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Carbon storage in a heavy clay soil landfill site after biosolid application

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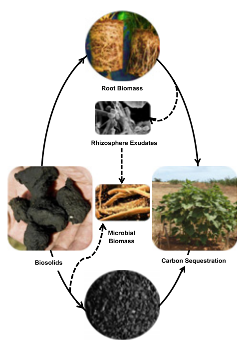
HIGHLIGHTS

- ► Comparison of decomposition rate amongst various organic amendments including biosolid, compost and biochar.
- ► Iron and aluminium contents influence the decomposition of biosolid in soils.
- ► Quantification of biosolid-induced C sequestration in soils under field condition.
- ► Biosolid increases C storage through direct supply of organic matter and indirectly by increasing root biomass.

GRAPHICAL ABSTRACT

Biosolid application enhances carbon sequestration through biomass production and accumulation of residual carbon.



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ABSTRACT

Applying organic amendments including biosolids and composts to agricultural land could increase carbon (C) storage in soils and contribute significantly to the reduction of greenhouse gas emissions. Although a number of studies have examined the potential value of biosolids as a soil conditioner and nutrient source, there has been only limited work on the impact of biosolid application on C sequestration in soils. The objective of this study was to examine the potential value of biosolids in C sequestration in soils. Two types of experiments were conducted to examine the effect of biosolid application on C sequestration. In the first laboratory incubation experiment, the rate of decomposition of a range of biosolid samples was compared with other organic amendments including composts and biochars. In the second field experiment, the effect of biosolids on the growth of two bioenergy crops, *Brassica juncea* (Indian mustard) and *Helianthus annuus* (sunflower) on a landfill site was examined in relation to biomass production and C sequestration. The rate of decomposition varied amongst the organic amendments, and followed: composts > biosolids > biochar. There was a hundred fold difference in the rate of decomposition between biochar and other organic amendments. The rate of decomposition of biosolids decreased with increasing iron (Fe) and aluminum (Al) contents of biosolids. Biosolid application increased the dry matter yield of both plant species (by 2–2.5 fold), thereby increasing the biomass C input to soils. The rate of net C sequestration resulting from biosolid application (Mg C ha^{-1} yr^{-1} Mg^{-1} biosolids) was higher for mustard (0.103) than sunflower (0.087). Biosolid application is likely to result in a higher level of C sequestration when compared to other management strategies including fertilizer application and conservation tillage, which is attributed to increased microbial biomass, and Fe and Al oxide-induced immobilization of C.

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1. Introduction

Global warming is a critical environmental issue of the 21st century and the carbon (C) cycle plays a major role both in the cause and mitigation of the global climate change (Scholes and Noble, 2001). Recent concerns over increased atmospheric carbon-dioxide (CO_2) have increased interest in the investigation of soil organic C (SOC) changes and C sequestration capacity in various ecosystems (Bandaranayake et al., 2003). Promoting soil C sequestration is considered as an effective strategy for reducing greenhouse gas (GHG) emissions including atmospheric CO_2 (IPCC, 2006; Lal, 2008). Indeed, soil C sequestration is an important option not only to mitigate climate change but also to enhance soil fertility and the productivity of agroecosystems (Manlay et al., 2007).

Carbon can accumulate in the soil due to increased inputs or reduced losses or a combination of both. Two major mechanisms, (bio)chemical alteration and physicochemical protection stabilise SOC, and thereby control its turnover (Jastrow et al., 2007). In addition to increasing plant C inputs, strategies for increasing C sequestration in soils include minimizing cultivation and other soil disturbances through conservation tillage, application of organic wastes such as biosolids and composts, and improved crop rotation involving cover crops (Jastrow et al., 2007; Lal, 2008). However, the value of these potential climate-change mitigation measures is negated by the fact that intensive farming practices generally lead to the depletion of C from soil, thus reducing its capacity to act as a C sink (Smith et al., 2008).

Municipalities around the world generate two major sources of organic wastes that include municipal solid wastes comprising garden and urban green wastes, and biosolids (often referred to as sewage sludge). Large quantities of biosolids, ranging from approximately 0.07×10^6 Mg yr^{-1} in Australia to 7.5×10^6 Mg yr^{-1} in the USA are generated from wastewater treatment plants (Park et al., 2011). Biosolids have the potential for being recycled on agricultural and degraded lands, and land application of biosolids is considered as an integrated approach to sustainable management of this waste resource. Applying organic wastes including biosolids and composts to agricultural land could contribute to both restoring soil quality and sequestering C in soils, thereby reducing GHG emission (Haynes et al., 2009). Although biosolids are re-used for beneficial purposes such as land application, contaminated site reclamation, and energy production in a number of countries including Australia, Europe and North America (LeBlanc et al., 2008), unfortunately, a substantial proportion of biosolids are not used mainly due to local public opposition and potential hazards, and are disposed of in landfills (NEBRA, 2011).

Optimum use of these by-products requires knowledge of their composition not only in relation to beneficial uses but also to environmental implications. Environmental concerns associated with the land application of biosolids encompass all aspects of non-point source pollution that include increased metal(loid)s input, contamination of surface water with soluble and particulate phosphorus (P), leaching losses of nitrogen (N) in subsurface drainage and to groundwater, and reduced air quality by emission of volatile organic compounds (Pritchard et al., 2010). Thus, maintaining the quality of the environment is a major consideration when developing management practices to effectively use biosolids as a nutrient and C resource, and soil conditioner in agricultural production system. Although a number of studies have examined the potential value of biosolids as a nutrient source, there has been only limited work on the impact of biosolids application on C sequestration in soils (Haynes et al., 2009; Tian et al., 2009; Table 1).

While landfilling provides an economic means of waste disposal, if not managed properly, it can lead to environmental degradation by releasing various contaminants. The major environmental challenges associated with the sustainable management of landfills are the surface and ground water contamination, and GHG and odor emissions (Albright et al., 2006). Contamination of surface and ground water by landfill leachate, which is enriched with a range of inorganic and organic contaminants, is widespread in many landfill sites and can

Table 1
Selected references on the effect of organic amendments on carbon sequestration.

Organic amendment	Application rate	Carbon sequestration	Reference
Biosolids	455–1654 Mg ha^{-1} for 8–23 years	Carbon sequestration for biosolid amended soils: 0.54 − 3.05 Mg C ha^{-1} yr^{-1}; for unamended soil: −0.07–0.17 Mg C^{-1} ha^{-1} yr^{-1}	Tian et al. (2009)
Pig manure	7.5–22.5 Mg ha^{-1} yr^{-1} for 10 years	Soil organic C was increased by 12.5–18.2%	Ding et al. (2012)
Horse manure	7 Mg ha^{-1} yr^{-1} for 20 years	Carbon sequestration for manure alone: 8.9 Mg ha^{-1}; manure plus fertilizers: 9.2 Mg ha^{-1}	Lou et al. (2011)
Farm yard manure	7.5 Mg ha^{-1} for 25 years	26.1% of C applied was sequestered in continuous cultivation. In unamended soils, total depletion of C by 39% was observed.	Ghosh et al. (2012)
Cow manure	10 Mg ha^{-1} for 5 years	Soil organic C sequestration rate ranged from 2.52 to 2.84 Mg ha^{-1} yr^{-1} for the 0–15 cm depth	Shrestha et al. (2009)
Cattle manure	5–25 Mg ha^{-1} cattle manure + 0.1 Mg N ha^{-1} for 7 years	Soil organic C in soils increased from 0.8% in control soils to 2.6, 3.2 and 3.5%, respectively in 5, 15 and 25 Mg ha^{-1} of cattle manure-applied soils	Dunjana et al. (2012)
Cattle manure, Spent mushroom compost	Cattle manure (20 Mg ha^{-1} yr^{-1}); spent mushroom compost (16 Mg ha^{-1} yr^{-1}) for 28 years	Cattle manure or spent mushroom compost resulted in high C sequestration (30 Mg ha^{-1}). However, the use of a low nutrient-organic material was recommended, to avoid an increased risk of N leaching	Morlat and Chaussod (2008)
Poultry litter	0.1–0.2 Mg N ha^{-1} for 10 years	Carbon sequestration rate over the 10-year period amounted to 0.51 Mg ha^{-1} yr^{-1} with poultry litter and −120–147 Mg ha^{-1} yr^{-1} with mineral fertilizer (NH_4NO_3)	Sainju et al. (2008)
Poultry litter	0.1 Mg N ha^{-1} for 3 years	Poultry litter with no-till reduced soil CO_2 emissions by 27 and 25% respectively, compared with conventional and mulch tillage	Roberson et al. (2008)
Poultry and cattle manures	10 Mg ha^{-1} for 10 years	Soil organic matter increased from 0.46 to 2.8 and 1.1% in poultry- and cattle manures-applied soils.	Bakayoko et al. (2009)
Beef cattle manure	0–180 Mg ha^{-1} yr^{-1} for 32 years	Manure application (0, 60, 120 and 180 Mg ha^{-1} yr^{-1}) showed no additional C sequestration for application rates beyond 120 Mg ha^{-1} yr^{-1} indicating C saturation in SOC pools	Gulde et al. (2008)