

Stabilization of soil organic carbon in microaggregates under contrasting land uses in Alfisols and Oxisols

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A Thesis Submitted for the Degree of Doctor of Philosophy

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University of New England, Australia

June, 2012

Acknowledgements

I would like to pay my deepest gratitude to Almighty Allah who has given me opportunity and strength to pursue my PhD study.

I am very much indebted to my principal supervisor Dr. Heiko Daniel who from the first day of my candidature helped me to understand my work. I enjoyed academic liberty he offered to me while working under his supervision. He was also very keen to my academic and professional development. Without his constant support and encouragement it would not possible for me to complete many key parts of my research work especially using NMR facility at UNSW and AMS facility at ANSTO. His support to my plan to use X-ray microtomography in my research made it possible. I would like to specially acknowledge the support and input he gave me during writing and finalizing the thesis. It is not easy to write down how much I have learnt from Dr. Brian Wilson during the writing stage. He constantly went through my thesis chapters from first to final draft and his critical but positive annotations, comments and suggestions made me rethink, realize and improve my writings. Thanks also for his support in site selection and soil sampling. I would like to express my gratitude to Dr. Iain Young for his encouragement and support to understand micro-scale structure of soil. His research works and advice on soil biophysics and X-ray microtomography is inspiration to me. I am cordially grateful to Dr. Peter Lockwood for his help during laboratory work and for his constructive discussions and suggestions on thesis. Dr. James Hook and Dr. Rasmus Linser at UNSW taught me the basic operation and experimentation with solid state NMR. I could not forget how they patiently try to understand my research objectives and help me to complete my work under their constant supervision. I would like to express sincere gratitude to Dr. Quan Hua (ANSTO, Sydney) for his supervision of radiocarbon analysis using AMS, radiocarbon model execution and data analysis. His untiring interest in soil radiocarbon models helped me immensely to understand radiocarbon dynamics in terrestrial ecosystem.

Much appreciated thanks to UNE to provide me UNE international scholarship, 2009 to peruse PhD here in Armidale. It was extraordinary opportunity for me to work in Institute for Environmental Research at ANSTO. I would like to express my gratitude to AINSE for providing me a research grant.

Dr. Matt Tighe, Dr. Paul Kristiansen, Dr. Gregory Falzon (Spatio-Temporal Support Unit, UNE) and Jackie Reid (Statistics, UNE) been very nice to me and helped me ardently whenever I need it most. I would like to thank Dr. Annette Cowie and Dr. Bob Martin for their support from PIIC, UNE. Much needed laboratory assistance that I received from Linda Barry (IER, ANSTO) and Fiona Bertuch (IER, ANSTO) is highly acknowledged.

My project was fully based on laboratory work. I am grateful to Mr. George Henderson for his consistent help to set up wet sieving apparatus, vacuum suction arrangements and soil sampling. The assistance of Mrs. Leanne Lisle and Mr. Gary Cluley to run the chemical analysis of my samples was terrific. I could not finish soil sampling without generous help from Mr. Greg Chamberlain who been very friendly and helpful during my field sampling in Guyra and Dorrigo. Mr. Dan Altar deserves special thanks for running XRD analysis of my clay samples. Mr. Michael Fain gave all kind of assistance during my work in potting shed. I would also like to thank Mr. Allan Rummery and Mr. Andrew Gasbarri of Science and Engineering Workshop, UNE and Mr. Andrew Wallace of Chemistry, UNE for their timely help to solve the technical difficulties. Special thanks to Dr. Holger Roth, GE Sensing, Germany for his assistance with operation of X-ray microtomography.

It was great for me to have many great friends here in agronomy. Thank you very much Habibullah Bahar, Nazma Begum, Nimai Senapati, Richard Flavel, Giregon Olupot, Phobe Barnes, Karim Bhiah, Yadunath Bajgai, Slamet Supriyadi and Christine Walela for their support and friendship. I would also like to thank the landowners of sampling sites in Armidale, Guyra and Dorrigo for their permission and help to work in their property.

Finally I would like to thank my wife Tania Khandakar and daughter Noshin Anbar for their support, encouragements and patience they showed to me during my project and especially in writing stage. I would like express my gratitude to my parents, brother and sister for their prayer and good wishes for me.

Abstract

Soil microaggregates play a key role in stabilization of soil organic carbon (SOC) and influence dynamics of SOC in terrestrial ecosystem. SOC can be stabilized in microaggregates through physical, physico-chemical and biochemical protection mechanisms. The study of SOC stabilization mechanisms poses a number of challenges. Firstly, all these mechanisms operate simultaneously in nature and, secondly there are significant methodological constraints of separating SOC fractions with different turnover times. Moreover, the importance of various stabilization mechanisms varies considerably in different climates, soil types and management systems.

The overarching hypotheses of the study were (i) physical protection of SOC is a dominant SOC stabilization mechanism in soil microaggregates over physico-chemical protection (ii) land use and soil type determines the relative importance of different stabilization mechanisms. The specific objectives of the research work were to investigate (i) the SOC stabilization in water stable aggregates (ii) microbial decomposition of SOC and its relationship with chemical composition of SOC and pore geometry of microaggregates (iii) the mean residence time of SOC in microaggregates and (iv) the influence of land uses on the distribution and stabilization of SOC in microaggregates.

Two soil types were investigated, Alfisols and Oxisols, both located on the Northern Tablelands, NSW, Australia. Contrasting land uses in Alfisols were native pasture, crop-pasture rotation and Eucalypt woodland whereas in Oxisols land uses were improved pasture, cropping and remnant rainforest. Macroaggregates (250-2000 μm), microaggregates (53-250 μm) and <53 μm fractions of Alfisols and Oxisols were isolated by wet sieving with a combination of slaking and shaking pretreatments. The mean weight diameter and percent water stable aggregates were calculated using weights of aggregates retained on sieves during wet sieving. The SOC associated with macroaggregates, microaggregates and <53 μm fraction was determined by LECO CN analyzer. Physical SOC fractions associated with macroaggregates and microaggregates were isolated by size and density fractionation scheme. Sodium iodide solution of density 1.6 g cm^{-3} was used for density flotation and 0.5% sodium hexametaphosphate was used to completely disperse the soil aggregates. The isolated physical SOC fractions were light fraction (<1.6 g cm^{-3}), coarse particulate organic carbon (>250 μm), fine particulate organic carbon (53-250 μm) and mineral associated organic carbon (<53 μm). The stable SOC was determined by oxidation of SOC associated <53 μm fractions of

macroaggregates and microaggregates and <53 μm fraction isolated using wet sieving with 10% hydrogen peroxide. Basal respiration rate, sizes of active and slow SOC pools and mean residence time of SOC in macroaggregates, microaggregates and <53 μm fraction were estimated by incubation experiments. A solid state ^{13}C NMR technique was employed to investigate the chemical structure and degree of decomposition of SOC associated with various aggregate sizes. Evaluation of pore geometry (i.e. porosity, pore size distribution, pore connectivity, fractal and spectral dimensions) of macroaggregates and microaggregates was performed by high resolution X-ray computed tomography. The mean residence time of SOC in soil aggregates was investigated by measuring the post-bomb radiocarbon signature with accelerated mass spectroscopy.

In Alfisols, fine particulate organic carbon in macroaggregates and microaggregates stored 8-31% of aggregate associated organic carbon. The mineral associated SOC comprised 30-59% of aggregate associated carbon. The content of fine particulate organic carbon and mineral associated organic carbon was significantly higher in microaggregates than that of macroaggregates. However, percent water stable aggregates did not have a statistical significant relationship with fine particulate organic carbon and mineral associated organic carbon. The basal respiration rate of SOC associated with <53 μm fraction was significantly lower compared to macroaggregates and microaggregates. Moreover, the mean residence time of SOC in <53 μm fraction was significantly longer than that of macroaggregates and microaggregates. The similar mean residence time of macroaggregates and microaggregates measured by an incubation study was also supported by its measurement by radiocarbon signature. Moreover, stable SOC concentration associated with <53 μm fraction of macroaggregates and microaggregates was significantly higher than <53 μm fraction isolated by wet sieving. The ratio of alkyl/O-alkyl carbon determined by solid state ^{13}C NMR was an index of degree of decomposition of SOC, and was higher in microaggregates than in macroaggregates. It was also observed by solid state ^{13}C NMR that the degree of decomposition increased from light fraction to mineral associated SOC. Evaluation of pore geometry suggested that the porosity and pore connectivity of macroaggregates were significantly higher than those of microaggregates. The 3D images of macroaggregates also indicated the presence of microaggregates inside macroaggregates which corroborated the findings of similar mean residence time of both aggregates. The X-ray microtomography observed pores in both macroaggregates and microaggregates were sufficiently large to be accessible to microbes. However, the estimated pore size distribution suggested that low pore

connectivity might create constraints for SOC decomposition inside macroaggregates and microaggregates. Among the land uses water stable aggregates and fine particulate organic carbon significantly decreased in crop-pasture rotation compared to native pasture and woodland. The mean residence time was significantly longer under crop-pasture rotation and woodland compared to native pasture. In summary, the long mean residence time and high stable SOC content of mineral associated SOC indicated the significance of physico-chemical protection for long term SOC stabilization. Moreover, fine particulate organic carbon became physically protected due to low pore connectivity and accumulation of alkyl carbon in microaggregates.

In Oxisols, on average >60% of SOC was associated with mineral particles and mineral associated SOC had a significant positive relationship with aggregate stability. Fine particulate organic carbon comprised about 8% of aggregate associated SOC of macroaggregates and microaggregates. The basal respiration rate did not vary significantly in macroaggregates, microaggregates and <53 μm fractions. But this finding was not supported by mean residence time measured by radiocarbon. The mean residence time of SOC in macroaggregates measured by radiocarbon technique was longer compared to that of microaggregates. The 3D images of Oxisols showed that microaggregates could occur in macroaggregates and microaggregates could additionally have a distinct microstructure inside it. The porosity and pore connectivity were significantly higher in microaggregates compared to macroaggregates. The decomposition of fine particulate organic carbon might alter the pore geometry of aggregates. Among the land uses mineral associated carbon was significantly lower under cropping and forest compared to improved pasture. The findings of the current study suggest that in Oxisols adsorption of SOC and Fe/Al oxides on mineral particles was responsible for SOC stabilization.

List of Publications from this thesis

Journal Articles

- Sheikh Mohammad Fazle Rabbi, Brian R. Wilson, Peter V. Lockwood, Heiko Daniel, Iain M. Young. 2012. Storage of soil organic carbon in aggregates and size-density fractions under contrasting land uses. Paper to be submitted to *Australian Journal of Soil Research*
- Sheikh Mohammad Fazle Rabbi, Brian R. Wilson, Peter V. Lockwood, Heiko Daniel, Iain M. Young. 2012. Biological and chemical carbon pools of soil aggregates under contrasting land uses. Paper to be submitted to *Soil Biology & Biochemistry*
- Sheikh Mohammad Fazle Rabbi, Rasmus Linser, James M. Hook, Brian R. Wilson, Peter V. Lockwood, Heiko Daniel, Iain M. Young. 2012. Characterization of soil organic matter in aggregates and size-density fractions by solid state ^{13}C CPMAS NMR spectroscopy. Paper to be submitted to *Soil Biology & Biochemistry*
- Sheikh Mohammad Fazle Rabbi, Iain M. Young, Brian R. Wilson, Heiko Daniel, Peter V. Lockwood. 2012. 3D pore geometry of soil aggregates under contrasting land uses using X-ray computed tomography. Paper to be submitted to *Plant and Soil*
- Sheikh Mohammad Fazle Rabbi, Brian R. Wilson, Peter V. Lockwood, Heiko Daniel, Iain M. Young. 2012. Soil organic carbon fractions in aggregates under contrasting land uses in relation to pore geometry of aggregates in two Oxisols. Paper to be submitted to *Geoderma*
- Sheikh Mohammad Fazle Rabbi, Quan Hua, Heiko Daniel, Peter V. Lockwood, Brian R. Wilson, Iain M. Young. 2012. Mean residence time of soil organic carbon in aggregates under contrasting land uses based on radiocarbon measurements. Paper to be submitted to *Radiocarbon*

Conference Presentations

- Sheikh Mohammad **Fazle Rabbi**, Peter V. Lockwood and Heiko Daniel. 2010. How do microaggregates stabilize soil organic matter? Poster presented at 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia.
- Sheikh Mohammad **Fazle Rabbi**, Heiko Daniel, Peter V. Lockwood and Brian R. Wilson and Iain M. Young. 2011. Linking soil physical carbon pools, basal respiration rate and pore geometry of microaggregates under contrasting land uses. Oral

presentation at 3rd International Symposium on Soil Organic Matter, Organic matter dynamics-from soils to oceans, 11-14 July 2011, Leuven, Belgium.

Sheikh Mohammad **Fazle Rabbi**, Heiko Daniel, Peter.V. Lockwood and Brian R. Wilson and Iain M. Young. 2011. Stabilization of organic carbon in soil aggregates under contrasting land uses on the Northern Tablelands, NSW, Australia. Oral Presentation at Rural Climate Change Solutions Symposium, 3-4 May 2011, University of New England, Armidale, Australia.

Sheikh Mohammad **Fazle Rabbi**, Quan Hua, Heiko Daniel, Peter V. Lockwood, Brian R. Wilson, Iain M. Young. 2012. Turnover times of soil organic carbon in aggregates based on radiocarbon measurements. Submitted to Joint Soil Science Australia and New Zealand Soil Science Conference, 2-7 December, 2012, Hobart, Tasmania, Australia

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