation of country-specific DCFs and weighting factors for individual LUs, management practices and inputs for upscaling to regional/international level.

Composting and compost utilization in rice paddy field: Trade-off between greenhouse gas emission and soil carbon sequestration in whole rice cropping system

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Organic matter applications showed contrasting effects on soil quality and greenhouse gas (GHG) emissions, in particular methane (CH₄) emission in a rice cropping system. Therefore, to mitigate CH₄ emissions, stabilized manure like compost and biochar is recommended without considering the additional GHG emissions during the industrial processes and soil organic carbon (SOC) stock changes. To determine the integrated effect of compost utilization on the net global warming potential (GWP) of a rice cropping system, the fluxes of GHGs during the whole process were computed using a life cycle assessment (LCA) method. The model framework was composed of GHG fluxes from two compartments: the industrial activities, and the composting and rice cropping processes. Since manure application can increase SOC stock, the annual SOC stock changes were analyzed by the net ecosystem C budget (NECB) which implies the difference between C input and output. Manure applications significantly increased rice productivity and the net primary production (NPP) as a C input source without difference between fresh and composted manures. NPK+fresh manure application significantly increased CH₄ and N₂O emissions by 81% and 37% over the NPK treatment in rice cropping system, respectively, and depleted SOC stock with 1.3Mg C ha⁻¹ year⁻¹, due to priming effect. As a result, NPK+fresh manure application increased the net GWP by 80% over the NPK treatment. In comparison, NPK+compost utilization decreased the net GWP by 30% over that of the NPK+fresh manure during the whole process. Manure composting increased the GWP of the industrial processes by 7%, but the 20% reduction of CH₄ flux and 0.5 Mg C ha⁻¹ year⁻¹ of SOC stock increase significantly decreased the net GWP during the whole rice cropping process. As a result, the GHG intensity which means the net GWP per gain yield was not different between the NPK+composted manure and the NPK treatments. In conclusion, compost application can be a reasonable soil management strategy to reduce GHG emission impact and to increase crop productivity in rice cropping systems.

Are soil carbon stocks controlled by a soil's capacity to protect carbon from decomposition?

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Greenhouse gas emissions can be off-set by increasing soil organic carbon (SOC), but the factors controlling changes in SOC storage must be understood to identify suitable management practices. Soils differ in their ability to stabilise SOC, but do soils have a maximum capacity to stabilise carbon, or does stabilisation simply act to reduce turn-over rates without limits? Here, we use observations from two specific NZ sites, and from national soils data to gain insights into the controls of SOC stabilisation. They showed:

1. When other factors such as climate, soil fertility, and pasture management were the same, SOC was linearly correlated with soil specific mineral surface area (Sm).
2. At each soil depth, SOC and Sm were linearly related, with the slopes and intercepts of the relationships decreasing with depth.
3. Small intercept values at zero Sm implied that SOC was mostly protected by the soil matrix rather than biochemically, that mineral surface area was the functionally relevant measure of stabilisation capacity, and that its effectiveness was independent of carbon input rates.

We analysed New Zealand's national soils data based for evidence of a maximum stabilisation capacity. We reasoned that if SOC was limited by maximum stabilisation capacity it should result in a skewed distribution of SOC around mean values. Some points could be much lower than the maximum stabilisation capacity, but points could not exceed that maximum capacity. SOC in the national data set, however, was normally distributed, thus being inconsistent with maximum stabilisation capacity as a SOC limitation.

Instead, our analysis suggested that protected SOC, C_p , could be described as:

$C_p = C_{in} S_m / f(T, W, \dots)$, where C_{in} is the carbon input rate, and $f(T, W, \dots)$ is a SOC turn-over rate depending on temperature, soil moisture or any other factors able to affect decomposition rates.

Fungal stable isotope compositions reflect contrasting nutrient-cycling dynamics in ecto- vs. arbuscular mycorrhizal-associated forests

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Introduction:

Increasing evidence indicates that nitrogen dynamics in forest soils depend on the associated mycorrhizal type. For temperate forests, two main mycorrhizal types are distinguished: ectomycorrhiza (EcM) and arbuscular mycorrhiza (AM). Due to differing nutrient dynamics, higher quality of AM litter, faster N cycling rates and lower C stocks in AM-associated systems compared to EcM are predicted. However, the direct impact of mycorrhizal fungi on C and N cycling in forest ecosystems remains elusive.

While EcM fungi release exo-enzymes to actively decompose SOM, AM fungi may activate saprotrophic microorganisms and scavenge for nutrients released. We hypothesize that different N cycling rates and the accessibility of SOM pools with distinct turnover times lead to contrasting isotopic compositions of AM and EcM fungi in forest ecosystems.

Methods:

Stable isotope natural abundance measurements were performed on fruiting bodies of EcM and saprotrophic fungi (SAP), AM hyphae, plant shoot and root material, mineral N and SOM fractions with varying turnover time. Stable hydrogen (²H), carbon (¹³C), nitrogen (¹⁵N) and oxygen (¹⁸O) isotopes, C/N ratios and C and N contents were determined. Fractionation factors between fungal tissue, autotrophic reference plants and various SOM fractions were calculated.

Outcome:

The specialization of mycorrhizal fungi on specific nitrogen sources and their effect on SOM decomposition results in nutritional differences and distinct isotopic signatures of AM and EcM fungi. To recent knowledge, the production of exo-enzymes and assessment of more stable SOM fractions by many EcM and SAP fungi results in their 3-5 ‰ ¹⁵N-enrichment compared to reference plants. AM fungi lacking these enzymes show ¹⁵N values between plants and EcM/SAP fungi, indicating their utilization of more labile compounds.

Overall, our study indicates that the isotopic composition of mycorrhizal fungi reflects different nutrient-acquisition strategies, with a stronger ¹⁵N-enrichment for actively SOM-decomposing fungi and a ¹⁵N-depletion for passively SOM-decomposing fungi.

Modeling the effect of soil organic matter on microaggregate formation in soils and their influence on soil functions

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Microaggregates are the fundamental building blocks of soils and thus important for their structure, properties, and functions. Mathematically based modeling can facilitate the understanding of self-organization, formation, build-up, composition, properties, and stability of microaggregates provided that the complex coupling of biological, chemical and physical processes is taken into account.

Our model is based on a cellular automaton method (CAM) for the pore scale evolution of the solid, biomass and liquid (water, air) phases, all transport and reaction processes are described continuum mechanics based. In the CAM framework, prototypic solid building units quartz (spherical), goethite (needle-like), and illite (platy) are implemented to investigate the formation and self-organization of soil microaggregates. Interaction of these building units by means of stabilizing sticky agents (EPS) in combination with electrostatic attraction/repulsion lead to composite building units and eventually to soil microaggregates. Modern numerical techniques (DG methods) allow for the simulation of the full model. The operational, comprehensive model allows rating the influencing factors for the formation of soil microaggregates and also investigating optimal aggregation conditions. Moreover, our modeling approach enables revealing the effect soil organic matter has as nucleus for the aggregation process.

Finally, soil's characteristic properties such as porosity, effective diffusion tensors and permeabilities for the resulting complex geometries are deduced rigorously on the basis of such a detailed structure evolution and allow for Darcy scale simulations of flow and reactive transport taking into account the pore scale evolution at the level of detail described above. In this way it is possible to assess the impact of microaggregate formation on soil functions.

Decomposition and alteration of organic matter during remediation of a sandy acid sulfate soil

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When acid sulfate soils dry, oxidation of pyrite can cause strong acidification (pH <4) to form sulfuric material. Re-saturation of acid sulfate soils with sulfuric material can lead to re-formation of Fe-sulfides and pH increase through activity of sulfate reducing bacteria (SRB), which require sufficient available organic carbon (OC). Despite the general knowledge about positive impacts of OC sources for ameliorating sulfuric soils, little is known about OC consumption and changes of OC composition of native and added organic substrates during the amelioration process. To investigate remediation of a sandy, OC-poor sulfuric soil (initial pH = 2.5), a 10-week anoxic incubation experiment was conducted under submerged conditions. Organic C amounts between 50% up to 200% of the native soil OC content were added as wheat straw and lactate. Lactate was used to test if this selectively promotes the activity of SRB, and thus, accelerates sulfate reduction and pH neutralization. The results showed that OC additions of $\geq 50\%$ of native soil OC content and pre-adjustment of pH to values ≥ 5.0 were sufficient to enhance microbial reduction, which increased the pH to values ≥ 5.5 . Further, OC additions of $\geq 100\%$ of native soil OC increased mineral-associated OC. The addition of OC as lactate solution in combination with wheat straw led to quickest changes of pH and redox values and resulted in pH ≥ 7 and redox values $\leq -300\text{mV}$, which was accompanied by high CO₂ release indicating an active microbial population. Thus, application of wheat straw-lactate – mixtures led to the quickest remediation success. However, OC losses due to microbial degradation and formation of less available mineral-associated OC may require repeated OC addition.

Composition of soil organic matter drives the loss of persistent organic pollutants

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The internationally banned agricultural insecticides dieldrin and dichlorodiphenyltrichloroethane (DDT) continue to exceed government thresholds in some Australian surface soils (0 - 10 cm) - 30 years after their last use. Their extreme persistence in soils is believed to be governed by sorption to soil organic matter (SOM), hence their existence in SOM-rich, high-value pastures limits land use options as grazing animals accumulate residues in their fat. To enhance remediation, more knowledge is needed of soil factors and microbial community dynamics involved in microbial in-situ degradation of these man-made organochlorine chemicals. Furthermore, while DDT-degrading strains have been successfully isolated in the past, there are no known microbial species with substrate specificity to dieldrin. A total of 12 contaminated paddocks with records of dieldrin and DDT concentrations dating from 1980 were sampled again in 2017. We hypothesised that SOM is a key factor affecting microbial biomass and diversity which would in turn affect biodegradation and total loss of the pollutants after 30 years. Correlations between total loss and current concentrations of dieldrin and DDT residues and soil physicochemical measurements, microbial biomass carbon, microbial community diversity indices and microbial community abundance were analysed. Low C:N ratios of SOM, high microbial biomass and high fungal community evenness correlated with an increased loss of dieldrin after 23 - 30 years, but sorption to SOM and clay likely inhibited further degradation. This indicated that co-metabolism of dieldrin and DDT could be enhanced by manipulating the quality of SOM to cater for a broad microbial functional diversity. Future culture studies will help to confirm whether microbial metabolism in these soils has evolved to utilise dieldrin or DDT as a primary carbon source, which taxa are involved and what role SOM composition plays in degradation of these pollutants.

Convergence and divergence of carbon pathways by soil organic matter formation

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Microbial transformation of organic substances is a key process of carbon (C) stabilization and soil organic matter (SOM) formation. Two general pathways are possible: i) convergence: means that C from initial organic compounds (e.g. in litter or rhizodeposition) are completely mixed and it is not possible to trace back their origin; or ii) divergence: means that the C fate by SOM formation completely depends on the initial organic compounds. We proved two opposite hypotheses that convergence and divergence of the fate of organic substances and of C atoms depend on microbial recycling and decomposition at two levels: 1) intermolecular: high recycling intensity leads to convergence of the C fate and is mainly important for the difference between the organic compounds, and 2) incorporation of C from various molecule positions into microbial metabolic cycles define the C fate at intramolecular level. We tested these hypotheses based on own and literature data to the fate of polymeric substances: sugars, proteins, lipids and lignin, as well as by C atoms from various positions of pentoses and hexoses by position specific ¹³C and ¹⁴C labeling.

The fate and functions organic compounds depends mainly on microbial recycling: C of the intensively recycled sugars and proteins, key components of microbial biomass, remains relatively long in soil, much longer than non-recycled clearly plant-specific compounds like lignin monomers. This is explained by two steps decomposition-stabilization mode of recycled compounds in contrast to one step decomposition mode of non-recycled substances. So, the convergence of the C fate is common for substances with fast microbial recycling that contrasts to divergence of slowly decomposed compounds.

For the intramolecular differences, we traced the fate of position-specific and uniformly ¹³C labeled glucose and ribose under field conditions for 800 days. Both sugars were simultaneously metabolized via glycolysis and pentose phosphate pathway. The similarity between position-specific ¹³C recovery in microbial biomass and soil reflected high contribution of microbial necromass to SOM. Despite the mean residence time (MRT) of glucose C-6 and ribose C-5 in soil were longer than of the other C positions, the MRT of uniformly labeled ¹³C of ribose in the soil was 3 times longer than that of glucose. Consequently, ribose and glucose were incorporated into different cellular components, defining their long-term fate in soil. The convergence of glucose C positions in soil and microbial biomass revealed that recycling dominated glucose transformation. In contrast, divergence of ribose C positions in soil revealed that intact ribose-derived cell components are reused or preserved in SOM.

Thus, convergence versus divergence distinguished the two key fates explaining the long persistence of C at inter- and intra-molecular levels: microbial recycling leads to convergence, whereas slow decomposition and preservation define the divergence of C pathways in soil.

Laboratory capacity for the analysis of Soil Organic Matter in Pacific Island Region and the Blue Carbon Initiative

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The Institute of Applied Sciences Analytical Laboratory at the University of the South Pacific (USP) is an accredited laboratory that serves USP 12 member countries in the Pacific Island Region (PIR). The analysis of Organic Carbon in soil and sediment samples are performed using the Walkley and Black method using 1 g of soil. A key difficulty is that the Walkley-Black method may result in low test results for certain soils with organic matter greater than 6%. However, the method performs well with soil or sediment samples with low organic matter. To further develop testing capacity for measuring Organic Carbon for ongoing Initiative on Blue Carbon, there is a need to adopt measurement techniques with direct sample introduction such as the CHN analyser by loss of ignition. Additionally, there is a need to build capacity in the laboratory so that technicians in the laboratories in the Pacific Island Region are able to achieve accreditation for the testing of Organic Carbon. Taking part in soil proficiency testing offered by ASPAC could assist in improvements in quality control. This will ensure quality data is produced in the Pacific Island Region laboratories and can be useful for development of Policies in the Region on initiatives like the Blue Carbon.

The potential of temperature-dependent carbon differentiation for soil analysis

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Detailed information about carbon contents, fractions, and pools in soils are essential for understanding biogeochemical processes and the consequences for land use, waste management, and climate change. The methodological challenge in the determination of carbon fractions is the accurate differentiation of organic, inorganic and in particular elemental carbon. Additionally, it is important to understand the soil organic carbon (SOC) storage and degradation processes. Therefore, knowledge about the SOC stability and association is highly beneficial.

We tested the advantages and drawbacks of a temperature gradient program with different hold times compared to classic direct and indirect methods for the determination of carbon fractions and species (e.g., EN 15936).

The soli TOC[®] cube of Elementar Analysensysteme GmbH has been used for comparison measurements of different soils, waste as well as pure substances. It offers the opportunity to run a free configurable temperature program due to its dynamic heater and catalytic post combustion. Accordingly, carbon compounds are combusted and transformed to CO₂ due to their thermal stability at different temperatures and the CO₂ is detected. Also, different carrier gases have been tested for separating elemental and inorganic carbon under oxidative and pyrolytic conditions.

For most soils, the organic carbon fractions determined by the direct procedure, match the sum of elemental and organic carbon according to the temperature ramping program. The differentiation of organic and elemental carbon is determined by using a temperature of 400°C for splitting these fractions. Furthermore, the flexibility of the temperature gradient offers more opportunities for a reliable and accurate separation of carbon fractions and possibly even species. Consequently, there are more options for special samples and research questions compared to acidification and combustion methods, which use only one temperature above 900°C.

Different offsetting greenhouse gas intensity (GHGI) between chemical and organic fertilization by plastic film mulching in maize upland soil

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Plastic film mulching (PFM) utilization is rapidly expanded in intensive farming fields. PFM is very effective to increase crop productivity via improving soil temperature and moisture conditions. However, since PFM can deplete soil organic carbon (SOC) stock and increase greenhouse gas (GHG) emission, the utilization of PFM is still debating. In this two year-field study, to determine the influence of PFM on global warming impact, PFM and no-mulching treatments were installed in maize cropping field under chemical and organic fertilizations. In organic fertilization plots, cover crop was cultivated during the fallow season, and the whole biomass was recycled as green manure before sequential maize seedling. Maize productivity and net global warming potential (GWP) were analyzed during cropping seasons. To estimate net GWP, two GHG (N₂O and CH₄) fluxes and SOC stock changes were determined. SOC stock changes were analyzed using net ecosystem carbon budget (NECB), which implies the difference between C input and C output. GHG intensity (GHGI) was calculated using net GWP per unit of grain yield. PFM significantly increased maize grain yields by 45-78% over no-mulching under the same fertilization, but it was more effective in organic fertilization than chemical, due to higher nutrient input. In contrast, PFM considerably increased seasonal N₂O and CH₄ emissions by 4-11 and 132-263 % over no-mulching under the same amendment, respectively. PFM depleted SOC stock 29-36 and 186-227% more in chemical and organic fertilization than no-mulching, respectively. Irrespective with fertilization and mulching background, net GWP was decided by SOC stock change, which covered 75-93% of net GWP. PFM differently influenced net GWP and GHGI between chemical and organic fertilizations. In chemical fertilization, PFM increased net GWP by approximately 30% over no-mulching, but decreased GHGI by 20-32%. However, in organic amendment, PFM highly increased net GWP and GHGI by 147-177% and 45-71% over no-mulching, respectively. Therefore, PFM in chemical fertilization system could be very powerful tool to decrease global warming impact via crop yield increase. However, in organic farming system, PFM should be carefully selected to increase crop yields, due to highly increased global warming impact.

Abiotic nitrogen immobilization affect organic matter composition and stoichiometry

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Nitrogen mineralization and immobilization are important functions of soil organic matter that affect both the availability of inorganic nitrogen for plant uptake as well as soil carbon sequestration by alleviating constraints imposed by nitrogen stoichiometry. Here we show that ammonia gas can react with soil organic matter without a biological process to form covalent carbon-nitrogen compounds. Abiotic nitrogen immobilization was greater through reactions with decomposition products and more oxidized organic matter than with plant litter. In highly oxidized organic matter, more than 10% of the nitrogen bonds formed during ammonia exposure contained heterocyclic structures. These reactions operated quickly and increased organic nitrogen contents several fold within short periods of times of second to minutes. This presentation provides evidence for abiotic immobilization as a quantitatively important and rapid reaction of inorganic nitrogen to form a variety of covalent bonds in soil organic matter. This process is highly relevant for soil fertility management as well as carbon sequestration in soil.

Differential responses of the components of ecosystem carbon exchange to irrigation frequency in mesocosms with a C4 grassland

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Conversion of non-irrigated grasslands to high-intensity farm systems with irrigation is a major land-use change in dryland areas of New Zealand. The conversion has the potential to cause major changes in ecosystem carbon cycling but differences in the sensitivities of the components of net ecosystem carbon dioxide (CO₂) exchange (FN) to water availability are not clear. Here, we partitioned the components of FN for the C4 plant Bermuda grass (*Cynodon dactylon* L.) growing in mesocosms irrigated every 1, 3, and 6 days (I1, I3, and I6, respectively) with a constant intensity (14.8 mm). FN decreased linearly with increasing soil water deficit (W), indicating increasing ecosystem CO₂ losses with decreasing irrigation frequency. Over the 30 days of the experiment, FN reached 657 ± 44 (mean \pm standard deviation, $n = 4$), 604 ± 29 , and 552 ± 47 g C m⁻² for I1, I3, and I6, respectively. This was due to a linear decrease in ecosystem gross primary productivity with increasing W that exceeded the decrease in ecosystem respiration (RE). RE declined non-linearly with increasing W with the aboveground component increasing and the below-ground component (soil respiration rate, RS) decreasing non-linearly with increasing W. Using a ¹³C natural abundance isotopic technique, RS was partitioned into autotrophic (RA) and heterotrophic respiration (RH) at the end of the experiment, when differences in W between the treatments were greatest. RH contributed 41 ± 17 , 23 ± 21 , and $30 \pm 14\%$ of RS for I1, I3, and I6, respectively. Increasing irrigation frequency resulted in increased ecosystem CO₂ uptake as a result of diverging responses of gross primary production and respiration components. However, care in interpreting the implications for changes in soil carbon stocks is warranted as RH was also highest for the I1 treatment with highest CO₂- uptake, suggesting possible positive priming.

Inferring trait-based physiological strategies of leaf litter microbial communities along a precipitation gradient

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Microbial physiology may be critical for projecting changes in soil carbon. Still, predicting the ecosystem implications of microbial processes remains a challenge. Here we argue that this challenge can be met by identifying microbial life history strategies based on their phenotypic characteristics, or traits, and representing these strategies in models simulating different environmental conditions. By adapting several theories from macroecology, we define microbial high yield (Y), resource acquisition (A), and stress tolerance (S) strategies. We empirically validated our Y-A-S framework by studying variations in community traits along gradients of resource availability and abiotic conditions. Metatranscriptomics and metabolomics were used to infer variations in traits of in situ microbial communities on plant leaf litter in response to long-term drought in Californian grass and shrub ecosystems. We hypothesised that drought causes greater microbial allocation to stress tolerance relative to growth pathways and that shrub litter of poorer chemical quality further constrains growth through increased investment in resource acquisition traits. The most discernable physiological adaptations to drought in grass litter communities were production or uptake of compatible solutes like trehalose and ectoine as well as inorganic ions to maintain cellular osmotic balance. Grass communities also increased expression of genes for synthesis of capsular and extracellular polymeric substances possibly as a mechanism to retain water. These results show a clear functional response to drought in grass litter communities with greater allocation to survival relative to growth that could affect decomposition under drought. In contrast, communities on chemically complex shrub litter had smaller differences in gene expression and metabolite profiles in response to drought, suggesting that the drought stress response is constrained by litter chemistry. Overall, our findings suggest trade-offs between drought stress tolerance, resource acquisition and growth yield, thereby providing a framework to link microbial physiology with ecosystem function.

Full inversion tillage offers opportunity for increased C sequestration, implications and agronomic effects

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Increasing soil organic carbon (SOC) has been proposed as one method to reduce atmospheric CO₂ concentrations and in turn help offset agricultural greenhouse gas emissions. In New Zealand grasslands, SOC is typically concentrated at the surface and declines rapidly with depth (i.e. stratified). The use of full inversion tillage (FIT) during a pasture renewal (FIT-renewal) event provides an opportunity to redistribute and increase the SOC stock. Multiple field trials were established in New Zealand (North and South Islands) to assess the effects of FIT performed during pasture renewal on the SOC stock, dry matter production, nitrogen losses and agronomic costs. The field sites covered a range of soil types and simulated pasture renewal in either spring or autumn conditions. For all the sites, FIT resulted in a redistribution of the SOC in the top 30 cm by depositing C rich topsoil below 10 cm and bringing low C subsoil to the surface providing an opportunity to increase SOC stocks at the surface. Dry matter production was increased following FIT-renewal across all sites with greater yields (~30% higher) observed in the trials with a grass-crop-grass rotation following FIT. An accumulation of mineral N following FIT-renewal appeared to increase the risk of NO₃⁻ leaching during an autumn renewal. The increase of mineral N and consequent leaching risk was reduced over the winter/spring period through the use of a catch crop (forage oats and Italian ryegrass). In a North Island site leaching losses were reduced under FIT compared to other renewal treatments (e.g. direct drill and shallow till) when a brassica crop was included in the spring renewal rotation. Our results demonstrate that the additional agronomic costs (e.g. tillage, fertiliser) associated with FIT is more than offset by the increase in dry matter production of the renewed pasture/crop.

Irrigation changes the distribution of new photo-assimilated carbon into various soil size fractions

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Globally, the need for irrigation to increase dry matter production (DMP) on grazed pastures has been steadily increasing to support the growing demand for meat and dairy products. However, research on the effects of irrigation on the dynamics of soil carbon (SOC) in these pastures has been scarce and produced contradictory results. Our objective was to quantify the effects of irrigation on the storage and stability of new photo-assimilated carbon (C) in a plant-soil system.

The experiment consisted of two soil moisture treatments (simulating either Dryland or Irrigated conditions) applied to soil mesocosms established with perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pasture. Plants were continuously pulse labelled with ¹³CO₂ between December 2016 and March 2017 (e.g. an irrigation season) by growing within a sealed plant growth chamber. Following the labelling phase, the soil moisture regimes, for both treatments, were adjusted to simulate autumn/winter conditions. The mesocosms were destructively harvested at 1, 12, 125, 237 and 349 days after the last labelling event. The partitioning of new photo-assimilated C was determined through ¹³C analysis of herbage, roots, bulk soil, rhizosphere soil and soil size fractions (>250 µm, 53–250 µm, 20–53 µm, 5–20 µm and <5 µm). The net storage and subsequent loss of new photo-assimilated C in soil was monitored through time.

Our results showed that despite irrigation causing a significant increase in DMP (additional ~2000 kg DM ha⁻¹) compared to the dryland treatment, the net input of new photo-assimilated C into the soil during the labelling phase was similar for both treatments (~2500 kg C ha⁻¹). However, irrigation did effect the distribution of new C into certain fractions (53–250 µm, 5–20 µm and <5 µm). Our results did not support the common perception that increasing production via irrigation would result in increased SOM.

The crucial role of organic carbon availability in driving geochemical cycles in wetland and floodplain soils

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Many of the key geochemical cycles in wetland and floodplain soils (e.g. sulfate reduction, denitrification, methanogenesis) are driven or influenced by organic matter. Microbes play a central role in many of the geochemical reactions using organic carbon as an energy source. The bioavailability of the organic carbon to microbes, rather than its total concentration, is hence of central importance. We review and synthesise findings from several studies to show that the availability of organic carbon in many hydric soils controls geochemical reactions. Particular focus is placed on organic carbon availability in acid sulfate soils, as these can create severe and sustained acidification and metal release impacts following drainage/drought. In our long term field site in the Lower River Murray (South Australia), soils have not recovered from severe acidification (pH<4) over 10 years after the drought ended. Soil organic carbon concentrations are moderate (1-2% C) in the acidified soil layers but microbial reduction reactions are very limited. In contrast, when we add available organic carbon in the laboratory the soils can recover within weeks, but only if the pH is first adjusted to above 5. This suggests toxicity by low pH or high metal (e.g. Al³⁺) concentrations limiting microbial activity. Solid state ¹³C NMR studies have revealed that, compared to the native soil organic matter, soils with fresh organic matter addition are characterized by high proportions of O/N-alkyl C, which is readily decomposed compared to other components. The concentration of terminal electron acceptors (e.g. nitrate) may also influence microbial reduction reactions. While organic carbon availability limitations can be overcome by addition of organic materials, practical difficulties may be present in amending deep soil layers in wetland soils. The potential for enhanced greenhouse gas release following soil amendment also needs consideration.

Linking soil structure formation and soil organic matter cycling in the rhizosphere

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Due to its large interface between soils and plants, the rhizosphere, the volume of soil around living roots directly influenced by root activity, plays a key role in soil formation. Especially the root derived input of organic carbon into the soil matrix triggers a multitude of soil processes. The soil structure formation, i.e. aggregation of solid soil particles into three dimensional clusters, is the key process for the formation of a soil's pore space and specific surface area, determining the air, water and nutrient balance and thus shaping both plant and microbial habitats. The formation of associations built by the interaction of minerals with organic matter supplied by rhizodeposition or decaying roots together with microbial residues is unique to soils. The high input of organic carbon in the rhizosphere (both from plants and microorganisms) in contrast to root free bulk soil, promotes the formation of micro- and macro-aggregates, and thus the development of a 3D soil structure with positive effects on soil carbon sequestration. As the rhizosphere is a hot spot for organic carbon input and microbial activity, it becomes evident that it also plays a special role for the long term carbon sequestration at greater soil depth. Results from a number of studies will be presented on the importance of roots and the rhizosphere on soil organic matter cycling and sequestration. This will range from using artificial root systems at the lab scale to determine the effect of root exudates on soil aggregate formation and microbial community structures, up to the field scale exploring the major role of roots for soil organic carbon stability.

Indigenous soil microbes and multi-planting strategies for increasing soil carbon and function in dryland restoration

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Global environmental changes and other anthropogenic impacts are rapidly transforming the structure and functioning of ecosystems worldwide. These changes are leading to soil degradation with an estimated 25 % of the global land surface being affected. The need to develop cost-effective large-scale solutions to restore disturbed landscapes becomes imperative to preserve biodiversity and achieve ecosystem functionality and sustainability. As part of a large-scale industry-academia partnership, we have developed a soil research program that aims to build knowledge and design strategies to restore degraded landscapes in Western Australia and other dryland regions worldwide. Within this program, a series of laboratory experiments, glasshouse studies, and field trials, have been conducted over the last five years to advance our knowledge on soil limitations and to provide solutions to enhance soil carbon levels and restore above and belowground biodiversity in restoration programs. These studies include (i) the analysis of the influence of multi-species planting on soil organic carbon and microbial activity and diversity (ii) the evaluation of soil physicochemical and microbiological indicators to assess functionality of restored soils in degraded semiarid ecosystems and (ii) the development of nature-based strategies based on bio-tools (e.g. inoculation of soil biocrust cyanobacteria) to increase soil carbon and enhance overall soil function. In this presentation we will highlight some key findings of these studies that include the benefits of combining diverse plant species and using native microbes and organic amendments for increasing soil carbon and promote soil function in reconstructed soil substrates. We will also discuss the potential applicability of these bio-technological approaches in landscape-scale restoration programs.

Decomposition of plant litter and carbon turnover as a function of soil depth

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Decomposition of plant litter and carbon turnover as a function of soil depth

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The storage of carbon in the deeper layers of the soil offers opportunities for carbon sequestration because of potentially longer turnover times and longer storage times. This presentation reports on an investigation into the processes controlling litter decomposition to a depth of 100cm in Red Chromosol soil and an Alluvial soil in south eastern Australia. The aims of the investigation were (i) determine whether decomposition was slower in the deep soil and (ii), identify the mechanisms responsible. A field based litter-bag study and a laboratory incubation experiment were both conducted to measure litter decomposition rates directly.

Litter bags of different plant and substrate materials were buried at depths of at 5, 10, 25, 50, 75 and 100cm. Litter materials were plant materials (leaf, shallow roots and deep roots) from lucerne, Themeda, Phalaris. Cotton tape was used as a benchmark material. Litter bags were recovered at 75, 159, 275, 307 and 405 days after burial.

Litter decomposition was found to be slower at depth by a factor of 3.3- 6.3 depending on the plant species from which the litter was derived. Variation in litter quality caused decomposition rates to decline by a factor of 2.2 to 4.2 between leaf litter and root materials. Litter inputs to surface soils were higher in quality than those in deeper soils. Soil edaphic constraints caused decomposition rates to vary by a factor of 1.5 between the surface and the deeper soils. This was primarily attributed to nitrogen deficiency and was largely ameliorated in the laboratory when soluble N was added. Adding N did not account for all the differences between surface and subsoils. Indirect evidence suggested that bulk density and oxygen deficiency may have been a factor. Soil biological differences between surface and deep soils may have been were part of the deep soil constraint.

Intensification of no-till agricultural systems: An opportunity for carbon sequestration

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No-till is the key component of conservation agriculture adopted over 125 million hectares worldwide in order to address an ever-growing demand for soil and water quality, food security, and climate change adaptation and mitigation. However, as the French Government launched the '4 per 1000 Initiative' at the COP21 promoting soil carbon sequestration (at 0.4% per year) as an alternative to halt the increase in atmospheric CO₂, a long-lasting debate aroused on the potential of conservation agriculture to promote carbon sequestration. Previous reviews reported no differences on carbon storage in the deep profile of no-till and tilled soils, questioning the role of no-till soils in climate change mitigation. Here we present the results of a global meta-analysis of studies assessing carbon and nitrogen storage and sequestration in no-till soils from the most important agricultural regions of the world. Overall, our results show that no-till soils store both more carbon and nitrogen (up to 100 cm depth) than tilled soils in contrast with previous findings. However, carbon sequestration depended on the increase of crop frequency and nitrogen inputs in association with decreased soil disturbance. Single cropping of fallowing systems lacks carbon inputs to maintain soil carbon throughout the soil profile. However, double-cropping systems led to a decrease in soil nitrogen that may constrain future carbon sequestration whereas the use of legumes showed to alleviate nitrogen losses and supply extra nutrient to support carbon sequestration. Briefly, our findings indicate that no-till can effectively mitigate climate change by either avoiding CO₂ emissions from tilled soils or by promoting soil carbon sequestration in intensified agricultural systems.

Soil carbon decomposition is regulated by microbial accessibility and diversity

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Most studies addressing relationships between soil carbon dynamics and microbial diversity have not considered the role of carbon accessibility in regulating net carbon balance. We manipulated carbon accessibility to microbial decomposition by adding different proportions of carbon-binding active mineral surfaces to a constant mass of soil to investigate the linkages between soil microbial communities and cycling of stable soil carbon. Three proportions of an active mineral (0, 15, and 50%) were added to three soils with contrasting carbon concentrations of 3, 4.5 and 6%. We used four independent methods to determine differences in carbon accessibility, comprising (a) soil respiration rate, (b) enrichment of ¹³C isotopic signature of respired CO₂, (c) soluble carbon extracted in cold and hot water, and (d) aluminium and iron pyrophosphate concentrations as a proxy for the degree of organo-mineral binding interactions at 1, 4 and 8 days after the active mineral surfaces were added to the soils. DNA was extracted and the diversity and abundance of bacterial communities were estimated from bacterial 16s gene abundance. All four methods showed that additions of the active mineral to the soils proportionally reduced carbon accessibility by up to 80% with a constant trend observed for the three soils and no significant differences between days after addition. The observed proportional $\delta^{13}\text{C}$ enrichment from -28‰ (no active mineral addition) to -22‰ (50% mineral addition) was interpreted as a shift in the substrates used for decomposition, from labile C to microbially-processed, presumably older stable C. We present relationships between bacterial diversity and abundance and cycling of soil C in relation to its accessibility, providing new insights to reveal a mechanistic understanding of processes linking microbial accessibility and regulation of soil carbon decomposition.

How frequently do Sorghum roots reoccupy the same soil pore spaces?

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X-ray computed tomography (xCT) has enhanced our understanding of how soil structure impacts the spatial distribution of root systems. Pore space characteristics and presence of root channels are two physio-chemical properties of the soil which influence spatial root distribution. Our current understanding of how regularly roots utilise a single pore space seasonally is limited. This in turn has implications for resource depletion (e.g. phosphorus), accumulation of plant products (e.g. root exudates) and physical legacy. This study evaluated the occupancy of an actively growing root system in pre-existing root pore spaces and the potential for root derived microbial and exudate hotspots.

The experiment involved growing Sorghum (*Sorghum* spp.) in pots for two 8 week growth periods separated by a 12 week decomposition period. At the beginning of the decomposition period plant above-ground biomass was removed and roots were left to decompose naturally. X-ray computed tomography was utilised to image a small section of the pot for determination of the spatial distribution of roots and pore spaces. The images collected at the end of each growth and decomposition period were then overlaid and compared to determine the proportion of roots that reoccupied the pre-existing root pore spaces.

Under the experimental conditions of this study, the sorghum roots did not appear to preferentially occupy the root channels created by the previous crop. The study findings will be utilised to better explain the broader implications for nutrient and water acquisition, microbial and exudate hotspots, and soil physical properties.

'Hidden' soil carbon at risk of erosion in the rangelands

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Wind erosion preferentially removes fine organic carbon (OC) and nutrient rich soil. Enriched dust can be transported long distances resulting in a net loss from the terrestrial ecosystem and reduced soil fertility, moisture holding capacity and soil aggregate stability which may feedback to promote more erosion. Changes in the structure and spatial distribution of vegetation associated with land management can accelerate soil erosion and carbon loss. This study was located in the semi-arid rangelands of western New South Wales (NSW) where over 2.7M ha of land has been contracted to sequester carbon (C) in woody vegetation under the Emission Reduction Fund. We investigated the location and form of OC within the soil matrix and assessed the capacity of soil to protect OC from erosion under different vegetation communities. Surface soil samples were collected from plots comprised of five replicates of three densities (high, medium and low) for Pine (*Calitris glaucophylla*), Box (*Eucalyptus populnea*) and Mulga (*Acacia aneura*) communities. Soil samples (0-1 and 1-5cm) were dry and wet sieved, then each aggregate class was analysed for total OC (dry combustion) and OC fractions (MIR). Vegetation community significantly influenced aggregate stability, size distribution, SOC concentration and fractions, with Box communities having a higher degree of aggregation and SOC compared with Pine and Mulga. Box communities are located along drainage lines and these areas typically have higher soil moisture and nutrient content and typically accumulate water-transported sediment high in OC. The high concentration of SOC (specifically humic-OC) within the high proportion of <0.83mm (dry sieved) aggregates, and poor aggregate stability in the surface 1cm of all soils highlights the vulnerability of SOC to loss via erosion. Thus our results suggest it is important to account for potential loss of SOC (via wind erosion) when considering the quantum abatement in western NSW.

Compacted and suppressed: physical constraints of soil microbial response to carbon supply in the subsoil

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Recent studies highlight the importance of dissolved organic carbon (DOC) in soil carbon (C) dynamics through microbial processes. Both the quantity and spatial accessibility of DOC influence the relative importance of microbial processes compared with physical processes. However, the extent to which microbial activity responds to DOC and differences in physical condition through the soil profile remain largely unknown. Here, we conducted a laboratory incubation to quantify microbial respiration responses to DOC in the topsoil (0–30 cm) and the subsoil (30–100 cm) along a simulated soil compaction gradient (disturbed, no adjustment, slightly compacted and compacted), using the soils collected from cotton-based cropping systems under different tillage and rotational managements. Preliminary analysis showed that basal respiration decreased in response to compaction, but increased following disturbance in both topsoil and subsoil. DOC addition increased microbial respiration. However, the response differed between the physical treatments and soil profiles. Both disturbance and compaction resulted in reduced respiration, with a greater reduction observed in the topsoil than the subsoil. When adjusted for field bulk density, the estimated respiration responses to DOC showed much larger responses in the topsoil than the subsoil and in maximum tillage than minimum tillage systems. These results suggest that under field conditions, subsoil respiration will be lower than that of the topsoil due to both physical and substrate constraints. The contrasting effect of disturbance on basal and DOC-induced respiration also suggests that there is a complex interplay between physical and biological processes in regulating C fluxes. Our study demonstrates that soil physical conditions modulate microbial responses to substrate availability, and that agricultural practices that affect physical conditions can have a significant impact on C dynamics and sequestration in agricultural soils.

Soils with Smart Carbon

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Enhancement of carbon storage in global soils has been urged as per the “C 4 per mil Initiative”, launched following “the Paris Agreement” for climate change mitigation. However, what kind of carbon should be increased or how the increased carbon could serve soil fertility and ecosystem functioning while mitigate climate change, has been not yet well understood. Global agricultural soils have been depleted organic carbon and therefore have a big potential to feed carbon. Any forms of organic carbon ultimately derived from biomass could help to build up soil C storage but their effects on carbon cycling and food production are widely variable. While to captured or stabilize C in soil, we need carbon to restore soil fertility and soil health and to promote plant growth and food quality, the “Smart C” in agriculture. Such carbon should have stable structure, high reactivity and bioactivity (for example, plant growth/metabolism promotion). Biochar, as an example, is engineered carbon from crop straw and functions in improving soil aggregation/structure, root growth and plant development, and in stabilizing potentially toxic metals, organic pollutants and even pathogenic microbes. The co-benefits to food production, soil/water conservation and environment protection should be assessed and accounted for in the fight against climate change. The characterization, processing and production, and application of smart carbon in agriculture deserve urgent international collaboration, particularly under the framework of “C 4 per mil” action.

Physico-chemical protection predicts soil carbon and nutrient availability across Australia

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Physico-chemical protection has been identified as an important mechanism for predicting soil organic carbon (SOC) and nutrients, but its relative contribution is uncertain when considering concurrent regulatory effects of climate, plant productivity, and soil biodiversity. We used topsoil (0–10 cm) and subsoil (20–30 cm) from 628 sites across the Australian continent, spanning a broad range of climatic conditions and parent materials, and found that physico-chemical protection plays the most important role in determining SOC and nutrients, challenging current models in which these soil resources are controlled by climatic or biotic factors. The importance of protection factors is evident across soil depths and ecosystem types (i.e., tropical, temperate, arid, and cropland ecosystems). We acknowledge that distinguishing between physical and chemical processes can be arbitrary. However, our statistical approach provides insight into the relative importance of chemical protection mediated via redox mineral reactive sites compared to physical protection mediated by surface area. At the continental scale, SOC had the highest correlation with extractable iron (Fe), compared to all the other factors (including climate and biota) ($r = 0.59$ and 0.52 in topsoil and subsoil, respectively). Moreover, chemical protection had the highest predictive power for SOC in arid and cropland ecosystems while having the second most important predictive power in tropical and temperate ecosystems. Although physico-chemical protection played the most important role in predicting SOC and nutrient availability at continental and ecosystem scales, other drivers should also be considered. Climate, generally regarded as one of the primary controls, had both direct and indirect effects, but played a less significant role in predicting SOC or nutrients. Our results show that the soil matrix ultimately controls the fate of SOC and nutrients, and highlights that maintaining soil physico-chemical protection will help secure ecosystem sustainability.

Impacts of residue quality and N input on aggregate turnover using the combined ^{13}C natural abundance and rare earth oxides as tracers

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The effects of residue quality and nitrogen (N) input on soil aggregate turnover are not clarified. In this study, aggregation pathways and C cycling were tracked by using rare earth oxides (REOs) and ^{13}C natural abundance as tracers, respectively. Two residues (maize straw, C/N=32; miscanthus straw, C/N=220) coupled with or without N application (200 kg N ha⁻¹) were incorporated into the REO labelled soil ($\delta^{13}\text{C}=-23.2\%$). Soil respiration, aggregate stability (MWD), REO concentrations and ^{13}C were measured after 0, 7, 14 and 28 days of incubation. The maize straw incorporation resulted in a greater soil respiration and MWD as compared with the poor residue quality miscanthus straw. The N addition improved the miscanthus straw decomposition and MWD, whereas this effect was negligible for the maize straw treatments. The change in the MWD was related to the soil respiration ($P < 0.001$). As a result, the aggregate turnover of the soil incorporated with maize straw was faster than that of the soil incorporated with miscanthus straw. The N input increased the aggregate turnover of the soil incorporated with miscanthus straw but this effect was minimal for the maize straw amended soil. The new C accumulated more, but decomposed faster in macroaggregates than in microaggregates. A significant positive relationship was observed between the ^{13}C concentration and the aggregate turnover rate ($P < 0.01$) in sole straw amended treatments, whereas this relationship became weak after N input. Our results demonstrate that aggregate turnover depends on the residue quality and N input when the residue decomposition is under N-limited conditions.

2D imaging spectroscopy and 3D X-ray CT high spatial resolution analysis – method combination for investigating potential interplay of SOM and soil structure development in intact soil samples

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Visible-near infrared (vis-NIR) spectroscopy is an acknowledged technique to simultaneously observe several soil parameters, such as soil organic matter, nutrient content, moisture, texture, and mineralogy. Imaging spectroscopy holds the potential to collect this information from intact soil samples with a high spatial resolution of $53 \times 53 \mu\text{m}^2/\text{pixel}$. In this study, we mapped physico-chemical soil properties using a hyperspectral vis-NIR camera (spectral resolution 196 bands between 400-1000 nm and spatial resolution of $53 \times 53 \mu\text{m}^2/\text{pixel}$) and combined them with information on soil structure as obtained using X-ray CT (spatial resolution of $19 \times 19 \times 19 \mu\text{m}^3/\text{voxel}$). We used undisturbed soil cylinders (diameter and height 3 cm) from agriculturally reclaimed soils in the open-cast mining area of Garzweiler near Cologne, Germany. First, we scanned the samples with a X-ray CT, and second embedded several slices from the cylinder in resin (polyester) and scanned them with a hyperspectral camera. For the first time image registration of 2D vis-NIR and 3D X-ray CT images was performed in elastix. This allowed us to correlate physico-chemical information on organic and mineral soil materials with structural data. We identified the impact of reclamation management and plant root on soil organic matter accumulation, and their interplay with biopores and soil structural development.

Species and root traits control C stabilization in the rhizospheric soil of a Mediterranean common garden experiment

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The objective of this work was to evaluate how the roots of different plant species and life forms affected soil organic carbon (SOC) stabilization. We analyzed the soil attached to the roots (i.e., rhizospheric soil) under 13 Mediterranean species grown in monocultures in a common garden experiment for four years, and compared it to a bare soil kept free of vegetation. We used a density fractionation procedure to separate uncomplexed organic matter found in the light fraction of the rhizospheric soil from mineral-associated organic matter found in the dense fraction. We measured root traits and SOC concentration in the rhizospheric bulk soil and its fractions. We used a comparative approach to test significant differences among species, and explored relationships between root traits and SOC stabilization. We observed that the concentration of mineral-associated SOC in rhizospheric soil was on average 40% greater than that in the bare soil, with a strong effect of plant species ($P < 0.0001$). Some species such as *Bromus erectus*, *Centaurea pectinata* and *Festuca christianii-bernardii* showed increases up to 60%. Root morphology and architecture exert strong control over SOC stabilization in the rhizospheric soil. Increased specific root length (SRL), root length density (RLD) and the proportion of very fine (<0.2 mm) roots promoted greater mineral-associated SOC in the rhizosphere, while increased root diameter and proportion of coarse (1-2 mm) roots had the opposite effect. Overall, our results suggest that plant species with morphological and architectural root traits related to resource acquisition (i.e., fine roots with high SRL and high RLD) favor the stabilization of SOC in the rhizosphere more than species with root traits related to resource conservation (i.e, high proportion of thick roots).

Beyond the Rhizosphere: Microbial potential in sub- and bulk vertosols

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The continuation of sustainable agricultural practice, despite climate change and an increasing human population, presents a global challenge requiring approaches that push beyond the boundaries of current research. One solution may reside within our soil microbial communities. Australian cotton (*Gossypium hirsutum*) is predominantly grown in vertosols, dynamic soils that can move nutrients from the soil surface into the sub-soil and from rhizosphere to bulk soil. Whilst cultivation of crop rotations may improve soil properties, the potential impact on microbial communities in response to this regime, remains unexplored.

Our work assessed and compared microbial activity (using respiration incubations) and biomass (via substrate induced respiration), in the top- (0-30 cm) and sub- (30-100 cm) soils of continuous cotton (CC) and cotton-maize (CM) rotations at three time points (pre-, in- and post-crop) for two growing seasons, sampling in the plant line, but not targeting the rhizosphere. In addition, we used a $\delta^{18}\text{O}$ -HCl stable isotope method to gauge the long-term impact of crop rotation on sub-soil microbial activity.

Our results highlight that, regardless of crop rotation, sub-soil microbial activity does not significantly ($P = 0.11$) differ from top-soil, with sub-soil microorganisms contributing 46% to the overall profile activity. Sub-soil microbial activity only differed ($P = 0.03$) when cotton was in-crop, resulting in a decrease in activity. Microbial biomass was different ($P = 0.00$) between both soil depth and crop rotation, with sub-soils contributing 37% to the profile's microbial biomass. The long term implementation of rotations found CC system promoting microbial activity down the entire profile, in comparison to CM ($P = 0.01$). Our work emphasises the importance of considering soils beyond the surface as a significant amount of activity and, to a lesser extent, biomass is occurring below 30 cm, with crop rotation and establishment significantly influencing microbial properties beyond the crop rhizosphere.

Mechanistic modeling of managed grasslands: Model validation and projections of climate change effects on pasture productivity, GHG exchanges and soil carbon stocks.

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The CenW ecosystem model simulates carbon, water, and nitrogen cycles following ecophysiological processes and management practices on a daily basis. In the first part of the study, we tested and evaluated the model using five years eddy covariance measurements from two adjacent but differently managed grasslands in France. The data were used to parameterize CenW for the two grassland sites until good agreements, i.e., high model efficiencies and correlations, between observed and modeled fluxes were achieved. The CenW model captured day-to-day, seasonal, and interannual variability observed in measured CO₂ and water fluxes. We also showed that following mowing and grazing, carbon gain was severely curtailed through a sharp and severe reduction in photosynthesizing biomass. We also identified large model/data discrepancies for carbon fluxes during grazing events caused by the noncapture by the eddy covariance system of large respiratory losses of C from dairy cows when they were present in the paddocks. The missing component of cows' respiration in the net carbon budget of the grazed grassland can turn sites from being C sinks to being neutral or C sources, highlighting that extra care is needed in the processing of eddy covariance data from grazed grasslands to correctly calculate their annual CO₂ balances and carbon budgets. In the second part of the study, the calibrated CenW model was used to get a better understanding on how grasslands ecosystems and their soil carbon stocks will respond to future climate and to changes in management practices. We used 3 different sets of meteorological variables corresponding to possible future conditions at the study site according to RCP 2.6, 4.5 and 8.5 to run the model for long term. We showed that the long-term grassland productivity, milk production, carbon and water fluxes and soil carbon stocks were strongly modified by climate alteration.

Rhizodeposition processes as a major lever for soil carbon sequestration

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Plants represent the main source of organic carbon in soils. While inputs of carbon from the aerial parts are easy to measure, the difficulty in quantifying inputs from roots has prevented us to estimate the actual potential of soil carbon sequestration associated to each type of organic matters released by the roots. Besides the decay of root tissues, root systems have been shown to release organic carbon by various mechanisms, e.g. exudation of soluble compounds, mucilage secretion, and cells sloughing. Such rhizodeposition processes may consume 5% to 15% of the total amount of carbon photosynthetically fixed by the plant, and can generate an input of carbon to the soil ranging from 0.5 to 5 tC ha⁻¹ yr⁻¹. Because of this large range and the uncertainties associated to rhizodeposition mechanisms, current models of soil organic matter dynamics poorly assess the actual sequestration potential offered by plants. We performed a meta-analysis of the literature data generated over the last 60 years in order to assess which rhizodeposition processes quantitatively prevail, and what is the maximal amount of carbon inputs that can be expected from an entire growing root system, depending on plant species, growth stage, soil properties, and environmental conditions. According to our current dataset, the exudation of soluble sugars represents the major flow of organic carbon into the rhizosphere in most conditions, but other rhizodeposition processes such as mucilage secretion and cells sloughing can locally become as important in terms of carbon release. Following the presentation of these results, the consequences of these emissions on the actual soil carbon sequestration potential will be discussed based on our current understanding of carbon use efficiency and priming effect.

Abiotic and microbial degradation of biochars depend on biochars' chemistry and temperature under laboratory conditions

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Biochar is a carbon (C) rich material produced from pyrolysis of biomass under no or limited supply of oxygen. Use of biochar for multiple purposes depends on its physico-chemical characteristics-driven stability and decomposition. We investigated abiotic and microbial mineralization of a range of low-pyrolysis temperature (400 °C) biochars at 15, 30 and 45 °C incubation temperatures. Biochars were developed from eucalyptus leaves (ELB), wheat straw (WSB), poultry manure (PMB), cotton sticks (CSB), vegetable waste (VWB), lawn grass (LGB) and citrus leaves (CLB). In addition to elemental composition, biochars were characterized for pH, electrical conductivity (EC), labile organic C (L-OC) and LOC characteristics including specific ultraviolet absorbance (SUVA), aromaticity, hydrophilic and hydrophobic C fractions and total phenolic contents. Carbon mineralization was measured for seven days using abiotic (sterile incubation with mineral nutrients) and microbial (microbial inoculum with mineral nutrients) experimental conditions. We found that abiotic degradation of biochars were generally less than microbial degradation, however, these patterns significantly varied between feedstocks and incubation temperatures. Both abiotic and microbial C mineralization was also strongly controlled by incubation temperatures. However, increase in incubation temperature was not always associated with acceleration in abiotic and microbial CO₂ efflux. Percent C mineralized (PCM) of L-OC was higher under microbial incubation at 30 °C and higher for PMB, CSB and CLB. Water extractable OC (WEOC) also showed significant variations with respect to biochars and incubation temperature whereas WEOC correlated significantly positively with CO₂ efflux under abiotic and microbial incubation conditions. Characteristics of L-OC seem to have strong influence on both abiotic and microbial biochar degradation; positive relationships with pH, volatile matter, L-OC and total phenolics and negative relationships with EC and SUVA. These observations warrant the consideration of abiotic (chemical & photo-oxidation, solubilization) and microbial decomposition of biochars before its application to soils.

Soil microbiome and carbon under the A (horizon)

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Central USA was dominated by tallgrass prairie across a large precipitation gradient broadly representative of both current and future precipitation regimes. Much of the prairie is now under cultivation. Much research has focused on the role of the soil microbiome in the global C cycle, given soils can serve as a sink or source of greenhouse gases. These microbial functions are strongly influenced by microbial resource limitations and available moisture. Microbes also influence soil structure. Soil aggregation mediates soil chemical, physical, and biological properties and improves soil quality and sustainability. Identifying drivers of the long-term persistence of soil organic C represents another challenge for projecting future interactions between soil properties, water, and soil microbial behavior. The aim of this study was to investigate the soil biophysical properties across a precipitation gradient with different land uses. Soil profiles were sampled to 1m for soil C and N, aggregate structure, and microbial community composition by phospholipid fatty acid (PLFA) analysis. Microbial biomass C (MBC) in the native prairie and agriculture were not significantly affected by the precipitation gradient. Large aggregates (>2 mm) were higher in the native prairie at central > west and east. Large aggregates (>2 mm) were higher in the native prairie relative to agriculture. Total PLFA was higher in the native prairie with greater precipitation. Total PLFA was higher in the native prairie relative to agriculture. Higher AMF content was found under greater precipitation regime in all land uses. The aggregate structure was highly correlated to fungal and mycorrhizal fungi biomass. Relations with C, depth, and microbial community composition are being explored.

Vegetated subsoil exposed during geotechnical operations has massive carbon storage potential: a study of ¹³C partitioning into soil respiration and different soil fractions

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Geotechnical operations such as embankment construction influence soil carbon (C) storage since massive amounts of C-poor subsoil are brought to the surface. We hypothesize that subsoil can sequester relatively more C than C-rich topsoil due to its lower C-saturation. We excavated topsoil (0.0 to 0.3 m) and subsoil (1.1 to 1.4 m) from the same profile. We sieved soil and sowed *Medicago sativa* and *Lolium perenne* (n=6 pots of each species x soil). Controls were soil with no vegetation (n=6 x soil). To trace the fate of C, pots were incubated for 6 months under a continuously ¹³C-enriched-CO₂ (2%) in three growth chambers with controlled conditions. Soil respiration (CO₂ and ¹³C) was quantified every 2 weeks and was higher in the topsoil, due to greater root and microbiological activity. The ¹³C enrichment of the respired C was significantly higher in *M. sativa* regardless of soil type. After 6 months, soils were divided into four different fractions: particulate organic matter (POM), fine POM, silt, silt+clay, and total C and ¹³C enrichment were analyzed. Results show that the total C (g new C/cm³ soil) stored depended on root biomass. Topsoil had significantly more biomass, and stored more labeled plant derived-C, especially under *M. sativa*. However, when results were weighted as new C stored in cm³ of soil per g of root biomass, subsoil stored relatively more C, especially in POM and silt+clay fractions (increase in new C stored in subsoil compared to topsoil for POM: *M. sativa* +135%, *L. perenne* +33% and for silt+clay: *M. sativa* +56%, *L. perenne* +16%). The higher relative increase of organo-mineral protected C in subsoil corroborates the hypothesis that C saturation influences C storage and protection. Vegetating subsoil with appropriate species could act as a major C sink, valorizing geotechnical infrastructures as resources for carbon storage.

Age matters: consequence of ageing on the fate of soil organic matter in earthworm casts

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Earthworms are impacting the soils' carbon cycle and particularly organic carbon dynamics. However, their effect on the stabilisation of soil organic matter (SOM) pools over time is unknown. We hypothesised that SOM properties in casts evolve during ageing to reach similar properties than those of the surrounding topsoil. The aim of this study was to assess the fate of SOM in surface casts produced by the anecic earthworm *Amyntas khamy* in comparison with control aggregates (0-10 cm depth) sampled in a tropical woodland in Northern Vietnam. Casts presenting five different ages were selected according to their humidity and degradation features. We determined physicochemical properties of bulk aggregates as well as their chemical composition by analytical pyrolysis (polysaccharides, lignin and N-compounds), Rock-eval pyrolysis (hydrogen-index) and medium reflectance infrared Fourier transform spectroscopy (humic-index). Moreover, we assessed the distribution of soil organic carbon in three density fractions (light fraction: FLF-C, occluded light fraction: OLF-C and heavy fraction: HF-C). Our results indicated that properties of casts were significantly different from control aggregates regardless their age. On average, casts showed higher OC (4.8 vs. 2.6%), polysaccharides (14.7 vs. 10.6%), lignin (1 vs. 0%), hydrogen-index (180 vs. 154), FLF-C, (0.2 vs. 0.1 %), OLF-C (0.5 vs. 0.1%), HF-C (4.1 vs. 2.4%) and a lower humic-index (22.5 vs. 34.2) than control aggregates. SOM properties of casts were stable during the first month after production and afterwards changed gradually, to reach after 6 months of ageing closer properties than control aggregates. In conclusion, our results indicated that SOM in casts contained chemically and thermally labile C regardless their age and higher amounts of mineral associated SOM, suggesting a high level of protection. This study highlights the need to take into account the age of casts when assessing the impact of earthworms on carbon storage.

The role of the 4p1000 initiative in defining research priorities for soil organic carbon under the sustainable development agenda

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Soil carbon sequestration may be the link between several sustainable development goals in particular those concerning climate, life on land, and no hunger. While SOC sequestration can contribute to partly offsetting greenhouse gas emissions, its main benefits are related to increased soil quality and climate change adaptation. The STC of the 4p1000 initiative established general criteria for informative assessment actions under 4p1000 framed by UN sustainable development goals. We also elaborated a research plan highlighting the main gaps to be addressed for successful implementation. Science is needed to define and test promising region and context specific agricultural management practices. For evaluation of impacts of these practices, quantitative ex-ante assessment and ex-post monitoring, reporting and verification (MRV) strategies have to be developed and tested. Organic carbon baselines need to be established for specific situations. Finally, there is a need to quantify the socioeconomic impact of increased SOC sequestration to businesses, stakeholders and farmers. This requires not only inter- and transdisciplinary collaboration between scientists but also multi-stakeholder collaboration at the science-policy interface to demonstrate effects and put sustainable land management strategies into practice. The objective of this talk is to present the aims of the initiative, to identify barriers, risks and trade-offs and show how science based evaluation of critical issues can be useful in the context of collaboration between multiple parties in order to stimulate innovation and to initiate the transition of agricultural systems toward sustainability.

Organo-mineral granulation is a green option for improving nitrogen use efficiency and soil organic matter

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Improving the soil organic matter content is becoming more important due to its positive effect on soil health, crop growth and nutrient dynamics in agro-ecosystems. Integrated application of organic and inorganic fertilisers has been shown to increase the soil organic carbon (C) and use efficiency of nitrogen (N) fertiliser. Addition of C rich brown coal (BC) as an organic amendment can alter N cycling by reducing its losses in different ways as well as may help to improve soil organic matter content. However, the effect of brown coal-urea (BCU) granulation on N cycling and soil organic C accumulation is poorly understood. Therefore, a series of glasshouse and field trial studies were conducted to assess the effects of BCU granulation on the dynamics, use efficiency of N and its influence on the organic matter content of soil. Granulation of urea with BC showed a promising impact on the behavior of N fertiliser in the soil system. Compared to urea, BCU granules generally suppressed total N₂O and NH₃ emissions by 31% and 43%, respectively. Incorporation of BCU granules in soil maintained significantly higher amounts of mineralisable N in soil compared to urea application only. This is supported by the leachate analysis data, which showed that less mineral N was leached from soil in the BCU blends compared to urea. The granules with higher BC had lower N₂O and NH₃ emissions and maintained higher mineral N in soil compared to the granules with lower BC. Moreover, addition of BCU granules significantly increased the organic C content of the top soil compared to urea alone. The overall results suggest that granulation of urea with BC can strongly reduce N losses and increases the fertiliser N use efficiency. The increase of soil organic C due to addition of BC might be helpful to build up soil organic matter content in the long run.

Keywords: Brown coal-urea granule, soil organic C, dynamics and mineralisation of N, fertiliser N use efficiency, soil health.

Manure fosters both soil N supply and C storage through heavy-particulate organic matter formation

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In a unifying framework based on the MEMS model, Robertson et al. (2019) recently suggested that the heavy-particulate OM fraction (composed of litter fragments and microbial residues associated to mineral surfaces) could play an important role in soil nutrient cycling and be a precursor of stable C in soil. Maillard et al. (2015) showed that dairy cattle manure application resulted in a preferential accumulation of C in this heavy-particulate OM fraction. Because they contain microbial metabolites, we hypothesized that animal manures in general foster the formation of heavy particulate OM and therefore sustain both C storage and N supply soil functions. We tested this hypothesis using a long-term (9 years) agronomic trial located in eastern Canada. This factorial experiment evaluated the effect of different fertilizer sources (no-N control (PK), complete mineral fertilization (NPK), liquid pig, liquid dairy cattle, and solid poultry manures) on two soil types (silty clay and sandy loam). Soil samples (0-7.5 cm) were collected and fractionated using a size-density method (Maillard et al. 2015). In both soil types, the heavy-particulate OM fraction was the most sensitive to treatments with greater C and N accumulation in that fraction with poultry manure and liquid dairy manure as compared to the NPK and no-N control treatments. In the silty clay, there was also C and N accumulation in the finer and presumably more stable organo-mineral complexes, but not in the sandy loam. We propose that the heavy-particulate OM (i) is a meaningful fraction in terms of nutrient cycling likely linked to manure legacy effect, and (ii) is a precursor to long-term accumulation of stable C and N forms where soil texture allows the formation of finer organo-mineral associations.

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Effect of organic and sustainable fertilisation and soil organic carbon content on energy use efficiency, GHG emissions, and cost-effectiveness

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The aim of this study was to assess different fertilisation methods in organic and sustainable farming using energy, environmental, and economic indicators. This research was based on a long-term study of cultivating winter wheat (*Triticum aestivum* L.) and the following spring barley (*Hordeum vulgare* L.) with the under-sowing of red clover (*Trifolium pratense* L.) under two organic (SC-I and SC-II) and two sustainable (SC-III and SC-IV) fertilisation scenarios in soils with low or moderate organic carbon content. The fertilisers used in SC-I, SC-II, SC-III, and SC-IV were green manure, green manure + farmyard manure, farmyard manure + NPK, and green manure + NPK, respectively. SC-I and SC-IV exhibited the lowest total energy inputs and highest energy efficiency ratios (EER) of 8.73 and 8.37 in soil with a low organic carbon content, and 9.15 and 8.72 in soil with a moderate organic carbon level, respectively. In SC-II and SC-III, the energy input for farmyard manure accounted for 45.0–49.3% of the total energy input. The results of the environmental impact assessment indicated that fertilisation with farmyard manure resulted in a tenfold increase in the total GHG emissions from those of the green manure fertilisation scenarios. Economic analysis showed that, although the lowest gross production costs were achieved in SC-I (515.15 EUR ha⁻¹), SC-I also provided the highest returns and the best cost-effectiveness ratio (CER) of 2.45 and 2.55, respectively, in soil with low and moderate organic carbon levels. The difference between the CER of SC-I and other scenarios was significant.

Keywords: organic and sustainable farming, soil organic carbon content, fertilisation, green and farmyard manure, energy use efficiency, GHG emission, cost-effectiveness

Carbon sequestration opportunity in South Australian sandy soils with subsoil clay addition

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Sandy soils cover a large proportion of Australia's agricultural region and are significant soil types globally. These soils often have low productivity because of limited water and nutrient capacity. The poor plant growth and therefore low organic carbon (OC) input along with rapid decomposition because of low clay concentration makes it difficult to increase OC concentration. For this reason, sandy soils are often omitted from global agricultural soil carbon sequestration models. There is large potential to increase carbon sequestration if the OC storage capacity of sandy soils can be increased through clay addition. The addition of subsoil clay to sandy soil is a practice used in South Australia, Victoria and Western Australia to overcome water repellence, improve water and nutrient retention, and increase plant productivity. It also has the potential to increase soil OC storage through improved OC input and increased capacity to stabilise the new OC by binding to the added clay. To determine if subsoil clay addition to sandy soil increases OC storage, soil cores were collected to 50 cm depth from South Australian field sites and assessed for OC and clay concentration and select physical and chemical properties of clay-amended treatments compared to unamended sands. Clay amendment treatments differed in the amount of subsoil clay added to the surface 30 cm of sand and the depth of incorporation (shallow and deep). The greatest potential for increased OC storage in clay-amended soil was in the 10-30 cm depth with a positive correlation between OC and clay stock. Even vertical distribution of many, small clods of clay within the surface 30 cm was a key factor to increase OC storage in clay-amended soils. Subsoil clay properties and the amount added to the surface 30 cm, as well as depth to undisturbed subsoil also influenced OC stock.

Resource nutrient stoichiometry controls microbial growth, carbon-use efficiency and soil carbon priming in an organic-amended alkaline sodic-subsoil

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Subsoil sodicity is one of the main constraints on soil functionality, productivity and sustainability, particularly in arid and semi-arid regions. In recent years, the role of organic amendments (OAs) combined with inorganic fertilizers or gypsum has received much attention for ameliorating soil physicochemical constraints and improving carbon (C) storage in sodic-subsoils. However, little is known about the effect of resource nutrient stoichiometry and gypsum on C dynamics in organic-amended sodic-subsoils. Here, we examined the role of OAs (application rate of 6.2 g OA-C kg⁻¹ soil; C4 vegetation-derived: $\delta^{13}\text{C}$ –12 to –15‰) in altering microbial C mineralization, microbial C use efficiency (CUE) and soil C priming, with and without the exogenous supply of nutrients or gypsum, in an alkaline sodic-clay subsoil (5.8 g C kg⁻¹ soil; C3 vegetation-derived: $\delta^{13}\text{C}$ –24‰).

The cumulative OA-C mineralization ranged between 70 and 630 mg CO₂-C g⁻¹ OA-C across the treatments over 270 days. The CUE of OAs was the highest in the mill mud-treated subsoil (0.25–0.80) and the lowest in the sorghum stubble-treated subsoil (0.07–0.42). The inherently balanced C-nutrient stoichiometry of OAs (such as mill mud) enhanced CUE, whereas lowering the imbalanced nutrient stoichiometry of other OAs (sorghum stubble, sugarcane bagasse) via exogenous nutrient inputs increased microbial growth but not CUE. Over 270 days, extra 0.7–8.3% of native soil organic carbon (SOC) was lost via priming across the treatments. In the first three months, the positive priming effect by the OAs was the highest in the sorghum stubble-treated subsoil, which was mainly driven by microbial co-metabolism and N mining. At the later stage, the balanced resource nutrient stoichiometry enhanced the PE. This study suggests that balancing the C-nutrient stoichiometry of OAs can increase soil functions and biological processes, such as microbial degradation of OAs, microbial growth and positive SOC priming, which may enhance nutrient availability and improve soil structure during amelioration of sodic-subsoil constraints.

Microbial density and substrate identity interact to determine the stabilization efficiency of microbial-derived, mineral-associated organic matter

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A substantial proportion of persistent, mineral-associated organic matter (MAOM) is microbially-derived. Despite the importance of this stable carbon pool for understanding and modeling the terrestrial carbon cycle, the controls on microbial formation of MAOM remain unclear. One key but under-explored control is the density of soil microbes where a carbon substrate enters the mineral soil, as a higher microbial density should increase the probability that an assimilable substrate undergoes microbial uptake and transformation prior to mineral-stabilization, whereas a lower density will decrease that probability, and increase the chance that a substrate directly encounters a mineral surface.

To understand the interacting role of microbial density and substrate identity on the efficiency MAOM formation, we directly manipulated microbial density in laboratory soil microcosms, while standardizing for the amount of added carbon substrate. We repeatedly inserted fixed quantities of four different ¹³C-labeled substrates (vanillin, phenol, glucose, and acetic acid) into microcosms with varying microbial densities. We measured uptake of these substrates into different microbial taxa (¹³C-PLFA), as well the amount of ¹³C-MAOM, and the amount of stable ¹³C-MAOM. We also analyzed the composition of the ¹³C-MAOM to determine the extent of microbial transformation of added substrates through ¹³C-NMR.

We found a significant interaction between substrate type and microbial density ($F=4.4$, $p=0.008$), as well as a significant interaction between mineral type (illite vs. allophane) and substrate type ($F=3.0$, $p=0.04$). Generally, for the less reactive mineral type 'illite', we found positive relationships ($p<0.05$) between microbial density and stable ¹³C-MAOM formation, and no significant relationship in the more reactive mineral 'allophane'. Overall, we found that microbial formation of stable MAOM increased with microbial density, and with carbon substrates metabolized with higher carbon use efficiency (e.g. glucose versus phenol), but also that the magnitude of this relationship was modulated by the dominant mineral type.

Short-term aerobic digestion of cover crop biomass significantly decreased Net Global Warming Potential during rice cultivation

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Cover crop cultivation is strongly recommended during the fallow season to increase soil organic carbon (SOC) stock. However, since its biomass recycling as green manure can dramatically increase greenhouse gas (GHG) emission, in particular, methane (CH₄) during rice cropping season, smart cover crop management strategy should be developed. In our previous research, CH₄ emission during cropping season was dramatically reduced via short-term aerobic decomposition before irrigation (Lee et al.). However, due to a fast response rate of aerobic decomposition, the effect of mitigating CH₄ emission could be offset by SOC depletion which results in accelerating global warming. To evaluate the comprehensive impact of the short-term aerobic decomposition on global warming, net global warming potential (GWP), defined as the difference between GWP and SOC stock change was employed. SOC stock change was estimated using net ecosystem carbon budget (NECB), a balance between soil C input and output. The mixture of barley and hairy vetch cultivated during the dried fallow season, and then its whole biomass was incorporated 0-30 days before irrigation for rice transplanting. The aerobic decomposition of cover crop biomass significantly reduced CH₄ emission by 24-85% over control but negligibly influences N₂O emission. Total C input and output were unaffected by the aerobic digestion. Although carbon emission before flooding dramatically increased after biomass application in aerobic decomposition treatments, the mineralized C losses exhibited no differences among treatments. Based on these results, NECB values were similar in all treatments. This implies the aerobic decomposition did not stimulate SOC depletion, compared to the control. Finally, the net GWP highly decreased by 30-86% by the aerobic digestion due to the significant reduction of CH₄ emission. In conclusion, earlier application of cover crops before irrigation is a smart strategy to decrease methane emission, maintaining soil carbon sequestration effect of cover crop biomasses application

Warming alters soil respiration and soil organic matter fractions throughout the whole soil profile

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As the climate warms, heat is transferred to the land surface, warming soils throughout the whole soil profile. The impact of warming on soil organic matter (SOM) formation and decomposition may differ with soil depth. The decomposition signal is typically measured as fluxes from the soil surface but the effect on underlying SOM itself is harder to observe. Over five years of a whole-soil warming experiment in a mixed coniferous forest, we found that +4 °C warming led to a 30% increase in soil respiration. This increased respiration originated from microbial activity, measured from 5-90 cm deep, throughout all seasons and years of the experiment. After 3.5 years of warming, carbon and nitrogen stocks in the SOM light fraction showed a significant treatment effect, mainly driven by changes in the mass of these fractions with the warming treatment. We will also present results from a one-year decomposition experiment of ¹³C labeled root litter at three soil depths in the heated and unheated plots. Initial results show a clear decrease in SOM formation from root litter with depth. Together, results on soil respiration, SOM composition, and SOM formation from litter decomposition will be used to present a depth-resolved picture of warming impacts on SOM dynamics and carbon fluxes over five years of soil warming.

Does conversion to conservation tillage really increase soil organic carbon stocks in organic arable farming?

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Aggravation of weather extremes increases awareness of climate change consequences. Mitigation options are in demand which aim to reduce the atmospheric concentration of greenhouse gases. Amongst others, conversion from ploughing to conservation tillage is argued to increase soil organic carbon (SOC) stocks. Yet, main findings of reviews and meta-analyses comparing SOC stocks between tillage systems show different results: from a significant increase of SOC stocks to the question if there is any effect at all. Reasons are a sampling bias as in many campaigns only topsoil layers are assessed and horizons thickness is not considered adequately, different methods for SOC and bulk density determination, and the comparison of SOC stocks based on equivalent soil masses instead of equal sampling depths.

In order to address these limitations, we initiated the SOCORT consortium (Soil Organic Carbon in Organic Reduced Tillage) – an international network of nine agronomical long-term trials. All trials represent common mixed organic farming systems of the respective region with organic fertilisation and crop rotations including leys. Climatic conditions are similar, but age and soil texture vary (7 to 21 years and sandy to clayey soils). A common sampling campaign was consequently elaborated to answer the question if the combination of conservation tillage and organic farming can really increase SOC stocks. Undisturbed soil cores were taken with driving hammer probes (8 cm in diameter) to a maximum depth of 100 cm. Each core was divided in the increments 0-30, 30-50, 50-70, 70-100 cm. The topsoil layer (0-30 cm) was further divided into the different tillage depths of the respective trial. All samples were analysed in the same laboratory for bulk density, organic carbon content, pH and texture. We compiled the yields for each trial to assess carbon inputs. The SOCORT consortium in combination with the common sampling campaign will entangle the driving factors of carbon sequestration through reduced tillage and add important knowledge on carbon dynamics in agro-ecosystems.

Development of a Predictive Tool for Herbicide Sorption to Soil based on Mid-Infrared Spectrometry

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Sorption is considered one of the most influential processes on the mobility, bioavailability and rate of degradation of herbicides in soil. Site specific estimates of soil sorption coefficients are therefore a prerequisite for the accurate prediction of herbicide persistence in different soils. The adsorption affinity of a soil for a given herbicide is controlled by a wide variety of factors such as mineralogy, organic matter content, and organic matter speciation. However, direct measurement of sorption requires expensive and laborious construction of adsorption isotherms. The development of an effective predictive model could circumvent this testing, and advance our capabilities to predict herbicide persistence and ecological and agronomic risks.

Mid-infrared spectrometry (MIR) is a cheap, rapid technique that, given adequate calibration, can quantify a wide variety of factors including organic matter content and speciation, particle size distribution and mineralogy. This makes it especially promising for predictive modelling of small organic molecule sorption. There have been previous attempts to use MIR based modelling to predict herbicide adsorption affinity of soils, however, due to a limited dataset; these models have lacked the generality required for wider application.

The aim of this work is build a soils dataset with widely varying properties, and then to develop a compressive model capable of predicting herbicide sorption, based on MIR. By using a larger data set, comprised of 40+ sites from across Australia, a relatively universal model may be produced, capable of predicting adsorption affinity in soils outside of the initial data set. In this work, we assessed the adsorption of glyphosate, clopyralid and imazamox using MIR combined with principle component analysis, partial least squares and principle component regression techniques. Results will be presented in the context of herbicide sorption relationships to soil organic matter and mineralogy.

Long-term fallow management increased labile organic matter but not clay associated stable organic matter in Niger, West Africa

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Nutrient-poor sandy soils are widely distributed in the Sahel region, causing hunger and poverty in combination with a severe dry climate. Generally, fallow management is expected to increase the stable SOM associated with clay minerals or aggregates, but in Sahelian sandy soil, this might not occur and there are likely to be alternative mechanisms of SOM restoration. In this study, we verified the hypothesis that fallow management in Sahel mainly increases labile OM, e.g., plant residues, and that it significantly contributes to SOM restoration. We collected soil samples from continuously cultivated (C plot) and long-term preserved plots, i.e., fallow plot (F plot; > 30 yrs) in ICRISAT West and Central Africa, Niger (5 layers from 0–30 cm depth; 5 replications). We measured the total carbon (TC) and nitrogen (TN), clay contents, and bulk density. Then, we also measured light fraction (LF; < 1.6 Mg m⁻³) as labile OM and heavy fraction (HF; ≥ 1.6 Mg m⁻³) as stable OM. Increases in TC and TN were observed in all soil layers, particularly at the surface in F plots. TC was 11.8 and 7.7 Mg C ha⁻¹, LF-C was 3.3 and 0.9 Mg C ha⁻¹, TN was 809 and 468 kg N ha⁻¹, and LF-N was 202 and 59 kg N ha⁻¹ (0–30 cm depth) in F and C plots, respectively. Long-term fallow management clearly increased SOM, and the increase in LF-OM largely accounted for the increase in TC (59%) and TN (42%). In addition, we found there was no difference in HF-C per clay contents between F and C plots, indicating that the increment of HF-C in F plots was mainly caused by clay accumulation because of the capture of Harmattan dust. Thus, our hypothesis was confirmed, and the significance of clay accumulation by fallow management was also suggested.

Soil organic carbon and related impacts of the Warrumbungles wildfire

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A wildfire in the Warrumbungle range in January 2013 burnt 56,290 ha, 72% of it at high-extreme severity. We examined the effects of the fire on soil organic carbon (SOC), nitrogen and soil microbial activity, spatially extrapolated results to estimate the overall impacts of the fire and estimated the long-term post burn recovery trajectory. We measured SOC fractions at 64 sites across four fire severity classes and three main geology/soil types. Soils were sampled for LECO TOC, MIR soil C fractions and N (64 sites x 5 sub-sites x 4 depths) and soil microbial activity by MicroResp across the range of fire severities. Topsoil SOC in low severity sites was 14% lower than unburnt sites, and severely burnt sites were 54% lower. These results were also reflected in losses in N and microbial activity. Statistical models indicated that the key effects on SOC were fire severity and geology/soil type. The highest SOC values were from unburnt volcanic topsoils. Sandier and especially sandstone-derived soils have less SOC irrespective of the fire severity class. The lowest SOC values were from severely burnt sandstone ridges, where most of the remaining SOC occurs as resistant OC (including charcoal). Site data was extrapolated by 1m LiDAR DEM and a fire severity map based on RapidEye and ADS40 imagery. It was estimated that 2.5 Mt (44 t/ha) of SOC was lost over the fire ground to 10 cm, with ~74,000 t of N lost. Spatial fire history data were used to estimate rates of SOC accumulation and a timeline for long-term recovery of SOC in the absence of fire. Recovery of SOC to pre-burn levels is expected to take several decades.

A novel method to characterize soil organic carbon pools using thermal oxidation combined with multivariate analysis

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Soil organic carbon (SOC) pools range from rapidly decomposable particulate organic carbon (POC), slowly decomposable humic fraction (HUM) and resistant organic carbon (ROC). The ROC pool contributes strongly to the long-term sequestration of SOC. Several analytical methods have been proposed, to measure carbon pools including ¹³C-NMR (expensive) and mid infrared (MIR) spectroscopy (soil composition dependent). This study examines whether thermal oxidation of soil samples at temperature intervals between 110°C and 1000°C, and subsequent evolved gas (%CO₂) measurement combined with chemometric analysis, is capable of quantifying SOC pools in different soil types. For this purpose, thermal oxidation profiles of 179 samples collected across Australia were recorded using a Leco[®] RC-612 and compared with reference SOC pool data obtained by fractionation followed by the ¹³C-NMR method. The mid infrared (MIR) analysis confirmed a well distributed and wide range of soil composition. Sample set was randomly divided into calibration (120) and validation (59) data set to build a partial least square regression (PLSR) model. PLSR analysis indicated that it was not possible to assign a single temperature range to a specific SOC pool. The thermal oxidation patterns revealed that preferential oxidation of POC not only released at lower temperature but continued to release at higher temperatures, possibly due the conversion to more resistant carbon form during the thermal oxidation process. The PLSR calibration model validation using 59 independent samples showed that TOC POC, HUM and ROC fractions were predicted accurately with the R²= 0.99, 0.85, 0.96, 0.90 and Root Mean Square Error of Prediction (RMSEP) of 0.15, 0.18, 0.15, and 0.10 respectively. It is concluded that combined thermal and multivariate analysis provides a robust, rapid and accurate prediction of soil carbon pools in typical soil types and can be adopted easily for routine carbon pool analysis.

Soil faeces, springboard for SOM formation: what do we know and where do we go?

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Fragmentation of plant litter is one of the dominant pathways of litter decomposition and subsequent SOM formation. It is driven by a wide diversity of soil macrofauna (e.g., earthworms, millipedes, isopods, snails) that feed on litter and/or soil and egest faeces that present a complex architecture and composition. Although a large part of plant inputs is ingested by these animals during the decomposition process in many ecosystems, the characteristics and fate of these faeces remains poorly understood. We present recent advances depicting the chemical and physical characteristics of soil macrofauna faeces and exploring the factors regulating their fate in the soil over time. These advances point to a homogenisation of litter quality and increased lability following litter conversion into faeces, leading to faster decomposition rates and incorporation into the soil. This fragmentation pathway that results in the production of particulate OM, mineral-associated OM and/or dead bacterial residues, appears as a springboard for SOM formation. The evaluation of the importance of faeces in SOM formation emerges as a critical challenge requiring better understandings of (i) the consumption and assimilation of plant litter by soil animals to estimate how much litter enters the pathway, of (ii) the digestion and fragmentation of the litter to track the change in lability, and of (iii) the incorporation of these diverse faeces as SOM. In light of these results and remaining knowledge gaps, we present guidelines for future research investigating the fate of OM entering the fragmentation pathway. Addressing these knowledge gaps will require combining methods (e.g., imaging, bulk biogeochemical analyses) and disciplines (e.g., ecology, zoology, microbiology, soil science) at different time and spatial scales to tackle the interactions between plant residues, detritivores, microorganisms and mineral particles. Ultimately, this will allow incorporating the effects of soil macrofauna into SOM formation models and enhance their prediction accuracy.

New insights into how organic N is depolymerised

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Despite nitrogen (N) commonly limiting productivity, most soils contain a large pool of N in high molecular weight organic forms. High molecular weight forms of organic N are in general not directly available for uptake by microbes or plants, and only become available after they have been depolymerised by extracellular enzymes.

Surprisingly little is known about how high molecular weight organic N is depolymerized. A particular challenge is in determining the products that are produced when high molecular weight organic N is depolymerized. Depolymerisation of organic N is often equated with production of the terminal monomers, primarily amino acids. For example, many assays of enzyme activity focus solely on reactions that produce amino acids. Studies to date have not determined the chemical profile of products produced by depolymerisation of organic N, and thus we do not know if amino acids are the main products of depolymerisation.

Determining how high molecular weight organic N is depolymerized has proved challenging for two reasons. First, because the products of depolymerisation are rapidly taken up by microbes; and second, because it has proven difficult to identify and quantify complex mixtures of hydrophilic organic N compounds.

This presentation will describe development of mass spectrometry methods to characterize the products of organic N depolymerisation. We show that while amino acids are produced by depolymerisation they are not the dominant products. The main depolymerisation products of native organic matter and added proteins are instead peptides. The same peptides that are produced in large quantities by depolymerisation are at vanishingly low concentrations in intact soil, which is consistent with the idea that peptides are preferred N sources for soil microbes.

What can isotopes tell us about the controls on the coupling/decoupling of soil nitrogen and carbon?

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The isotopic composition of both the nitrogen ($\delta^{15}\text{N}$) and C ($\delta^{13}\text{C}$) entrained in soil organic matter (SOM) are altered by local biogeochemical reactions. They thus represent a potential integrative measure of SOM function that could bridge the distance between low cost, low sensitivity measures of bulk SOM stoichiometry and highly sensitive, but high cost, emerging SOM characterisation techniques. Here we tested this potential by using archived soil samples to explore $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ variations, 1) between climate and agriculture regions, and, 2) between physically separated SOM fractions. The re-analysed soils were collected at two depths during two previous recent national soil surveys (BASE for soils from natural ecosystems (0-20, 20-40cm), SCaRP for soils from agricultural ecosystems (0-10, 10-20cm)). For (1), we analysed soils from 413 sites across New South Wales. For (2), we analysed the previously separated 'humic' and 'particulate' components in soils from 300 farm sites across Australia. We found that $\delta^{13}\text{C}$ values were strongly aligned with land-use type (pasture, cropping, or un-cultivated). In contrast, $\delta^{15}\text{N}$ values in un-cultivated lands were strongly influenced by climate (aridity index). Cultivated soils deviated from this apparent climate-driven relationship. This suggests that $\delta^{15}\text{N}$ could be used to indicate where and when agricultural soils are 'regenerating' (moving closer to the expected relationship) or 'degrading' (moving farther from the expected relationship) through time. Overall our results suggest that measuring variations in soil $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ can add value to established metrics of SOM functionality.

Mutual interactions between decaying plant litter, soil microorganisms and mineral particles, controlled by soil texture

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Soil texture and microorganisms are key drivers controlling the fate of organic matter (OM) from decaying plant litter and thus soil organic matter (SOM) stabilization. A better understanding of mutual interactions between microbial litter decay and soil structure formation controlled by different soil texture remains challenging. We monitored the fate of litter-derived compounds (using ¹³C isotopic enrichment) from decaying litter (maize leaves) to microorganisms and soil in two differently textured soils (sand and loam). We incubated the two soils with litter mixed in the top layer in microcosms for three months with regular CO₂ and ¹³CO₂ measurements. Using a physical soil fractionation scheme, we assessed the fate of the litter-derived OM as free and occluded particulate organic matter (POM) as well as mineral associated OM (MOM) together with the effects of the different textures on the microbial communities using PLFA. The POM and MOM fractions were analyzed with respect to mass distribution, C, N and ¹³C contents, as well as the chemical composition using ¹³C-CPMAS NMR spectroscopy. We could clearly demonstrate higher contents of OM in the mineral associated fractions of the sandy textured soil in contrast to the loamy textured soil, where instead higher OM contents were detected in the POM fractions. Thus we show a distinct negative effect of the clay content on MOM, while clay sustains a high level of OM stored as POM. The ¹³C measurements showed higher enrichment in almost all fractions in the sandy textured soil compared to the loamy soil. The PLFA analysis revealed a coherent pattern between the textures, where microbial activity increased in the top layers and the community structure remained similar in both treatments. This interdisciplinary approach, where biogeochemical and microbiological methods were combined, gave insights in the interactions between decaying plant litter, microorganisms, and soil minerals.

Molecular-level investigation into the fractionation of dissolved organic carbon during co-precipitation with ferrihydrite

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Association with minerals, especially poorly crystalline iron (Fe) minerals, plays an important role in the persistence of dissolved organic carbon (DOC). Chemical fraction can occur for DOC upon its association with Fe minerals, however, scant information is available for the fractionation of DOC during co-precipitation with Fe-minerals. Herein, applying Fourier transform ion cyclotron resonance mass spectrometry (FTICR-MS), we investigated the fractionation of DOC during co-precipitation with ferrihydrite (Fh) in systems with C/Fe molar ratio of 0.5 and 3. Our results showed that high-molecular-weight DOC was preferentially precipitated for system with C/Fe of 3. In addition, a higher fraction of condensed polycyclic aromatic hydrocarbons (98.12%) was co-precipitated compared to unsaturated phenolic (66.25%) and aliphatic (39.01%) DOC. Our findings demonstrated that high-molecular-weight aromatic compounds preferentially co-precipitate with Fh in systems with feed C/F ratio relevant to the natural systems. Results from this study provided valuable information regarding the importance of DOC composition in its association with Fe-minerals and stability in the natural environment.

SOM chemistry and its relationship to water retention and hydraulic conductivity in Canadian and Australian peat soils.

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SOM has a strong interaction with soil hydrologic properties in peat soils due to the dominance of organic matter in the composition of peats. This paper explores the relationship between the chemistry and physics of peat soils from Australia and Canada. Peatlands in Australia are limited and uncommon due to the prevailing environmental conditions in the country, therefore, background information on peatlands in Australia is scarce. On the other hand, peatlands cover about 13% of Canada's terrestrial land surface and they are found in every province, so they have been more intensively studied. Peatlands in both countries are important in catchment hydrology and yet they have experienced high levels of degradation due to a range of anthropogenic impacts. Decades of peatland restoration research in Canada has identified that land managers require a sophisticated understanding of peat hydrology in order to successfully restore degraded peatlands. A mechanistic and empirical link between hydrologic and chemical properties, as explored in this study, would enable land managers to more rapidly and cost effectively assess peat hydrologic properties.

Effect of nitrogen loss on deep soil organic carbon decomposition

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More and more deep soil is exposed to the surface as a consequence of anthropogenic activities. The effect of nitrogen (N) loss through biological, chemical and physical processes is widespread on deep soil organic carbon (SOC). Despite researchers have realized the different regulatory mechanisms of SOC decomposition in response to increasing N availability in topsoil and in subsoil, very few experiments have considered the effect and mechanism of N loss on deep SOC. In this study, we selected grassland soil samples from 0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-100 cm soil depths and conducted 411-day incubation using ion exchange membrane to imitate N loss. Microbial respiration and the related variables including environmental factor (soil pH), substrate quality (SOC and total N of light and heavy fraction, dissolved C and N, and their ratios of C and N), and microbial attributes (active microbial biomass, microbial biomass C and N, the ratio of r and K strategies, extracellular enzyme activities, and microbial C efficiency) were measured during the incubation period. Our results indicated that the effect of N loss on SOC decomposition was nonlinear with the increase of soil depth. N loss significantly increased SOC decomposition in the surface, decreased in the middle layer, and increased in the deep layer. The increase of SOC decomposition in subsoil was twice that in topsoil. The difference of SOC decomposition at different depth was caused by the influence of substrate availability and environmental factors on the microorganism. The decrease of N availability mainly affected the SOC decomposition through the reduction of available N in topsoil, whereas through the increase of soil pH in subsoil. Our study provides new evidence of the vulnerability of deep SOC to global changes and is meaningful to accurately predict deep SOC dynamic in response to global N deposition.

Isotopic partitioning of soil respiration components in response to warming and altered precipitation in a grassland ecosystem

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How the two components of soil respiration, namely rhizosphere respiration and soil organic matter (SOM) decomposition, respond to climate change is important for predicting the feedback between carbon cycle and climate change. In this study, we used the natural abundance ^{13}C tracing technique to partition soil respiration in response to warming and altered precipitation in a grassland ecosystem in Kansas, USA. We grew a common C3 grass (*Bromus inermis*) in the native C4 grassland soil, and used infrared radiators and rainout shelters to control temperature (ambient and +2°C) and precipitation (ambient and delayed – increase dry intervals by 50% without changing total amount of rainfall) in the Konza Prairie Biological Station. Results showed that the root-derived CO₂ (Ra) was suppressed by delayed rainfall in summer and fall (but not in spring), and was not affected by warming in all three seasons. In contrast, the SOM-derived CO₂ (Rh) was enhanced by warming only in fall, and was not affected by delayed rainfall in all three seasons. The rhizosphere priming effect (RPE) was calculated as the difference in Rh between planted area and unplanted root-free area. RPE was minor in spring, but was significant in summer and fall. Moreover, RPE was not sensitive to warming or delayed rainfall in summer, but was stimulated by warming (but unresponsive to delayed rainfall) in fall despite no change in shoot or root biomass. Taken together, these results suggest that the impact of soil warming and altered timing of precipitation on soil CO₂ emissions varied with season (spring, summer or fall) and the source of CO₂ (Ra, Rh or RPE). This study presents one of the first measurements of RPE from field experiments using non-destructive isotopic tracing techniques and shows that soil warming could enhance the magnitude of RPE in the grassland ecosystem.

The unexplored role of secondary metabolites in root priming: phenolic root exudates cause striking changes in soil organic matter decomposition and microbial community structure

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Root-soil interactions fundamentally affect soil carbon cycling and thereby ecosystems feedbacks to climate change. This study investigated the microbial processes by which secondary metabolism of temperate forest tree species influence soil organic matter decomposition. We hypothesized that root phenolic compounds (secondary metabolites) have diverse functions in soils including food source, toxin, enzyme inhibitor and signaling. Therefore, we expected phenolics to cause contrasting trends in soil organic matter decomposition and lead to greater shifts in microbial community composition (MCC) than glucose (primary metabolite). Using a modified root exudate collection method and high-performance liquid chromatography (HPLC), we found that the root phenolic profiles are highly tree species-specific. As a preliminary screening test, we performed a five-day incubation study to assess the effect of a wide range of phenolic compounds representative of the biosynthetic classes identified by HPLC on soil microbial respiration. Here, our results show that root phenolic compounds can both increase, decrease or have no effect on microbial respiration, which is probably driven by specific functional groups. As a follow-up, we performed another soil-exudate incubation lasting 38 days aimed at understanding the microbial mechanisms behind phenolic-driven shifts in soil organic matter decomposition using stable isotope-labeled compounds, interval gas sampling, microbial sequencing and soil enzyme analyses. Our findings show that the degradation of phenolics varied by compound over time, while glucose was respired within the first two days of the experiment. Benzoic acid significantly increased soil organic matter decomposition, which was amplified in glucose-amended soils. Consistent with trends in SOM decomposition, benzoic acid caused the most striking shifts in MCC. Even the minimally-degraded phenolics often led to greater shifts in MCC than glucose. In conclusion, we demonstrate the drastic effects that root phenolics can have on soil organic matter dynamics and advocate for the inclusion of secondary metabolites in future priming studies.