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The impact of biosolids application on organic carbon and carbon dioxide fluxes in soil

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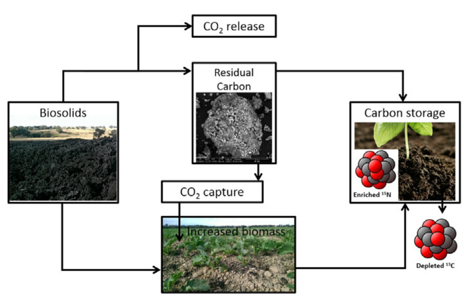
HIGHLIGHTS

- Increased non-labile and labile soil organic carbon under biosolids amended soils.
- Depleted $\delta^{13}C$ in biosolids amended soils showed the residual carbon contribution to soils.
- Application of biosolids caused enriched $\delta^{15}N$ in soils.
- Enhanced CO_2 emission observed under biosolids land application.
- Storing biosolids carbon in soils for a longer period is a challenge.

GRAPHICAL ABSTRACT



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ABSTRACT

A field study was conducted on two texturally different soils to determine the influences of biosolids application on selected soil chemical properties and carbon dioxide fluxes. Two sites, located in Manildra (clay loam) and Grenfell (sandy loam), in Australia, were treated at a single level of 70 Mg ha^{-1} biosolids. Soil samples were analyzed for SOC fractions, including total organic carbon (TOC), labile, and non-labile carbon contents. The natural abundances of soil $\delta^{13}C$ and $\delta^{15}N$ were measured as isotopic tracers to fingerprint carbon derived from biosolids. An automated soil respirometer was used to measure in-situ diurnal CO_2 fluxes, soil moisture, and temperature. Application of biosolids increased the surface (0 −15 cm) soil TOC by > 45% at both sites, which was attributed to the direct contribution from residual carbon in the biosolids and also from the increased biomass production. At both sites application of biosolids increased the non-labile carbon fraction that is stable against microbial decomposition, which indicated the soil carbon sequestration potential of biosolids. Soils amended with biosolids showed depleted $\delta^{13}C$, and enriched $\delta^{15}N$ indicating the accumulation of biosolids residual carbon in soils. The in-

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Soil δ^{13}C
Soil δ^{15}N

situ respirometer data demonstrated enhanced CO_2 fluxes at the sites treated with biosolids, indicating limited carbon sequestration potential. However, addition of biosolids on both the clay loam and sandy loam soils found to be effective in building SOC than reducing it. Soil temperature and CO_2 fluxes, indicating that temperature was more important for microbial degradation of carbon in biosolids than soil moisture.

1. Introduction

Sustainable strategies for overcoming anthropogenic climate change are needed. Increasing carbon storage capacity (i.e., carbon sequestration) in soils can increase sustainability. For the first time, the 21st Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP21) held in 2015 emphasised the importance of soil organic carbon (SOC) in mitigating climate change. At this conference, the French Agriculture Ministry proposed idea of "4 per Thousand", which has the goal of enhancing SOC at the 0–40 cm depth in world soils at the rate of 0.4% per year (Four per thosand, 2015). This strategy identifies soil as a sink for atmospheric CO_2 through SOC sequestration which is promoted by using recommended carbon management practices (RCMP) including conservation agriculture, mulch farming, agroforestry, and addition of biochar, manure, compost, and biosolids (Lal, 2016). Globally, it has been suggested that, through the adaption of RCMP, the annual rate for SOC sequestration could be 0.4–1.2 gigatons of carbon or 5–15% of the global fossil-fuel emission (Lal, 2004). Among these practices, application of biosolids has increasingly been used to improve soil health and increase soil carbon sequestration (Brown et al., 2011; Cogger et al., 2013).

Biosolids are a stabilised organic solid derived from sewage treatment processes. Currently, around 10×10^7 tons year^{-1} of biosolids are generated worldwide, and it is projected that 17.5×10^7 tons year^{-1} will be generated in 2050 (Wijesekara et al., 2016). Because they are a good source of organic matter and essential nutrients, biosolids are used to enhance the physical, chemical, and biological properties of soils, thereby improving soil health. Over the past four decades, they have been used extensively in agriculture, forestry, land reclamation and revegetation (Sopper, 1992; Tian et al., 2006; Kajitvichyanukul et al., 2008; Lamb et al., 2012; Brown et al., 2014; Torri et al., 2014). They provide ecosystem services such as food and energy production, water purification, nutrient cycling, and carbon sequestration, which represent the indirect benefits of applying them to land (Larney and Angers, 2012; Bolan et al., 2013; Chowdhury et al., 2016). Advances in treatment and management of sewage wastewater have resulted in a steady decline in metal content and pathogens in biosolids and a reduction of air pollution through greenhouse gases (GHGs) and volatile gases abatement.

Addition of biosolids to soil can enhance SOC sequestration through direct input of organic matter and increased crop rhizodeposition (Table 1). Experimental results relating to carbon in soil treated with biosolids are variable and depend on factors such as the experimental method and set-up, the climatic region, and the properties of the soil and biosolids. Supporting the positive linear relationship between rate and carbon accumulation, in many case studies a significantly higher soil carbon sequestration has been reported with high application rates of biosolids (Tian et al., 2009; Gardner et al., 2010). Leaching and mineralization of organic matter can cause depletion of the carbon content in soils (Toribio and Romanya, 2006; Schwab et al., 2007). Decreased SOC has been reported following cessation of biosolids land application (Li et al., 2013). Microbial degradation of biosolids has been identified as a major cause limiting carbon sequestration in soils, because it releases GHGs. Microbial induced GHG emissions occur during the life cycle of biosolids from their stockpiles to land application. Direct emission of GHGs from biosolids stockpiles has been examined in Melbourne, Australia (Majumder et al., 2014). In this study, the youngest (<1 years), those aged between 1 and 3 years, and the oldest (>3 years) released 60, 29, and ~10 kg of CO_2 equivalents per Mg (one megagram (Mg) equals a metric ton) of biosolids per year, respectively. Enhanced GHGs have been reported in many case studies (Ros et al., 2006; Mar Montiel-Rozas et al., 2015; Pitombo et al., 2015). Different authors have put forth contrasting conclusions to explain the higher CO_2 fluxes in the biosolids-soil environment. For example, a long-term study showed that addition of biosolids changed the soil biota community composition, thereby resulting in a higher basal respiration and metabolic quotient (Ros et al., 2006). Pitombo et al. (2015) concluded that soil CO_2 flux was highly responsive to soil temperature in treatments with biosolids, while Mar Montiel-Rozas et al. (2015) showed that soil moisture content negatively affected carbon escape from biosolids treated soils. However, the relationship between the application of biosolids and carbon retention or CO_2 fluxes, specifically focussing soil texture, has not been studied in detail. Therefore, the objectives of this study were (a) to estimate the CO_2 flux, and (b) to quantify the SOC contents, and its fractions in two texturally different agricultural soils, as influenced by application of biosolids.

2. Materials and methods

2.1. Site description

The experimental field sites were located in the Central West part of New South Wales, Australia. The Manildra (33° 9′ 44. 2512″ S and 148° 40′ 36.2064″ E) and Grenfell (33° 56′ 31. 5924″ S and 148° 2' 15.72" E) sites featured a hot, dry summer and cool winter, with the mean annual maximum and minimum temperatures of ~22.5 and ~9.5 °C, respectively and mean annual rainfall of ~624 mm. The soils in the Manildra and Grenfell sites are classified as Red Chromosol (i.e., also known as red brown earths or red podzolic soils) with a clay loam texture, and Brown Chromosol with a sandy loam texture, respectively, according to the Australian Soil Classification (Isbell, 2002). The properties of soils at the 0–15 cm depth, and site information are given in Table 2.

2.2. Experimental design

The two experimental sites were limited to two treatments: biosolids amended and unamended (control). At both sites, a single level of 70 Mg ha^{-1} biosolids was applied by the horizontal disc rear discharge spreaders and incorporated into surface soils (i.e., to the 15 cm depth) using chisel ploughs. The biosolids were produced through aerobic and anaerobic digestion processes at two sewage