Biosolids Application and Soil Organic Carbon Dynamics: A Meta-Analysis

Wijesekara.H[1], Colyvas.K[2], Bolan.N[3], Seshadri.B[4], Ok.Y[5], Awad.Y[6], Surapaneni.A[7], Saint.C[8], Kumarathilaka.P[9], Vithanage.M[10]

[1,3,4]Global Centre for Environmental Remediation (GCER), Advanced Technology Centre, Faculty of Science and IT, the University of Newcastle, Callaghan, NSW, Australia.

[2]School of Mathematical and Physical Sciences, Faculty of Science and IT, The University of Newcastle, Callaghan, NSW, Australia.

[5,6]Korea Biochar Research Centre, Kangwon National University, Chuncheon, South Korea

[7]South East Water, 20 Corporate Drive, Heatherton, Victoria, Australia.

[8]Natural & Built Environments Research Centre (NBERC), University of South Australia, Mawson Lakes, Australia.

[9,10]National Institute of Fundamental Studies, Kandy, Sri Lanka

Abstract

Soil carbon sequestration has been recognized as a potential “direct action” tool in mitigating climate change. Organic matter rich biosolids from wastewater industry has been applied to soils as one of the strategies to the carbon sequestration. However, most of the short- and long-term studies as influenced by land application of biosolids have been showed quite inconsistent results in carbon increments in soils. Therefore, soil carbon sequestration resulted by biosolids application is yet to be needed further studies to elucidate. This study presents a comprehensive Meta-Analysis (MA) on soil carbon sequestration as influenced by biosolids application. Datasets comprised with 175 independent paired-treatments across 25 countries were fed in to Comprehensive Meta-Analysis (version 3) programme and modelled. The MA compared Soil Organic Carbon (SOC as g/kg) changes as the functions of time after biosolids application and its rate over twelve groups under two categories: application age (time after application) as <1, 1-3, 3-5, 5-8, 8-11, >11 year, and cumulative application rate as <1-50, 51-100, 101-150, 151-200, 201-250, >251 tonnes/ha.The fixed model is applied to explicate overall effects of analysed data derived from the MA. The MA showed overall positive influences on soil carbon sequestration towards increasing SOC. For example, the highest effect on SOC was observed at 1-3 age group suggesting the need of short term biosolids application to develop carbon storage in soils. Overall, this study shows that land application of biosolids can be used to increase soil carbon storage and therefore has the potential to be a strategy for mitigating climate change towards carbon sequestration in soils.

Keywords: biosolids; soil carbon sequestration; ecosystem services; meta-analysis; climate change mitigation

Introduction

The organic matter- and essential nutrient-rich biosolids, derived from sewage treatment processes, can be used to enhance the physical, chemical, and biological properties of soils, thereby improving soil health. Over the past four decades, biosolids have been extensively used in agriculture, forestry, land reclamation and revegetation (Wijesekara et al., 2016a).

Restoring ecosystem services such as food and energy production, water purification, nutrient cycling and carbon sequestration are also associated with biosolids, indicating the indirect benefits of their land application (Wijesekara et al., 2016b).

The soil organic carbon (SOC) sequestration by land application of biosolids has been identified as one of the potential strategies in mitigating climate change. Therefore, this strategy has gained significant attention in soil resource management practises. However, most of the short- and long-term studies as influenced by land application of biosolids have shown quite inconsistent results in soil carbon increments (Jin et al., 2011, Tian et al., 2014). For instance, most of the short- and long-term studies showed relatively low (approximately <7 %) increment of SOC in biosolids applied soils. Further, decreased SOC has also been reported following cessation of biosolids land application. The factors such as land management practises, climatic region, and soil and biosolids properties are likely to influence these inconsistent outcomes. Therefore, further investigations are needed to understand the factors affecting the long term carbon sequestering in soils treated with biosolids. The Meta-analysis (MA) approach has been used as one of the best statistical approaches to quantitatively compare results derived from a range of studies based on different experimental variables (Borenstein et al., 2009). Hence, in this study, MA has been conducted to quantify the effects of land application of biosolids on selected SOC characteristics.

Highlights

- Datasets of 175 independent paired-treatments across 25 countries have been modeled
- Comprehensive Meta-Analysis (version 3) programme has been applied
- Meta-Analysis has been used to compare the SOC changes over twelve groups
- Results indicated that short term application of biosolids resulted in the highest SOC
- 201-250 tonne ha^{-1} group reflected the appropriate rate for biosolids application

Methodology

Articles were collected from Google Scholar, ISI Web of Science, Science Direct, SCOPUS, and Springer Link. Search term “biosolids AND carbon sequestration” showed 63 publications in SCOPUS at the cut-off date of 15 August 2016. Both laboratory pot and field experiments comprised of quantitative results were recorded to maximise the number of studies. Therefore, studies that did not report quantitative results were excluded from the MA. Corresponding authors were contacted whenever additional information such as standard deviations wee needed. To obtain more data (i.e., unpublished data) thereby reducing bias, steps such as contacting lead researchers on the topic of land application of biosolids and use of grey literature were also performed. Datasets comprised of 175 independent paired-treatments across 25 countries were collected. The overall structure of the MA is shown in Fig. 1. Data were required to group before the MA could be conducted, aiming for maximal in-group homogenisation. Accordingly, data were formed into 12 groups under two categories a) application age (time after application) as <1, 1-3, 3-5, 5-8, 8-11, >11 year, and b) cumulative application rate as <1-50, 51-100, 101-150, 151-200, 201-250, >251 tonnes ha^{-1}.

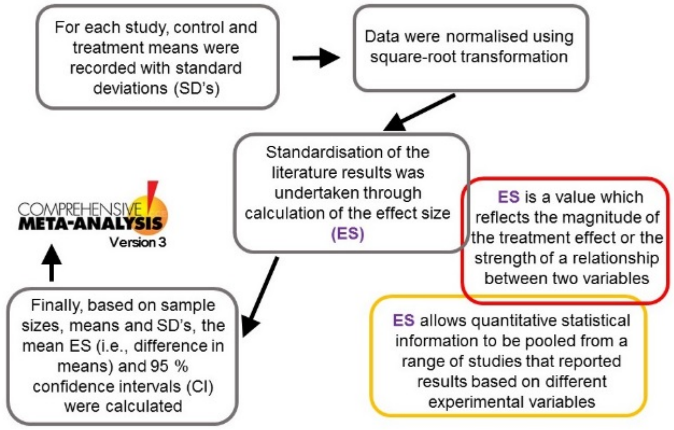

Fig. 1. The overall structure of the Meta-Analysis.

The mean differences (i.e., difference between control and treatment) were calculated as the effect sizes (ES's) in each group to understand the magnitude of the treatment effects. The Fixed model is used to explicate data derived from the MA.

Results

The MA showed overall positive influences of biosolid application on soil carbon sequestration towards increasing SOC.

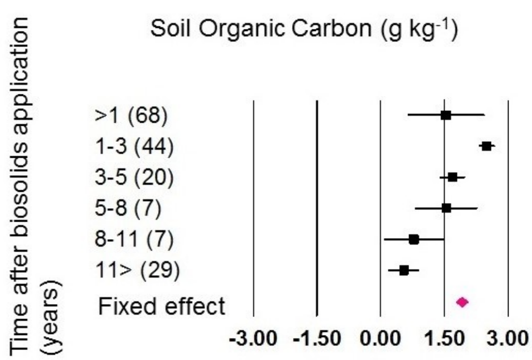

Figure 2 : Mean differences in SOC concentration as influenced by biosolids application:Effect of time. Numbers of observations in y axis are indicated in parentheses and mean differences are indicated in 95 % confidence intervals.

Figure 2 : shows that the short term (i.e., 1-3 year group) application of biosolids resulted in highest SOC content of 2.5 g kg^{-1} ($p<0.05$). A negative correlation between increasing time after biosolids application and SOC storage was also observed. The lowest SOC content was recorded in the long term (i.e., 11> year) group, possibly suggesting enhanced mineralization of organic matter with time. Overall impact of time after biosolids application can be identified from the fixed modeled value. The observed fixed effect of around 2 g kg^{-1} ($p<0.05$) suggests feasibility in increasing soil carbon by land application of biosolids.

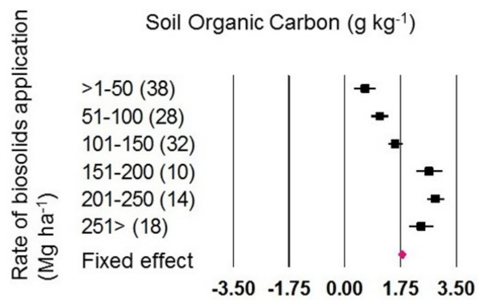

Figure 3 : Mean differences in soc concentration as influenced by biosolids application: Effect of application rate. Numbers of observations in y axis are indicated in parentheses and mean differences are indicated in 95 % confidence intervals.

Figure 3 reflects the rate of biosolids application on SOC storage. The highest mean difference for SOC content of 2.8 g kg^{-1} ($p<0.05$) observed at 201-250 tonne/ha group reflecting the appropriate cumulative rate for application of biosolids for most of the soil types analysed in this study. This observation from use of high rate of biosolids application reflects the potential application in mine site rehabilitation, thereby enhancing soil health and carbon sequestration. Up-to 201-250 Mg ha^{-1} group, a positive correlation was observed between increasing the rate of biosolids application and SOC contents. The highest application rate (i.e., 251> Mg ha^{-1}) showed a slightly decreased carbon storage value than the 201-250 Mg ha^{-1} group, reflecting possible leaching of organic matter with high dose treatments. The observed fixed model value of around 1.8 g kg^{-1} ($p<0.05$) for tested biosolids application rates sugests the positive impact of biosolids in carbon sequestration.

Conclusions

Based on the performed Meta-Analysis of sample literature, relatively small but statistically significant observations were identified towards soil carbon sequestration by application of biosolids. Therefore, land application of biosolids can be identified as a possible strategy to enhance carbon sequestration in soils. This analysis should be expanded to understand the different characteristics of soil (i.e., soil type and their management practices) and biosolids (i.e., impact of stabilization methods: co-composting, alkaline treatment; effect of aged and fresh biosolids, chemical composition) in carbon sequestration in soils.

Acknowledgment

We acknowledge the authors of the research articles and reports from extensive field work studies used for this study. Many authors were contacted and delivered additional data for our database.This study is one of the outcomes of the research project on “Carbon sequestration from land application of biosolids.”We thank South East Water (Dr. Aravind Surapaneni), Western Water (William Rajendran), Gippsland Water (Mark Heffernan), City West Water (Sean Hanrahan), Yarra Valley Water (Andrew Schunke), and Transpacific Industries (Chris Hetherington) for supporting this research project.

References

Borenstein, M., Hedges, LV., Higgins, J., Rothstein, H.R. (2009). Introduction to Meta-Analysis. Cornwall: Wiley & Sons.

Jin, V. L., Johnson, M.V., Haney, R.L., Arnold, J.G. (2011). Potential carbon and nitrogen mineralization in soils from a perennial forage production system amended with class B biosolids. Agriculture, ecosystems & environment. 141(3–4), 461-465.

Tian, G., Chiu, C-H., Franzluebbers, A.J, Oladeji. O.O., Granato, T.C., Cox, A.E. (2015). Biosolids amendment dramatically increases sequestration of crop residue-carbon in agricultural soils in western Illinois. Applied Soil Ecology, 85(0), 86-9.

Wijesekara, H., Bolan, N.S., Kumarathilaka, P., Geekiyanage, N., Kunhikrishnan, A., Seshadri, B. et al. (2016). Biosolids enhances mine site rehabilitation and revegetation. In M.N.V. Prasad, Kaimin Shih (Eds.), Environmental materials and waste - resource recovery and pollution prevention, Elsevier, Academic press (in press)

Wijesekara, H., Bolan, N.S., Vithanage, M., Xu, Y., Mandal, S., Brown, S.L. et al. (2016). Utilization of biowaste for mine spoil rehabilitation. Advances in Agronomy. 138(0), 97-173.