The initial lignin:nitrogen ratio of litter from above and below ground sources strongly and negatively influenced decay rates of slowly decomposing litter carbon pools

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ABSTRACT

Understanding the interactions between the initial biochemical composition and subsequent decomposition of plant litter will improve our understanding of its influence on microbial substrate use to explain the flow of organic matter between soil carbon pools. We determined the effects of land use (cultivation/native woodland/native pasture), litter type (above and below ground) and their interaction on the initial biochemical composition (carbon, nitrogen, water soluble carbon, lignin, tannin and cellulose) and decomposition of litter. Litter decomposition was studied as the mineralization of C from litter by microbial respiration and was measured as CO_2-C production during 105 d of laboratory incubation with soil. A two-pool model was used to quantify C mineralization kinetics. For all litter types, the active C pool decay rate constants ranged from 0.072 d^{-1} to 0.805 d^{-1} which represented relatively short half-lives of between 1 and 10 days, implying that this pool contained compounds that were rapidly mineralized by microbes during the initial stages of incubation. Conversely, the decay rate constants for the slow C pool varied widely between litter types within and among land uses ranging from 0.002 d^{-1} and 0.019 d^{-1} representing half-lives of between 37 and 446 days. In all litter types, the initial lignin:N ratio strongly and negatively influenced the decay rate of the slow C pool which implied that the interaction between these two litter quality variables had important controls over the decomposition of the litter slow C pool. We interpret our results to suggest that where the flow of C from the active pool to the slow pool is largely driven by microbial activity in soil, the rate of transfer of C will be largely controlled by the quality of litter under different land-use systems and particularly the initial lignin:N ratio of the litter. Compared with native pastures and cultivation, above and below ground litter from native woodland was characterized by higher lignin:N ratio and more slowly decomposing slow C pools which implies that litter is likely to persist in soils, however based on the sandy nature of the soils in this study, it is likely to lack protection from microbial degradation in the long term.

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1. Introduction

Plant litter decomposition plays an important role in the global carbon (C) cycle through its controls on fluxes of carbon dioxide (CO_2) from soils and its influences on the build-up of soil organic carbon (SOC) (Prescott, 2010). In order to effectively offset greenhouse gas emissions through soil C sequestration, the build-up of stable SOC fractions is important (Cotrufo et al., 2013). Recently, advances have been made in our understanding of the processes of litter decomposition and factors that control the proportion of litter derived C that is incorporated into the stable SOC fraction (Cotrufo et al., 2013). It has been suggested that stable organic matter compounds are formed in soils as a result of microbial transformations of labile substrates during the early stages of litter decomposition and that these microbial products interact with soil minerals to form strong and stable organo–mineral

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complexes (Bahri et al., 2008; Grandy and Neff, 2008; Rubino et al., 2010). This mechanism contrasts with the conventional process model whereby SOM stability is imparted by the inherently recalcitrant SOC components that preferentially accumulate in SOM during decomposition (Berg and McClaugherty, 2008).

Any factor that can act to constrain microbial activity, might in turn have a significant effect on the flow of organic matter between C pools (Sanderman et al., 2010). Biological processes are largely regulated by climate (moisture and temperature) (Lavelle et al., 1993) and in arid and semi-arid environments, such as those commonly found in Australia, it is possible that microbial activity and litter degradation might be constrained by water availability. Under such conditions, microbes might therefore preferentially decompose the most energetically favourable organic matter substrates entering the soil thereby regulating the flow of organic matter between C pools (Manzoni et al., 2012). In this case, complex plant structural compounds will incur a higher energy cost to degrade, (Bahri et al., 2008; Manzoni et al., 2012), and might therefore accumulate in soils and contribute to the slow cycling SOC fraction. Such a mechanism would generate the same outcome as the conventional two-phase mineralization kinetics model. Litter chemistry might therefore still play an important role in influencing the decomposition kinetics and therefore the flow of organic matter between SOC pools.

The majority of research on the biochemical composition of litter and its effect on decay has concentrated on above ground inputs as this litter is deposited on the soil surface thereby strongly contributing to SOC in the upper horizons (Lorenz et al., 2005). However, below ground C input also contributes to SOC with some reports showing that roots contribute more C to SOC than above ground inputs (Mafongoya et al., 1998; Wilhelm et al., 2004). Comparing the biochemical composition of both above and below ground litter with their respective decay kinetics may improve our understanding of the differential contribution of plant litter materials to SOC (Mafongoya et al., 1998; Johnson et al., 2007). Further, the litter decay kinetics may be used in C cycle models estimating the movement of plant derived C to SOC pools (Johnson et al., 2007). One of the methods used to study litter decomposition is through laboratory incubations which assesses the mineralization of C from litter residue due to microbial activity and is measured as CO_2-C production (Zeng et al., 2010; Cotrufo et al., 2010). This allows the relationship between plant quality and decomposition kinetics to be investigated under controlled conditions with variables such as temperature and moisture content (Johnson et al., 2007).

In this work, we studied the decomposition of above and below ground litter from three contrasting land uses namely; native woodland, native pastures and cultivation. Our aims were to a) determine the initial biochemical composition (litter chemistry) of above and below ground litter from the three land uses; b) determine the C mineralization dynamics of decomposing plant litter over time and c) examine the interactions between litter chemistry and C mineralization kinetics.

2. Materials and methods

2.1. Site characteristics

This study was conducted near the township of Uralla in the Northern Tablelands of New South Wales, Australia. Uralla lies at 30.64°S, 151.49°E at an altitude of 1012 m and receives a mean annual rainfall of 807 mm and has a mean maximum and minimum temperature of 26.4 °C and 12.5 °C respectively (1901–2012; Bureau of Meteorology, 2012). The soils of the area are largely derived from Permian granite and are classified as yellow Chromosols (Isbell, 2002) equivalent to Alfisols (Soil survey staff, 1999).

2.2. Field sampling of above and below ground litter

Site clusters containing the three land uses namely, native woodland, native pastures and cultivation were randomly selected at three separate locations (after Wilson et al. 2010, 2011). Above and below ground plant litter samples were collected from three randomly selected plots within each land use, giving a total number of 54 (3 sites × 3 land uses × 2 litter types × 3 reps) samples. The native pastures were dominated by native grasses such as *Microlaena stipoides*. Above ground biomass from this land use consisted of standing dead biomass and was sampled from quadrats measuring 50 × 50 cm randomly placed in the paddocks (after Sanaullah et al., 2010). Above ground biomass within each quadrat was cut above the soil surface and collected into plastic bags. Thereafter, roots were collected by excavating soil from within quadrats from the upper 15 cm soil layer. Native woodland consisted of a mixture of *Eucalyptus* species including Yellow box (*Eucalyptus melliodora*) and Blakely's Red Gum (*Eucalyptus blakelyi*). Above ground litter from this land use consisted of senescent leaves which were sampled from the ground within a randomly selected 25 × 25 m plot. Sampling for below ground root litter was done within the same plot by randomly selecting three trees, establishing a distance of 3 m from each tree base and excavating roots from 1.0 m soil depth.

The paddocks under cultivation had been predominantly cropped with forage oats (*Avena sativa*) for over 20 years. At the time of litter sampling these paddocks were fallow and therefore forage oats (*A. sativa*) were grown in glasshouse pots until physiological maturity from which standing dead biomass and roots were harvested. The soil used for sowing forage oats (*A. sativa*) was sampled from the field within the plough layer (0–15 cm). At physiological maturity, above ground litter was sampled by first discarding the stems bearing grains and harvesting only standing dead biomass. Roots were separated from the soil. In the laboratory, all above ground litter from all land uses was sorted to remove any green foliage and retain only brown litter. Roots were separated from soil by sieving through <4 mm and picked out with forceps. All plant above and below ground litter were oven-dried at 60 °C to constant weight (~48 h). Subsamples were taken from each above ground litter type and passed through <4 mm.

2.3. Litter chemistry laboratory analysis

The initial biochemical composition of all plant litter was determined on subsamples. Total C and N were determined by dry combustion using a CN LECO-1000 autoanalyser (LECO Corporation, St. Joseph, Mich). Water soluble carbon (WSC) was extracted following methods described by Don and Kalbitz (2005). Briefly, 0.2 g, of <4 mm above and below ground litter was weighed into 130 ml specimen jars. Litter samples were soaked in 100 ml of ultra pure water for 24 h at 25 °C. The mixture was then filtered using a <45 μm nylon filter into 70 ml specimen jars. The solution samples were analysed for WSC using a Shimadzu TOC-5000 A analyzer. Acid detergent fibre (ADF) and lignin were determined by the sulphuric acid procedure using Foss FibreCap (tm) (AOAC, method 973.18). In this study, lignin refers to the portion determined as acid unhydrolysable residue (AUR). Tannin was determined by extraction with an aqueous methanol solution and measured by colorimetry in the presence of Folin–Denis reagent (AOAC, method 952.03). Cellulose was calculated from Acid detergent fibre-lignin.

2.4. Carbon mineralization

The kinetics of C mineralization were studied through a laboratory incubation which was performed under controlled