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# Lignite amendment has limited impacts on soil microbial communities and mineral nitrogen availability

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ABSTRACT

The application of lignite (brown coal) as a soil amendment has been shown to provide a number of benefits under certain circumstances, including increased cation exchange capacity, increased phosphorus availability and reduced heavy metal availability. However, there is also evidence that some lignites can have negative impacts on soil biology, with very little known about how lignite affects soil nitrogen (N) dynamics and microbial activity. We conducted a microcosm experiment to assess the influence of lignite from Victoria, Australia, and the same lignite in combination with urea, on soil microbial community composition, biomass, activity and nitrogen cycling. Extractable $NO_3^-$ and $NH_4^+$, microbial biomass, phospholipid fatty acids (PLFAs), microbial respiration and enzymes activities were measured over a 120-day incubation period. The lignite had minor effects on inorganic N concentration in different soil types with or without urea application. Lignite reduced the total $CO_2$ emissions from soil over the incubation period, primarily by inhibiting respiration shortly after application. Changes to total microbial biomass were negligible, but shifts in the soil microbial community caused by lignite or urea application were detected up to 60 days after treatment. During this time, periodic increases in peroxidase and phenol oxidase activities in lignite-treated soils were also observed, but changes in dehydrogenase activities were only apparent in urea-treated soils. Our results indicate that raw Victorian lignite has only a minor, temporary impact on soil microbial activity, community composition and N-cycling and does not increase $CO_2$ emissions over a short time period of investigation. More research is now needed to determine potential longer-term impacts at the field scale.



## 1. Introduction

The burning of crop residues, frequent soil tillage and the overuse of chemical fertilizers has resulted in a dramatic decrease in the organic matter content of many agricultural soils (Minoshima et al., 2007; Ding et al., 2002). It is estimated that most agricultural soils have lost 30–75% of their antecedent soil organic carbon (C) pool (Lal et al., 2007), and that a 1 °C increase in temperature could ultimately lead to additional losses of 3–10%, depending on site-specific factors such as water availability (Kirschbaum, 1995). Because the depletion of soil organic matter directly affects soil ecological processes, the preservation and enrichment of soil organic C is crucial to ensure the long-term sustainability of agricultural and environmental ecosystems.

Rebuilding soil organic matter reserves is therefore a common goal of soil science research. Generally speaking, most management practices proposed for increasing soil organic matter through plant deposition (e.g., reduced tillage, crop rotation) are long-term solutions requiring reasonably productive soils for greater C input (Lal et al., 2007). Less productive or degraded soils may need more direct action to stimulate regeneration. The application of organic amendments, including composts, municipal wastes and biochars, is a common strategy for increasing pools of soil organic matter in order to overcome productivity constraints (Quilty and Cattle, 2011). Use of these materials also has the potential to reduce greenhouse gas emissions by slowing or avoiding oxidation/respiration ($CO_2$), methanogenesis (methane, $CH_4$) or denitrification (nitrous oxide, $N_2O$) processes that would otherwise occur if organic wastes were burnt or land-filled (Lou and Nair, 2009). Unfortunately, although numerous positive results have been observed, practical application can be limited because of availability, cost and contamination issues (Quilty and Cattle, 2011).

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Victorian lignite (brown coal) is an organic matrix that may be suitable as a soil conditioner in certain areas because it is a rich source of humic acids, relatively abundant and inexpensive. Lignite is formed from plant remains via coalification under heat and pressure (Durie, 1991). Because lignite is in the early stages of coalification, the properties of lignite can vary widely depending on their original source material and environmental and geological factors. Some low-rank coals contain high levels of heavy metals and may therefore be unsuitable as a soil amendment, but Victorian lignite has a very low ash and heavy metal content (Brockwell et al., 1991). Most lignites have a complex intra-particle pore structure, with numerous micropores (0.4–1.2 nm) contributing to a high surface area and thus a large number of active sites (Wei et al., 1988). Humic acids isolated from lignites have chemical features typical of humic acids isolated from soil samples (Pospíšilová and Fasurova, 2009). The presence of ion exchange sites, particularly carboxyl- and phenolic-functional groups, favors complexation of metal and other cations (e.g., $NH_4^+$) and influences water and air conductivity in soil (Kwiatkowska et al., 2008). Lignite application to soil can increase soil pH (Yazawa et al., 2000) and electrical conductivity in acidic soil (Imbufe et al., 2004), reduce heavy metal bioavailability (Janoš et al., 2010; Pusz, 2007; Sklodowski et al., 2006; Simmler et al., 2013) and enhance phosphorus uptake from fertilizer (Schefe et al., 2008a). These findings suggest a positive role for lignite in improving soil properties for plant production.

Nevertheless, care must be taken to ensure that lignite used as a soil amendment does not negatively impact on soil health. Frouz et al. (2005) showed that some lignite mine spoils inhibit the reproduction of potworms (*Enchytraeus crypticus*), mainly due to their low pH (<4) or high salinity. Simmler et al. (2013) also found that very high rates of lignite application to soil (7% w/w) reduced the growth of ryegrass. Moreover, few studies have monitored the effects of lignite on soil microbial processes and nitrogen (N) cycling. This is despite knowledge that soil microbial communities strongly influence the availability of nutrients for crop production through a myriad of mineralization, immobilization and transformation pathways. The major focus of previous research was on the effects of lignite found in rehabilitated lignite mine soils (Emmerling et al., 2000; Rumpel and Kögel-Knabner, 2004) or in natural lignite veins (Clouard et al., 2014). Evidence from these and other studies (Rumpel et al., 2001; Rumpel and Kögel-Knabner, 2002) suggests that lignite can be utilized by microorganisms as a carbon source, but it is relatively inert compared with plant litter and has few effects on microbial functions. However, information about the impact and degradation of lignite in agricultural soils is lacking. Furthermore, because unmined lignite is effectively 'sequestered C', the application of lignite to soil has the potential to act as a net source of $CO_2$ if it is quickly oxidized or respired by soil microbial communities. For lignite to be a viable alternative to other organic amendments, the potential for both positive and negative impacts on the environment need be assessed.

Therefore, the aim of this study was to determine the short-term effects of lignite under different N fertilizer regimes on changes to biochemical properties, N availability and microbial communities in agricultural soils. Specifically, because of its high C:N ratio, highly humified (aromatic) structure, and low ash content, we hypothesized that:

1. Lignite addition to soils will reduce the availability of inorganic N forms (ammonium and nitrate) through physicochemical immobilization via interaction with exchange sites;
2. Lignite will increase fungal dominance and associated activities of phenol oxidase and peroxidase, due to the chemical recalcitrance of humified carbon favoring microorganisms with these enzyme systems;
3. Lignite will not be respired to $CO_2$ in the short-term.

To test these hypotheses two experiments were undertaken. In the first experiment, the effects of lignite, with and without urea, on microbial community structure, enzyme activity and N dynamics in a single soil were investigated. In the second experiment, the effect of lignite application rate on soil respiration and N dynamics in two additional, contrasting soils was determined.

## 2. Materials and methods

### 2.1. Soils and lignite

Victorian lignite (Morwell, Victoria) was used as an organic soil amendment. The lignite was mined, crushed through a spinning hammer mill and sieved to <2 mm. At all times throughout processing, the coal was exposed to air for the minimum time possible to minimize spontaneous dehydration by storage in sealed 200 L plastic drums. The moisture content of the raw, sieved coal was 60% and the pH was $4.9 \pm 0.01$. The lignite was analyzed at Environmental Analysis Laboratory, Southern Cross University (see http://scu.edu.au/eal/ for full details of analytical methods) (Table 1).

To investigate the effect of lignite with and without urea, a clay loam soil from a mixed cropping (wheat, canola) enterprise near Balliang, Victoria, was used (hereafter referred to as Balliang loam). In the second experiment, a sandy soil sourced from Cranbourne, Victoria (Cranbourne sand), and a clay soil from Phillip Island, Victoria (Phillip Island clay), were used. The Cranbourne sand was sourced from a vegetable growing area that was subsequently converted to grazing, whilst the Phillip Island clay was sourced from land used for grazing. All sites are situated in Victoria, Australia, and experience a Mediterranean-type climate, with hot dry summers and cool wet winters. The soils were collected from a depth of 0–15 cm, air-dried and sieved to <2 mm before use. The soils were analyzed by the Environmental Analysis Laboratory, Southern Cross University (see http://scu.edu.au/eal/ for full details). The basic properties and classification of all soils are given in Table 2.

### 2.2. Microcosm incubation experiments

#### 2.2.1. Experiment 1—effect of lignite (10 t ha$^{-1}$) on microbial structure, enzyme activity and N dynamics

In this study, a four-month soil incubation was conducted to assess the effects of lignite on soil microbial activity, with and without N-fertilizer (urea) application. The overall design was a 22 factorial experiment (lignite, urea), with six measures over time and four replicates per treatment. This gave a total of 96 individual mesocosms. Air-dried soil (50 g, <2 mm in diameter) was weighed

**Table 1**
Elemental composition of the Victorian lignite.

| Macro-elements (g kg$^{-1}$) | | Micro-elements (mg/kg) | |
|---|---|---|---|
| C | 664.0 | Mn | 56 |
| H | 48.4 | Cu | <1 |
| N | 6.6 | Mo | <3 |
| S | 2.1 | Co | <3 |
| P | 0.1 | Ni | 6 |
| K | 0.2 | Zn | 3 |
| Na | 0.7 | Se | <20 |
| Mg | 2 | Cd | <0.8 |
| Ca | 4.9 | Pb | <8 |
| Fe | 2 | Cr | <1 |
| Al | 0.1 | | |