1 Composition and Cycling of Organic Carbon in Soil

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1.1
Introduction

Soil organic carbon (SOC) represents a significant reservoir of carbon within the global carbon cycle that has been estimated to account for 1,200–1,550 Pg C to a depth of 1 m and for 2370–2450 Pg C to a depth of 2 m (Eswaran et al. 1995; Lal 2004a). Comparative estimates of organic C contained in living biomass (560 Pg) and atmospheric CO_2-C (760 Pg) (Lal 2004a) indicate that variations in the size of the SOC store could significantly alter atmospheric CO_2-C concentrations. A 5% shift in the amount of SOC stored in the 0–2 m soil profile has the potential to alter atmospheric CO_2-C by up to 16%.

Land-use change can induce emission or sequestration of carbon depending on a range of soil and environmental properties and land management practices. Carbon sequestration in soils is a slow process but may offer the most efficient natural strategy for offsetting increased atmospheric CO_2-C concentrations induced by fossil fuel burning and conversion of natural terrestrial systems to agriculture (Lal 2004a; Metting et al. 1999; Post et al. 1999). It has been suggested that, over the next century, improved land management strategies could sequester up to 150 Pg CO_2-C (Houghton 1995; Lal 2004b; Lal et al. 1998); however, considerable uncertainty exists in such estimates because of an inability to accurately predict the total carbon sequestration potential of soils. Improving our understanding of SOC cycling processes and how these are affected by land management practices will be important to defining future opportunities for carbon sequestration in soils.

In addition to its importance in the global carbon cycle, SOC contributes positively to a range of biological, physical and chemical properties important to defining the potential productivity of a soil (Baldock and Skjemstad 1999;

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Reeves 1997). SOC provides the energy essential to biological processes and, when considered in combination with its associated nutrients (N, P and S), can contribute to the resilience of soil/plant systems. Soil physical properties influenced by SOC content include soil structural form and stability, water retention, and thermal properties. SOC also contributes to defining the cation exchange and buffer capacities of soils. The amount and form of SOC required to make significant contributions to these soil properties varies with the property being considered and the soil type (Baldock and Skjemstad 1999). For example, more carbon may be required to maintain the structural stability of a sandy-loam soil than in a self-mulching clay, yet in terms of provision of energy or nutrient mineralisation, more SOC may be required in the clay-rich soil. Likewise, pieces of plant debris with a high C/N ratio (>40) are likely to have a different effect on net nutrient mineralisation during decomposition processes than well decomposed materials with a low C/N ratio (<40).

Understanding the dynamics of SOC, both in its entirety and its various components, and the influence of environmental and soil properties is essential to adequately characterise the effects of management and land use on fluxes of carbon and soil productivity. In this chapter, the composition of SOC and the factors that define the biological stability and cycling of SOC will be examined. Given this scope, it would not be possible to present an exhaustive review of all relevant studies. Instead, the objective of this chapter was to identify the major soil and environmental properties and processes that influence SOC cycling and provide references that can act as a starting point for further exploration of the concepts presented.

1.2
Composition of Soil Organic Carbon

SOC exists as a heterogeneous mixture of a wide range of organic materials, including individual simple molecules (amino acids, monomeric sugars, etc.), polymeric molecules (e.g. cellulose, protein, lignin, etc.), and pieces of plant and microbial residues composed of a mixture of simple and polymeric molecules bound together into recognisable cellular structures. Plant and microbial residues represent the major parent material from which SOC is formed. The chemical composition of these residues has been reviewed by Kögel-Knabner (2002). Each molecular form of SOC can exist along a continuum from fresh unaltered materials through to materials whose chemical composition has been significantly altered by decomposition processes. In this chapter the term SOC is hereafter used to refer to the entire organic fraction of soils, and various SOC components are defined as delineated by Baldock and Nelson (2000).

Given the compositional variability of SOC, different components of SOC will accumulate or be lost at different rates depending on their accessibility to

decomposition and/or biological stabilisation. Changes in SOC content with time therefore represent the weighted average change in contents of all SOC components. Radiocarbon dating (e.g. Anderson and Paul 1984) and isotopic labelling (e.g. Ladd et al. 1981) experiments clearly demonstrated that different components of SOC turn over at different rates. A variety of chemical and physical fractionation procedures has been developed in an attempt to isolate and characterise relatively "homogeneous" fractions of SOC that exhibit different biological stability.

1.2.1
Chemical Fractionation of SOC

Early attempts at fractionating SOC were chemically based and involved the use of alkaline extraction followed by acidic precipitation (Muller 1887). This fractionation scheme continues to be used to partition SOC into fractions referred to as humic acids, fulvic acids and humin on the basis of solubility in alkaline and then acidic solutions. Radiocarbon dating of SOC in a chernozem revealed that humin and humic acid fractions were older and the fulvic acid fraction was younger than intact SOC (Campbell et al. 1967). Given the mode of extraction and isolation of humic materials from soil and the potential for a variety of inter- and intra-molecular interactions to occur after acidifying alkaline extraction solutions, the probability of mixing older and younger organic species during extraction is high, and complete segregation on an age basis can not be expected.

A second form of chemical fractionation uses various extraction or degradative methodologies considered to be "selective" for given molecular components. Such methodologies are used to identify fractions of SOC with different susceptibilities towards mineralisation based on differences in chemical recalcitrance. Hydrolysis with 6 M HCl or methanesulfonic acid can be used to quantify the proportion of SOC associated with proteins, amino acids and amino sugars (Appuhn et al. 2004; Friedel and Scheller 2002; Martens and Loeffelmann 2003). Hydrolysis with sulphuric acid has been used to quantify the fraction of SOC attributable to carbohydrate structures (Martens and Loeffelmann 2002; Rovira and Vallejo 2000). The proportion of lignin in SOC has been quantified using a variety of methods that attempt to either isolate the intact lignin molecule (Tuomela et al. 2000) or quantify the monomeric species released (Chefetz et al. 2002; Leifeld and Kögel-Knabner 2005). A range of organic solvent extraction techniques have been developed to quantify the amount of lipid and lipid-like carbon in soils (Poulenard et al. 2004; Rumpel et al. 2004).

Although these molecular extraction or degradation methods are capable of identifying relative differences between different samples of SOC, due to incomplete extraction and non-selective action, absolute quantities should be considered as approximate. This issue is well exemplified by the work of Preston et