Conference Report

Work package 3: Restoring marginal land for agriculture using low cost amendments and bioremediation

Bastian Saputra

Collins Amoah – Antwi

Rosa. Isabel Soria

15/12/2017

Contents

1. CONFERENCE "Biochar: Production, Characterization and Applications"

1.1 Conference description

Date: 20-25 August
Location: Italy, Alba
Fellows: Bastian Saputra (ESR9) and Rosa Isabel Soria (ESR8)

Introduction
When residual biomass (woody or agricultural materials, organic residues, food waste, sewage sludge, digestate) is thermally decomposed under oxygen limiting conditions, biochar is one of the resulting products. This is a porous material, rich in carbon and inorganic elements characterized for having high surface are. Upon the incorporation into the ground, biochar can improve some soil properties as moisture and pH, sequestrate carbon, supply minerals, prevent nutrients leaching and water contamination and retain soil moisture. As a result, biochar can be used as an efficient material to enhance soil properties while sequestering carbon. Additionally, biochar's properties make it also suitable for a variety of value-added applications (adsorption of pollutants, filler for composites, catalysts, material for electronic applications, among others). Biochar properties depend on the biomass feedstock used as well as the conditions used during its production. Moreover, they can be manipulated by pre- and post-processing creating the so called "engineering biochars" which are value-added materials for specific applications. The interest in biochar has been booming all over the world. Several companies have jumped into production and the user community is looking for carbon-negative applications.

Thus, during the conference a review of the existing knowledge was done in order to stimulate research activities to bring clarity to this field. The topics covered were wide ranging from feedstock selection and properties, to production and upgrading processes, from identification of applications to economics, from characterization to products standardization and policies. The conference was conducted as a forum where the current knowledge, limitations and challenges as well as the future directions were openly reviewed and discussed. The topics presented by the fellows at the conference were part of the biochar applications session and are detailed on Table 1.

Table 1Topics covered by fellows of Work package 3 during Biochar Conference

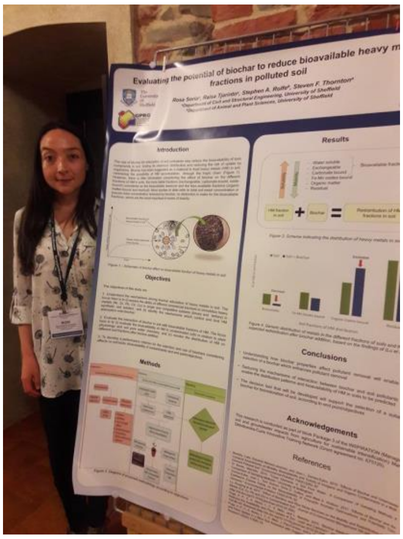
Fellow	Title	Oral	Poster	Evidence
Rosa Isabel Soria	Evaluating the potential of biochar for reducing bioavailable heavy metal fractions in polluted soil	✓	✓	See Apendix 1 (abstract, poster pdf. And pictures)
Bastian Saputra	Developing Biosensos as Monitoring Tools to assess the performance of Biochar-amended contaminated soil	✓	✓	See Apendix 1 (abstract, poster pdf. And pictures)

The topics covered during the 5 days of conference were the following:

- History of biochar: what can we learn from the past?
- Feedstocks for biochar and pre-processing
- Biochar production processes: from torrefaction to slow and fast pyrolysis
- Biochar reactor technologies
- Co-products (bio-oil and gas)
- Biochar characterization: relationships among feedstock, production technology and characteristics
- Biochar post-processing
- Biochar applications: soil amendments, adsorbents, catalysts, fillers for composites, electronic applications
- Biochar standardization (International Biochar Initiative, European Biochar Certificate, Biochar Quality Mandate)
- Biochar handling, storage, markets and commercialization
- Biochar systems
- Biochar sequential uses
- Biochar policies
- Case studies: success stories

1.2 Achievements

Bastian Saputra and Rosa Soria both presented successfully part of their current research as oral + poster modality (Figure 1)



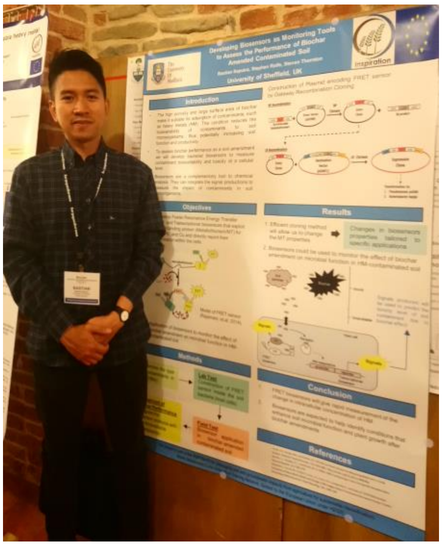


Figure 1 Fellows Rosa Soria (left) and Bastian Saputra (right) during the poster session at Biochar Conference.

Knowledge

- Techniques for the determination of functional groups present on biochar surface, mostly used XPS, NMR and also after discussion with some researchers who have been working on it for a while it was recommended a Boehm titration as a first step.
- Up to date methodologies in producing designed biochars impregnated with oxides for specific applications

- Novel applications of biochar in other fields as composite for cement and structures
- Influence of the production process and feedstock characteristics on biochar properties
- Different biochar production units for wide variety of purposes varying from pilot scale units to mobile field units

Networking

During the participation on the conference we established contact with some people who are working in the same area:

- Contact made with the UKBiochar Research Center of the University of Edinburg, with Professor Ondrej Masek. They are producing 10 different types of biochar that accomplish with the European regulations and which production process has been standardized. After talking about the research being conducted by ESR8, collaboration was obtained since they send free samples of 5 of the biochars they produce. Also the possibility of synergies was discussed and a future visit to Sheffield was agreed.
- Contact with the University of Swansea through the Emeritus Professor Alayne Street-Perrott. Recently, she contacted with the fellows working at the University of Sheffield proposing collaboration with a PhD student under her supervision who is also working on biochar related topic. At Swansea they have projects sponsored by a private company called Commons Vision Ltd. which among other activities is manufacturing biochar (EarthChar) by fast pyrolysis-gasification. They have been developing sustainable biochar-based products for use in the remediation of colliery waste, metal-mine waste, road and railway cuttings/embankments, SuDS. A visit to Sheffield was agreed to have place in February of 2018 to find out how can we collaborate.
- Other contacts were made with researchers from US and Canada who are developing novel biochars and would be interested on testing this biochar for heavy metal remediation.

1.3 Outputs

- A review paper is being elaborated between ESR8 (Rosa Isabel Soria) and ESR9 (Bastian Saputra) to be submitted as special issue of the Biomass & Bioenergy Journal with the same topic of the Biochar Conference on January 2018.

1.4 Appendix 1

1.4.1 Abstract submitted by ESR8

EVALUTATING THE POTENTIAL OF BIOCHAR FOR REDUCING BIOAVAILABLE FRACTION OF HEAVY METALS (Ni, Zn, Pb) IN POLLUTED SOIL

Rosa Soria, Department of Civil and Structural Engineering, University of Sheffield[a]
r.soria@sheffield.ac.uk
Raisa Trajinto[a]
Stephen A. Rolfe, Department of Animal and Plant Sciences, University of Sheffield
Steven F. Thornton[a]

Key Words: biochar, metals, adsorption, soil, bioavailability

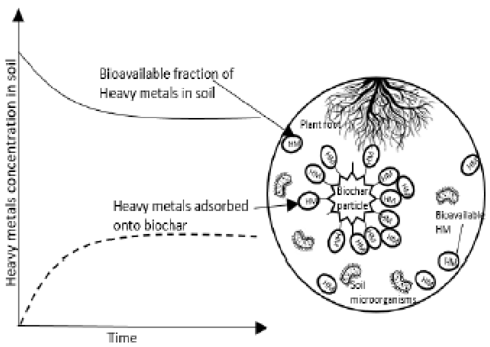


Figure 1 – Conceptual schematization of biochar effect over bioavailable fraction of heavy metals in soil.

Previous studies have proposed biochar as an adsorbent material with potential to be used in the remediation of polluted soils. The use of biochar for adsorption of soil pollutants may reduce the bioavailability of toxic compounds in the soil media, limiting its chemical distribution and reducing the risk of uptake by organisms. Therefore, biochar has been suggested for the treatment of heavy metals (HM) in soil, minimizing the possibility of accumulation of HM through the tropic chain (Fig 1). However, there is little information considering the effect of biochar on the different fractions of HM in soils, the bioavailable fractions (exchangeable, carbonate-bound, oxide-bound) and the less available fractions (organic matter-bound and residual). Most of the data reporting the use of biochar to remove HM is presented as total soil metal concentration or pseudo total concentration; no distinction has been established with the bioavailable fractions, which are the most important in terms of toxicity.

This research is conducted within the EU-funded INSPIRATION project to identify low cost amendments for

1.4.2 Abstract submitted by ESR 9

DEVELOPING BIOSENSORS AS MONITORING TOOLS TO ASSESS THE PERFORMANCE OF BIOCHAR AMENDED CONTAMINATED SOIL

Bastian Saputra, Dept. of Civil and Structural Engineering, University of Sheffield, UK
b.saputra@sheffield.ac.uk
Stephen Rolfe, Dept. of Animal and Plant Science, University of Sheffield, UK
Steve Thornton, Dept. of Civil and Structural Engineering, University of Sheffield, UK

Key Words: biochar, soil amendment, bioavailability, biosensor

The application of biochar as a soil amendment is an emerging technique for low-cost remediation of contaminated soil. The high porosity and large surface area of biochar make it suitable for adsorption of contaminants such as heavy metals (HMs) and polycyclic aromatic hydrocarbons (PAHs). Adsorption reduces the bio-availability of contaminants to soil microorganisms thus potentially increasing soil function and productivity. Many different biochars are available which differ in key properties such as contaminant adsorption and stability. To assess biochar performance as a soil amendment we will develop bacterial biosensors to measure contaminant bioavailability and toxicity at a cellular level. Biosensors are a complementary tool to chemical analysis. Sequential extraction and chemical analysis of soils provides a measure of contaminant concentrations in different soil phases whereas biosensors integrate the signals production to measure the impact of contaminants on cell physiology.

In this research we propose to develop two sorts of biosensors – transcriptional biosensors that report the activation of gene expression by specific contaminants and FRET (Förster Resonance Energy Transfer) sensors that directly report contaminant concentrations within living cells (Figure.1). These reporters will be constructed in *Escherichia coli* and then transferred to host cells more suitable for the analysis of soil samples e.g. *Pseudomonas putida*, and *Acinetobacter baylyi*. These hosts are robust and are found typically in contaminated soil environments.

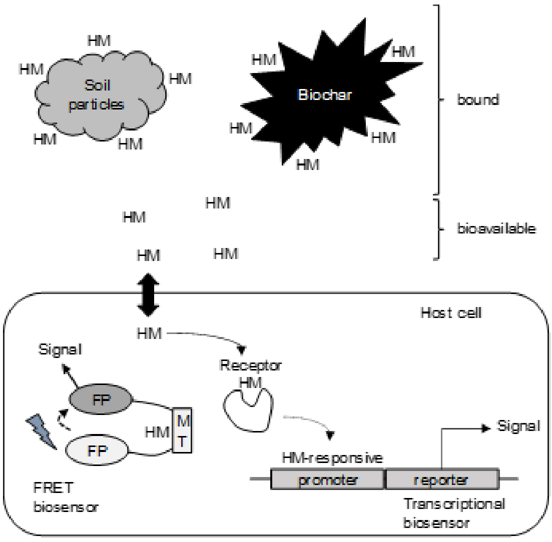


Figure.1. Interaction of contaminants (e.g heavy metals/HMs) with soil particles, biochar, and biosensors

The FRET-based sensor will exploit the heavy metal-binding capability of metallothionein (MT) proteins. Metallothioneins are small metal-binding proteins that can be utilised as recognition element for Zn, Cd, Pb, and Cu. The MT protein is inserted between cyan and yellow fluorescent proteins (FP) and expressed from a constitutive promoter. In the absence of HM, the FPs are widely separated but are brought together when metals are bound to MT. This alters the fluorescent properties of the recombinant protein allowing the concentration of HM within the host bacterial cell to be quantified as change in excitation and emission fluorescence spectra (Figure.1). Alternatively, HM and PAH responsive genes from bacteria can be fused to a reporter gene (FP or luciferase) to form a transcriptional biosensor. When a contaminant is present, gene expression is activated and the reporter protein produced. MT and PAH-responsive promoters will be used in these constructs.

The FRET-based biosensors are extremely rapid (changes in intracellular concentrations of HMs can be detected within milliseconds) whilst transcriptional biosensors respond more slowly but can potentially detect a wider range of contaminants.

1.4.3 Poster Presented by ESR8

Evaluating the potential of biochar to reduce bioavailable heavy metal fractions in polluted soil

The University Of Sheffield.
GPRG Groundwater Protection & Restoration Group

Rosa Soria[a], Raisa Tjarinto[a], Stephen A. Rolfe[b], Steven F. Thornton[a]
[a]Department of Civil and Structural Engineering, University of Sheffield
[b]Department of Animal and Plant Sciences, University of Sheffield

Inspiration

Introduction

The use of biochar for adsorption of soil pollutants may reduce the bioavailability of toxic compounds in soil, limiting its chemical distribution and reducing the risk of uptake by organisms. Biochar has been suggested as a material to treat heavy metals (HM) in soil, minimizing the possibility of HM accumulation through the tropic chain (Figure 1). However, there is little information considering the effect of biochar on the different fractions of HM in soils, the more labile fractions (exchangeable, carbonate-bound, oxide-bound) considered as the bioavailable reservoir and the less available fractions (organic matter-bound and residual). Most studies to date refer to total soil metal concentration or pseudo total concentration removed by biochar; no distinction is make for the bioavailable fractions, which are the most important in terms of toxicity.

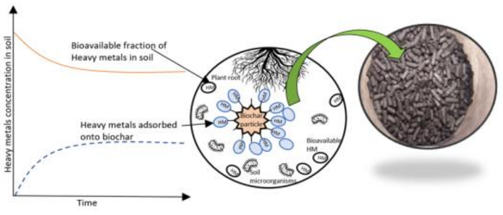


Figure 1 – Schematic of biochar effect on bioavailable fraction of heavy metals in soil.

Objectives

The objectives of this study are:

1. Understand the mechanisms driving biochar adsorption of heavy metals in soil. The focus here is to (i) assess the ability of different commercial biochars to immobilize heavy metals (Ni, Zn, Pb, Cd, Cu) in single and competitive systems (binary and tertiary) in synthetic soil solution, and (ii) identify the mechanisms which control and limit HM adsorption onto biochar.

2. Evaluate the interaction of biochar in soil with bioavailable fractions of HM. The focus here is to (i) evaluate the bioavailability of HM in contaminated soils in relation to plant physiology and soil pore water chemistry, and (ii) monitor the distribution of HM on different soil fractions after biochar addition.

3. To develop a performance criterion for the selection and use of biochars considering effects on soil biota, bioavailability of contaminants and end point/objectives.

Methods

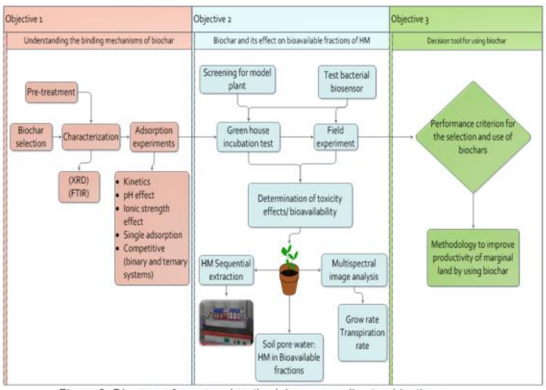


Figure 2. Diagram of proposed methodology according to objectives

Results

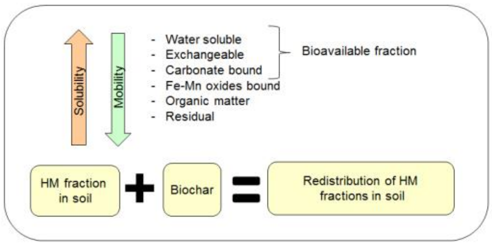


Figure 3. Scheme indicating the distribution of heavy metals in soil

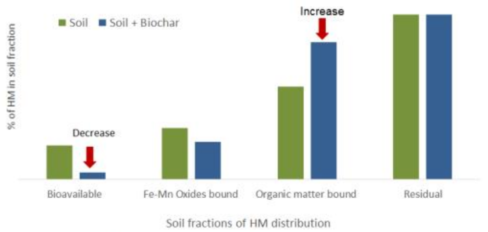


Figure 4. Generic distribution of metals in the different fractions of soils and the expected redistribution after biochar addition, based on the findings of (Lu et al. 2017).

Conclusions

- Understanding how biochar properties affect pollutant removal will enable the selection of a biochar which enhances pollutant removal
- Deducing the mechanisms of interaction between biochar and soil pollutants will enable the distribution patterns and bioavailability of HM in soils to be predicted
- The decision tool that will be developed will support the selection of a suitable biochar for biorestoration of soil, according to end point/objectives

Acknowledgements

This research is conducted as part of Work Package 3 of the INSPIRATION (Managing soil and groundwater impacts from agriculture for sustainable intensification) Marie Skłodowska-Curie Innovative Training Network (Grant agreement no. 675120).

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1.4.4 Poster Presented by ESR9

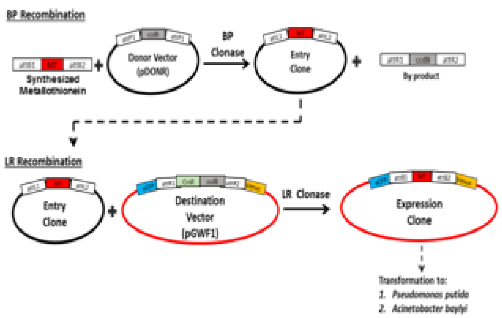
Developing Biosensors as Monitoring Tools to Assess the Performance of Biochar Amended Contaminated Soil

Bastian Saputra, Stephen Rolfe, Steven Thornton
University of Sheffield, UK

Introduction

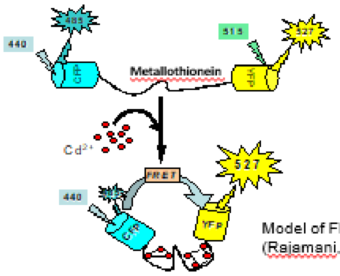
- The high porosity and large surface area of biochar make it suitable for adsorption of contaminants, such as heavy metals (HM). This condition reduces the bioavailability of contaminants to soil microorganisms, thus potentially increasing soil function and productivity.
- To assess biochar performance as a soil amendment we will develop bacterial biosensors to measure contaminant bioavailability and toxicity at a cellular level.
- Biosensors are a complementary tool to chemical analysis. They can integrate the signal productions to measure the impact of contaminants in soil microorganisms.

Construction of Plasmid encoding FRET sensor by Gateway Recombination Cloning



Objectives

1. To develop Foster Resonance Energy Transfer (FRET) and Transcriptional biosensors that exploit the metal binding protein (Metallothionein/MT) for Zn, Cd, Pb, and Cu and directly report their concentration within the cells

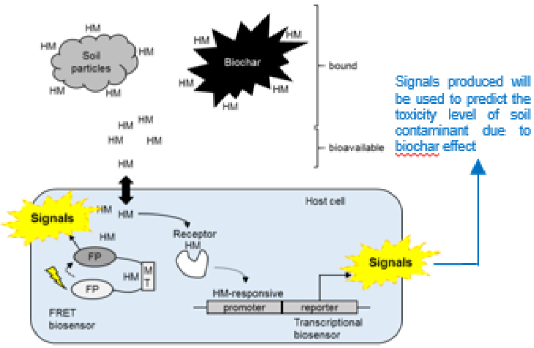


Model of FRET Biosensor (Rajamani, et.al, 2014).

2. Application of biosensors to monitor the effect of biochar amendment on microbial function in HM-contaminated soil.

Results

1. Efficient cloning method will allow us to change the MT properties → Changes in biosensors properties tailored to specific applications
2. Biosensors could be used to monitor the effect of biochar amendment on microbial function in HM-contaminated soil



Methods

Determine the type of contaminants in soil (HMs) → **Lab Test** Construction of FRET sensor inside the soil bacteria (host cells) → **Field Test** Biosensor application in biochar-amended contaminated soil → **Assessment of Biochar Performance** (Integrate the biosensor analysis with plant-bioavailable contaminants)

Conclusion

1. FRET biosensors will give rapid measurement of the change in intracellular concentration of HM
2. Biosensors are expected to help identify conditions that enhance soil microbial function and plant growth after biochar amendments

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This project is part of the INSPIRATION (Managing soil and groundwater impacts from agriculture for sustainable intensification) Marie Sklodowska-Curie Innovative Training Network, funded by the European Union under H2020

1.4.4 Certificates of oral presentation

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CERTIFICATE OF PARTICIPATION

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The University of Sheffield
United Kingdom

Biochar: Production, Characterization and Applications

August 20 – 25, 2017
Alba, Italy

Oral Presentation

Evaluating the potential of biochar for reducing bioavailable heavy metal fractions in polluted soil

Barbara K. Hickernell
Barbara Hickernell
Executive Director

32 Broadway, Suite 314, New York, NY 10004
Tel: +1-212-514-6760 | Fax: +1-212-514-6030
info@engconfintl.org | www.engconfintl.org
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2. 6th INTERNATIONAL SYMPOSIUM ON SOIL ORGANIC MATTER (SOM 2017)

Date: 3-7 September 2017

Fellow: Collins Amoah – Antwi

2.1 INTRODUCTION

The SOM 2017 Conference took place at the Rothamsted Research, Harpenden, UK from 3 – 7 September 2017. The theme of the conference was the theoretical and applied study of SOM science. Under this, a range of sessions altogether made contributions to current management of agricultural soils to deliver environmentally and economically sustainable supplies of sufficient, nutritious food for all, in the context of global population increase, climate change and unequal resource distribution. The recent focus on the role of soil health to help bridge the yield gap has confirmed the important role of SOM as natural capital. Therefore, optimizing SOM management offers the potential to both mitigate greenhouse gas emissions and increase food production and quality.

The topic covered during the conference were grouped into seven sections, under which various oral and poster presentations holistically reviewed and presented work on the current state of SOM science:

- Session 1: **Global perspectives**
- Session 2: **Modelling SOM: From soil pore to climate change** – soil self-organization; next generation SOM models; C sequestration and climate change
- Session 3: **Methods 1: Visualizing SOM Models** – Visualising SOM at the soil pore scale; spatial variability of SOM concentration, composition, and persistence; mapping and monitoring of SOM
- Session 4: **Methods 2: Quantifying pools and fluxes of SOM** – Mass spectrometry – the key to the SOM 'Black Box'; what is humified organic matter; organic nutrients
- Session 5: **Soil health 1: Biological interactions** – Ecosystem Engineers; hot moments, hotspots and hotspheres; Biology of deep soil: the final frontier?.
- Session 6: **Soil health 2: The role of decomposition** – SOM decomposition: links between carbon and nutrient cycling; managing soil organic matter decomposition and stabilization for carbo sequestration and improved soil health; SOM in rice paddy systems.
- Session 7: **SOM as natural capital** – National and international SOM policy; management effects on SOM and ecosystem services; incorporating SOM into farming system evaluation.

2.2 KNOWLEDGE GAINED

New knowledge and advances in research gained from attending the SOM 2017 Conference include:

- Attempts at quantifying priming effects caused by SOM application to soils have yielded mixed results, yet elucidating this might increase the accuracy of time-dependent estimation of the soil organic carbon (SOC).
- Exponentially increasing SOC is not always positive for plant growth as evidence supports competition between C and P for sorption to Cl and other ions. P monitoring should be a crucial component of SOC studies, as reduced sorption resulting from SOM increases could result in leaching or runoff of P into groundwater.
- Measurement of the composition of soil alone is a weak indicator of soil health, hence a more comprehensive approach would additionally measure the soil function capacity. Hence it is not just about providing evidence of increased SOM or C sequestration but also providing evidence that these resources are being utilized by the plants.

2.3 OUTPUT

The abstract has been published online. Again, a review paper on the abstract presented at the conference will be submitted to the Journal of Soil Use and Management for publication.

2.4 Appendix

2.4.1 Poster presented by ESR 10

Dynamics Of Soil Organic Matter Transformation To Improve Soil Health

Inspiration

Collins Amoah – Antwi*, Jolanta Kwiatkowska-Malina
Department of Spatial Planning and Environmental Sciences, Faculty of Geodesy and Cartography, Warsaw University of Technology

Introduction

Feeding the current world's population of over 7.3 billion and the projected 9.5 billion people by 2050 require a corresponding increase of approximately 70% in agricultural production [1]. Agriculture intensification has become necessary for keeping up with food production rates, to provide food security, yet, resulted in degradation of the soil and pollution of groundwater, subsequently causing a decline in soil health and function.

The health of soils and their functionality are highly influenced by soil organic matter (SOM), which is also a natural hub for the soil's rich biodiversity. Soil organic carbon (SOC) present in SOM is fundamental to soil and ecosystem functions across a wide range of temporal and spatial scales, including site-specific fertility and biogeochemical recycling.

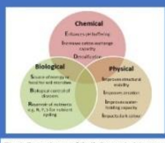

Fig 1.Functions of Soil Organic Matter

The application of exogenous organic materials to soil, especially on degraded and marginal agricultural lands, is critical for restoring, preserving and increasing SOC, to improve soil health and to augment the diverse natural functions of SOM (Fig 1).

Understanding the dynamics of SOM transformation to stable humic substances is critical for realizing the full benefits of organic matter application to soils. However, the formation and sequestration of significant quantities of humic substances typically takes over a decade, a situation responsible for the relatively low advancement in this research area, and the resulting lag in scientific knowledge.

Declining SOM/SOC Stocks

SOC stocks are in dynamic equilibrium between C inputs (from plant residues and organic fertilizers) and losses through decomposition of organic matter. SOC modelling studies indicate that C input must increase by 29% to maintain current SOC stock in agricultural soils [2]. Projections show decreasing SOC stocks for soils on both croplands and grasslands, on regional and global scales, albeit, with small increases in isolated cases [3]. Generally, 45% of all European soils are considered to have organic matter levels classified as low or very low [4].

Fig. 2. Zonal distribution of the current SOC stock in topsoil layer (0 – 20 cm) in Europe (EU26) (Yigini & Panagos, 2016) [5].

Future projections to 2080 indicate similar losses in SOC, however, favourable technological changes are predicted to increase SOC stock by 1-7 t C/ha in croplands and 3.2-6.2 t C/ha in grasslands in Europe [6]. Consequently, the European Commission's 7th and current Environmental Action Programme (EAP) has set out strategies for achieving various environment, climate change and waste management targets over the course of its implementation [7]. In all these priority areas, the role of SOM in improving soil health features prominently.

Dynamics of SOM Transformation and Modelling

Simulation models in SOM research provide a mathematical framework to integrate, examine and test understanding of SOM dynamics. The role of models in this context is to balance conceptual understanding of SOM decomposition processes with data available from studies, to enable accurate forecasting and prediction of the dynamics in a given time frame or region.

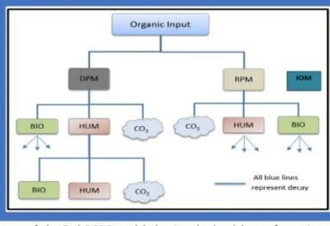

Fig. 3. Structure of the RothC-26.3 model showing the breakdown of organic matter and their distribution among the various organic matter pools: DPM – decomposable plant material; RPM – resistant plant material; IOM – inert organic material; HUM – humified organic material; BIO - microbial biomass. Adapted from Coleman et al., 1997 [8].

The RothC-26.3 model, tailored for non-waterlogged arable soils has basic data requirements and features that are relatively easy to modify. It works on hypothetical distribution of organic matter into SOM pools characterized by different decay kinetics (Fig. 3). At the coding level of the model, it is possible to modify the kinetic pools to include decay factors for exogenous organic matter from amendments such farmyard manure, brown coal, biochar etc. that would essentially cater for specific research needs.

Future Perspectives

The application of different organic amendments (Fig. 4) to the soil provides a useful way for the characterization of SOM dynamics, to allow for comparative assessment of the efficiency of each amendment and their corresponding optimal application rates. This essentially also prevents soil health damage potentially resulting from excessive phosphorus or nitrogen release caused by immoderate application of organic matter.

Empirical data such as land use changes, climatic factors, soil characteristics, C/N ratio and humification indices obtained from amended soils could be used for modelling the dynamics of SOM in each [9], and provide a basis for comparing the efficiency of the different organic amendments in improving soil health.

Fig. 4. Organic amendments for study of SOM dynamics

Data from short-term studies on SOM dynamics are often considered difficult to obtain or unreliable. However, mineralizable C, labile fraction and microbial biomass are sensitive to seasonal changes in soil conditions, hence provide a useful index for land management-induced SOM dynamics [10]. Improved approaches for characterizing SOM dynamics would integrate both short- and long-term studies, which will consequently contribute to the development of robust models for understanding SOM dynamics.

Current understanding on the role of SOM in improving soil health can be enhanced by studying how decomposition and stabilization processes in deeper soil horizons differ from the more commonly investigated surface soils.

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2.4.2 Abstract submited by ESR 10

Session 6b: Managing soil organic matter decomposition and stabilization for carbon sequestration and improved soil health

P-6b.39

Dynamics of soil organic matter transformation to improve soil health

*Collins Amoah-Antwi[1], Jolanta Kwiatkowska-Malina[1]
[1]Warsaw University of Technology, Spatial Planning and Environmental Sciences, Warsaw, Poland

Soil functionality largely depends on soil organic matter (SOM), which is a natural hub for the rich biodiversity in the soil. The application of exogenous organic matter to soil is an investment that conserves and increases the SOM level, thereby augmenting the numerous functions of SOM, which include: serving as a reservoir of nutrients for plants; providing a source of food and energy for microorganisms essential for biological soil processes; complexing with ions of toxic substances to decrease their bioavailability to plants; improving structural stability of soil; increasing water retention and; control of climate change by sequestering carbon in the soil. Understanding the dynamics of SOM transformation is essential for full realization of the benefits of its application. However, the long period (over 20 years) required for substantial transformation of SOM into humic substances is a major hindrance for carrying out such studies, resulting in the current knowledge gap. Current studies provide some understanding, yet, are biased towards biotic factors controlling the SOM transformation processes. A balance of both the biotic and abiotic factors is necessary for a comprehensive grasp of the dynamics of SOM transformation.

Agriculture intensification and mechanization have become necessary for sustaining food production for a rapidly growing world population expected to peak at about 9.1 billion by the year 2050. This resolution has been successful in attaining the food security target, but resulted in further deterioration of the environment: contamination of soils and groundwater. Consequently, the European Commission"s 7th and current Environmental Action Programme has set out strategies for achieving various environment, climate change and