Soil carbon characterization and nutrient ratios across land uses on two contrasting soils: Their relationships to microbial biomass and function

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ABSTRACT

Soil carbon (C) plays a central role in the global biogeochemical cycles of most major nutrients, but the degree to which the quality versus quantity of C controls microbial abundance and function across land uses is still somewhat uncertain. We measured soil organic matter (SOM) concentration and composition as well as nutrient ratios and other soil characteristics on two contrasting soil types across three land uses (forest, pasture, maize cropping), to determine their relationships to microbial abundance and specific measures of microbial activity (e.g. qCO_2, the ratio of respiration rate to microbial biomass, and net laboratory N mineralization). Although there was significant variability in bulk SOM composition (by ^{13}C NMR spectroscopy), we could detect differences between broad-leaved forest and pasture/maize systems on a landscape scale, primarily attributable to differences in aryl C content. Variability in O-alkyl C between sites correlated strongly with the soil C:N ratio, but variability in alkyl C (which was particularly evident in pasture sites) could not be adequately explained by measured environmental or soil characteristics. Soil C:P and N:P ratios followed similar patterns with forest > pasture > maize. Bulk soil C:N, hot-water extractable C:N and particulate C:N all followed similar patterns with forest > pasture ≈ maize cropping. Microbial biomass C:N followed a different pattern, however, with forest ≈ pasture > maize. Despite the differences in SOM composition and nutrient ratios, anaerobically mineralizable N and hot-water extractable C (as a measures of available C) best explained the variation in microbial biomass and function across sites. Anaerobically mineralizable N generally explained the most variation for microbial biomass and qCO_2 and had the smallest soil or land use effect. Hot-water extractable C explained the most variance for net N mineralization. Addition of stoichiometric measures and other soil attributes (e.g. soil C:N, C:P, δ^{15}N) in a multiple regression model explained more of the variation than a single factor plus the land use effect (though soil order still explained a small, but significant amount of variance for measures of microbial biomass). A measure of available C, however, was needed to explain the maximum amount of variance in microbial biomass and function across sites (i.e. total C plus nutrient status and other soil attributes could not explain as much of the variance). Our data suggest that nutrient content/stoichiometry does assist in defining the quality of SOM, but a measure of available C (similar to the "active" pool in C models) is also needed. Anaerobically mineralizable N and/or hot water–water extractable C appear to be adequate measures of available C that relate to "active" C, but C functional groups (from ^{13}C NMR spectroscopy) were not particularly useful for this purpose.

1. Introduction

Soil organic carbon (C) has been a topic of much research because of its vital importance for the overall carbon reservoir of the biosphere, and as the primary constituent of soil organic matter (SOM), which plays a central role in the global biogeochemical cycles of most major nutrients. Although there have been many studies worldwide on quantitative changes in SOM resulting from land-use change (Lal, 2000; Post and Kwon, 2000; Guo and Gifford, 2002; Murty et al., 2002; Degryze et al., 2004), there is less information on the composition of SOM across land uses, particularly on a landscape scale, and whether these changes affect the size and function of the microbial community.

While it has long been established that there is a relationship between soil C (and N) and microbial biomass, the relationship often differs between land uses or treatments (e.g. Anderson and Domsch, 1989; Wardle, 1992; Haynes, 2000). The Century model categorizes metabolic C and some forms of structural C (cellulose and hemi-cellulose) as active C (Parton et al., 1994). Several biochemical indicators or assays (hot-water extractable C and anaerobically mineralizable N) have generally shown greater correlation to microbial biomass and/or laboratory measured respiration rate than does total organic C or N (Hart et al., 1986; Sparling et al., 1998; Wang et al., 2003) suggesting that they may represent easily measurable pools of active C.

Hot-water extractable C is composed largely of carbohydrates and probably contains microbial biomass itself as well as other soluble organic constituents (Sparling et al., 1998; Ghani et al., 2003) and could be considered a pool of readily available C, while anaerobically mineralizable N possibly relates to the N mineralization of biomass killed by the anaerobic test conditions (Boone, 1990) and therefore indirectly relates to the size of the microbial biomass. For the purposes of this study, we loosely refer to measures of C that are thought to be more labile or active (and we include the anaerobically mineralizable N assay in this group as well as hot-water extractable C and POM C) as "available C". Soil nutrient stoichiometry can impart knowledge of nutrient limitation (Cleveland and Liptzin, 2007) and also may play a role in microbial abundance (Griffiths et al., 2012), but the extent to which nutrient stoichiometry effects microbial functioning (such as C metabolism) is unclear (Creamer et al., 2015).

Land use largely determines both the dominant vegetation and nutrient content of managed sites. A review by Mahieu et al. (1999) concluded that composition of SOM (i.e. humic and fulvic acid fractions) was largely similar across land uses. However, chemical characteristics of SOM under different vegetation types have been shown to differ (e.g. Golchin et al., 1997b; Condron and Newman, 1998; Quideau et al., 2001), particularly when controlled for soil type and/or particle size fraction (Baldock et al., 1992; Golchin et al., 1997a; Quideau et al., 2001). Similarly, soil type (e.g. mineralogy and clay content) affect the C saturation level of the soil and its ability to sorb organic fractions (see for instance Saidy et al., 2012; Wiesmeier et al., 2014).

Leifeld and Kögel-Knabner (2005) examined the applicability of SOM fractions as early indicators for shifts in carbon stocks caused by land-use changes in Southern Germany. The authors reported that the proportion of O-alkyl C in the clay fraction increased with SOC content, however, there was no specific land-use pattern observed. Ratios of alkyl to O-alkyl C in mineral fractions (<20 μm) differentiated samples better than the C-to-N ratios. Studies on the composition of SOM across land uses have often focused on paired site or controlled comparisons in an experimental manipulation (Hopkins et al., 1993; Mendham et al., 2002; Mueller and Köegel-Knabner, 2009; Abe et al., 2009) and few studies have focused on landscape scale variation in SOM composition. Additionally, there is little data on the variation in SOM composition at a landscape scale between contrasting soils and to what extent those differences relate to microbial biomass and function.

The overarching aim of this work was to determine if broader landscape scale relationships exist between land use, whole soil SOM composition, nutrient content/stoichiometry, and the relationship of these characteristics to microbial abundance and laboratory measures of microbial activity (specifically, qCO₂, the ratio of respiration rate to microbial biomass, and N mineralization). Specifically, we hypothesized that labile forms of C would be most highly correlated to microbial biomass and function, but other measures of SOM quality (stoichiometric ratios and ratios of C in different chemical and physical fractions) would explain additional variance associated with land use and soil type effects.

Baseline information was obtained on soil C (concentration and composition) as affected by land use on two contrasting soil types (a well-drained soil with high allophane content, and a poorly drained, non-allophanic, fine textured soil) across the Waikato region of the North Island of New Zealand. Specifically we investigated the degree to which: (1) land use (maize cropping, pasture (intensive (dairy) and extensive (drystock) pasture) and native broad-leaved forest) would have measurable effects on SOM composition and microbial abundance and functioning at a landscape scale because of differences in vegetation and nutrient inputs associated with each land use; (2) contrasting soil type would also affect the composition of SOM because of the different soil mineralogy and hydrologic regimes influencing the processing and storage of soil C and whether interactions between land use and soil type occurred; and (3) readily available forms of C were correlated to microbial biomass and function, and whether other measures of SOM quality (stoichiometric ratios and ratios of C in different chemical and physical fractions) would explain additional variance associated with land use and soil order differences.

2. Materials and methods

2.1. Site selection and soil sampling

Soils were sampled from the Waikato region of the central North Island, New Zealand (Fig. 1). Elevation and precipitation varied somewhat by site, but the region is temperate. Mean annual precipitation averages about 1200 mm yr⁻¹ for the city of Hamilton, with mean summer temperature of 18.1 °C and mean winter temperature of 11.5 °C. Summer (January through March) is generally the driest part of the year and drought conditions often occur, but the maritime influence on climate can result in significant precipitation throughout the year. Soils under four land uses (indigenous forest, extensive (drystock) pasture, intensive (dairy) pasture and maize cropping) were sampled on each of two contrasting soils, a well-drained silty textured soil with a high allophane content and a poorly drained fine textured non-allophanic soil. The two soils (New Zealand Soil Classification, Hewitt, 2010) were either Typic Orthic Allophanic Soils derived from volcanic ash (Udands − US taxonomic equivalent) or Typic Orthic Gley Soils (Aquic suborders in US taxonomic equivalent). Though generally coarser in texture than the Gley Soils, the allophane content of the Allophanic Soils results in greater chemical activity (i.e. greater cation and anion exchange capacity) than the Gley soils. Cation exchange capacity is typically in the range 25—35 cmol (+) kg⁻¹ for the Allophanic soils