The ground beneath our feet

Organic matter in soils is an important topic, not just for agriculture but for wider environmental concerns of climate change, as **Dr Daniel Rasse** is unearthing

Does soil organic matter (SOM) play a significant role in the Earth System and in wide-scale environmental change?

SOM is known to be the glue that binds soil particles together, preventing erosion and also retaining soil nutrients and water, which are then available for plant growth. Maintaining high levels of organic matter in cultivated soils has been a historical challenge for agriculture. Now, it has also become increasingly central in the climate change debate. SOM keeps carbon bound in solid form on the continents, rather than having it in the atmosphere in the form of CO_2 gas. Inventories of soil organic carbon stocks worldwide are constantly revised upwards, with the latest figures placing it at about three times that of the total CO_2-C of the atmosphere. In other words, a comparatively small decrease in SOM content worldwide could have catastrophic effects on the global climate, as it would directly translate into disproportionate quantities of CO_2 being released in the atmosphere. Therefore, maintaining high levels of SOM stocks in agricultural soils is critical for both food production and the stability of the global climate system.

Could you outline the main challenges of studying SOM?

Historically, the main roadblocks to understanding SOM decay and accumulation have been twofold. The first is a problem of time for experiments; SOM decays slowly, and carbon loss trends in agricultural soils can only be ascertained over decades. The second hindrance was our inability to analyse what SOM is actually made of – for many decades, organic chemistry was simply not advanced enough to tackle the problem. Studying the behaviour of a substance without knowing what it is actually made of is extremely challenging, and can lead to misinterpretations. Early soil scientists made interesting yet misleading observations. In summary, the paradigm was that SOM accumulation was largely driven by the chemical recalcitrance of lignin molecules and their recombination in soils.

Why is it important to understand the mechanisms of SOM formation?

A correct understanding of SOM formation actually has significant implications for farming, especially when it comes to the way in which residues should be managed to increase soil carbon stocks. Until now, based on our historical understanding, the restitution of high-lignin products such as straw was considered important for building SOM stocks. Recent research has questioned this view and is opening the way for using diverse by-products of biomass steams, eg. biochar. Our team's innovation-orientated objective is to start designing methods to improve the efficiency of carbon sequestration in soils, which we are doing in two main ways. The first involves making recalcitrant molecular structures out of plant residues, notably through exposure to high temperature, ie. pyrolysis and the formation of charcoal; the second involves researching products with a high interaction capacity with the soil particles, which fosters the stabilisation of carbon in soils.

How does biochar increase soil fertility and store carbon in soil?

Biochar is considerably more stable in soils than any non-treated plant residue. It is the one product where pure chemical recalcitrance is a key property explaining its long-time resistance in soils. At the same time, biochar appears to have most of the same positive soil-fertility functions as SOM; notably, a large capacity to retain water and soil nutrients within the root zone.

What activities have your team been undertaking in biochar research?

We are investigating two main questions: the stability of biochar in soils and its agronomic benefits. Regarding the stability, one thing we have learned is that not all biochar is created equal. By this I mean that the type of feedstock and the method for making biochar (called pyrolysis) have a huge impact on the property of the resulting biochar. Therefore, we are conducting fundamental research on the link between the pyrolysis production method, the physical and chemical properties of the biochar, and the resulting stability when added to soils. Plant growth improvement is the other key desired property of biochar. In Norway, we are running several field experiments on the effects of different types of biochar on crop yields, as part of a European network of biochar demonstration trials. It's an exciting time.

A burning **issue**

Exciting work at the Norwegian Institute for Agricultural and Environmental Research – **Bioforsk** – is bringing together researchers from across Europe to evaluate the long-term stability and carbon sequestration potential of biochars

SOIL ORGANIC MATTER (SOM) has been of importance to food producers since time immemorial, and it was only with the American Dust Bowl in the 1930s that large-scale alarm emerged about the loss of SOM as a major threat to food production and the quality of the environment. It has since been realised that understanding soil biogeochemistry is essential to the preservation and management of ecosystem services provided by soils. Such services include soil fertility (for food, fibre and fuel production), water quality, resistance to erosion and climate mitigation through reduced feedbacks to climate change. Research has shown SOM to contain more than three times as much carbon as the atmosphere and terrestrial vegetation. But scientists have still been puzzled as to why some SOM decomposes readily whereas other SOM persists for millennia. This knowledge gap, about the feedbacks between soil organic carbon and climate, poses problems for climate change predictions, and is one of the areas that Dr Daniel Rasse's research seeks to address.

SOM, LIGNIN AND THE MATTER OF HUMUS

For a number of years, Rasse has been leading research at Bioforsk (the Norwegian Institute for Agricultural and Environmental Research), in collaboration with partners across Europe (most recently through the MOLTER network), which has really started to challenge existing knowledge in this field.

Understanding the organic chemistry of SOM had previously been quite limited and involved what are now considered misinterpretations. "It is known that when incubated into soil, plant residues quickly lose their metabolic molecules, such as soluble sugars, and become enriched in the structural lignin-type molecules," Rasse explains. Looking at plant material – a more easily analysed material than SOM – it was possible to determine that the material that remained in leaf matter was largely cellulose and lignin. This had a lasting effect on thinking about SOM, as Rasse explains: "Because lignin seemed particularly resistant to decomposition, and SOM could not be easily analysed, researchers hypothesised for decades that SOM was composed of neo-formed macro-molecules based largely on a reassembly of lignin fragments and other organic fractions". The putative resulting substance was often referred to as humus. In the 1980s this theory even became embedded in models predicting the fate of SOM under various agricultural practices.

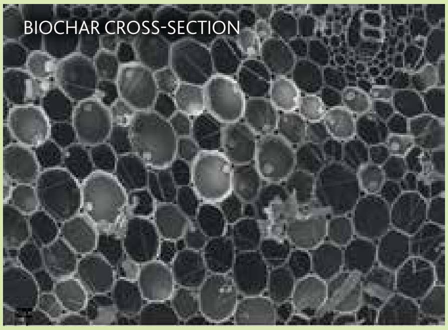
GETTING TO THE ROOT OF DECOMPOSITION

In the early 2000s, it became possible to directly extract the lignin fraction of SOM and to estimate its turnover rate by stable isotope methods. Rasse worked in collaboration with the BioEMCO laboratory in Paris, demonstrating that the lignin molecules present in the soil are actually young and decompose rapidly, mostly within a few years after incorporation to soils. Other international teams working simultaneously had been using high-energy molecular imaging of SOM at nanoscale. They were able to demonstrate that SOM is, in fact, mostly a mixture of fairly conserved plant and microbial molecules arranged within microsites in soils. In short, the lignin-derived humus does not appear prevalent. "This finding has been revolutionary because it shows that molecules of very different intrinsic chemical recalcitrance in soils co-exist and display a similar age," Rasse reveals. Moreover, it implies that the initial recalcitrance of the molecule in the plant residue is of little significance for the long-term storage of its constitutive carbon in soils. The research group suggests that persistence of soil organic matter therefore appears as an ecosystem property, as recently argued by Rasse in a co-authored *Nature* paper (Schmidt et al, 2011).

UNDERSTANDING BIOCHAR

Although it has been used in agricultural practices for centuries, biochar (intentionally pyrolysed biomass) has only recently gained the special attention of researchers, who are now studying it as a means to increase soil fertility and store carbon in soil for decades or even centuries. Early results from Rasse's research, alongside that of his colleagues, confirm that the carbon in biochar is intrinsically much more stable than other forms of carbon in soils. But, as he explains, these results also uncover further questions: "While very promising and

MISCANTHUS BIOCHAR


BIOCHAR CROSS-SECTION

of definitive technological interest, these results also show that even the recalcitrance of charcoal is not absolute and that different decomposition rates of biochar are observed in different soil environments, although much slower than ones seen in untreated plant materials". The fact that certain types of biochar degrade more rapidly in some soils than others, probably depending on the conditions under which they were produced, suggests that pyrolysis could be optimised to generate a more stable biochar.

OPTIMISING INTERACTION

As well as investigating pyrolysis production methods for the creation of more carbon-stable biochar, Rasse and his international partners have been researching products that will optimise the interaction between soil particles and organic molecules (and thus better stabilise carbon storage). Rasse is positive about some of the innovations made elsewhere in this field, notably in products emerging from the residue streams of the waste treatment and bioenergy industries: "Some of these products potentially have much higher interaction properties with soils particles than non-treated plant residues. Treatments need to be researched and will likely include combination with high-sorption biochar materials," he enthuses.

The future will likely see increasingly exciting synergy between fundamental research on organic matter structure and stability in soils, on the one hand, and technological innovations and applications on the other. "These innovations are based on methods to treat biomass streams for optimising energy outputs, carbon storage and soil fertility functions," Rasse suggests. Biochar is an example of this, but is certainly not the only possibility.

SEQUESTRATION AND GREENHOUSE GAS BUDGETS

There are many new concepts and technologies looking to pave the way for an agriculture that could generate higher soil organic carbon stocks under decreasing carbon inputs. The sequestration of carbon by SOM in agriculture would have significant impacts in relation to questions surrounding climate change and for policy issues such as greenhouse gas (GHG) budgets. Rasse suggests that, like an economic budget, a greenhouse gas budget can be balanced by reduction (of emissions of GHGs, instead of costs) or by increases (in the building up of carbon levels in soil, instead of revenues). By doing both at the same time, a healthy budget is achieved: "For example, some studies suggest that biochar application not only increases carbon stocks but also reduces N_2O emissions from fields," he notes. "For this reason, in our biochar field experiments we monitor N_2O emissions in addition to CO_2 for carbon sequestration efficiency."

The current focus of the climate debate for agriculture has been on reducing N_2O and CH_4 emissions, as agriculture is generally not considered a significant source of CO_2 emissions. This is because historical carbon losses have already happened and most mineral agricultural soils are no longer losing large quantities of CO_2. But Rasse and his colleagues have demonstrated that cultivated organic soils remain large CO_2 emitters, and that carbon storage in cultivated soil can be a key measure to reduce the overall GHG footprint of agriculture. The research is significant: it is already contributing to debates around agricultural and environmental policy in Norway, and we will watch to see how soon their work has similar impacts internationally.


BIOCHAR FIELD PREPARATION IN NORWAY

INTELLIGENCE

INTEGRATING FUNDAMENTAL RESEARCH INTO FIELD APPLICATIONS

FUNDAMENTAL TARGETED RESEARCH

- Advanced techniques to evaluate the long-term stability and carbon sequestration potential of different types of biochar
- Funding: Research Council of Norway (NFR 197531) for the period 2010-13
- Role: coordination of three national partners and eight international contributors

FUNDAMENTAL RESEARCH NETWORK

- Molecular structures as drivers and tracers of terrestrial C fluxes – MOLTER
- European Science Foundation – Research Networking Programme – 2008-13
- Role: coordination for 11 participating countries

EUROPEAN DEMONSTRATION NETWORK

- Biochar: Climate Saving Soils project
- INTERREG IV North Sea region programme
- Role: national representative

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