Ecological Engineering 73 (2014) 92–101

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Organic capping type affected nitrogen availability and associated enzyme activities in reconstructed oil sands soils in Alberta, Canada

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ARTICLE INFO

Article history:
Received 15 January 2014
Received in revised form 20 July 2014
Accepted 1 September 2014
Available online xxx

Keywords:
Land reclamation
LFH capping
Fluorimetric soil enzyme assay
PRS™ probe
Ecosystem development

ABSTRACT

Organic materials applied in land reclamation play a key role in the development of ecosystem properties and functions. Peat mineral soil mix (PMM) and LFH (identifiable litter (L), fragmented litter (F) and humus (H)) mineral soil mix (LFH) are commonly used organic amendments for oil sands reclamation in northern Alberta. These materials have contrasting soil properties, with organic matter in LFH more decomposed and having a lower carbon-to-nitrogen (C:N) ratio than that in PMM. We quantified the effects of LFH and PMM capping material on N availability and enzyme activities during early ecosystem development in the oil sands region. Monthly samples were taken from 0 to10 and 10 to 20 cm layers from June through October in 2011 and 2012. The N availability and activities of soil enzymes including β-1,4-N-acetyl glucosaminidase (NAGase), urease, arylamidase and protease were measured. In-situ N availability was measured using plant root simulator (PRS™) probes. Repeated measures ANOVA indicated that N availability and NAGase, arylamidase and protease activities were greater in LFH than in PMM and were affected by time of sampling. These differences were attributed to the lower C:N ratio in LFH than in PMM. We found greater N availability and enzyme activities in the fall than in the summer in both years. These differences were likely caused by fresh labile C inputs through root exudates and litter fall during fall that induced greater enzyme activities and led to greater N mineralization despite the potential limitation by the lower fall temperature. Overall, the greater N availabilities and enzyme activities in LFH suggest that LFH would be a better soil capping material than PMM for early ecosystem development in oil sands reclamation.

1. Introduction

Mining of oil sands in the Athabasca oil sands region in northern Alberta is one of the largest anthropogenic disturbances of terrestrial ecosystems in the world (Alberta Government, 2010). Surface mining activities in this region have impacted approximately 767 km^2 of land, representing 0.2% of the boreal forest (Alberta Government, 2013). Surface oil sands mining involves removal of several ecological layers including the vegetation, soil and geological material (Giesy et al., 2010). Current regulations require that oil sands companies reclaim disturbed areas to equivalent land capability after cessation of surface mining operations (Cumulative Environmental Management Association, 2006), but given the magnitude of the disturbance, much research is needed to help restore disturbed ecosystems to pre-disturbance conditions.

Successful reclamation of disturbed oil sands areas requires a broad understanding of nutrient cycling and ecosystem development. Nitrogen (N) is often a limiting nutrient in boreal forest soils in the oil sands region (Cheng et al., 2011), particularly in newly reconstructed ecosystems in the oil sands, where native N inputs are often lacking (Bradshaw, 1987). Availability of N in reclaimed ecosystems is strongly regulated by organic matter (OM) decomposition, which is greatly influenced by soil enzyme activities (Sinsabaugh et al., 1991). Soil enzymes associated with N cycling include β-1, 4-*N*-acetylglucosaminidase (NAGase), which is involved in the degradation of chitin, a component of fungal cell walls (Ueno et al., 1991), protease, which catalyses protein hydrolysis to peptides and amino acids and may also supply a large part of the bioavailable N (Ladd and Butler, 1972), and

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http://dx.doi.org/10.1016/j.ecoleng.2014.09.005
0925-8574/

arylamidase, which is involved in hydrolysis of N-terminal amino acid from peptides and amides in soils (Acosta-Martinez and Tabatabai, 2000). In contrast, urease plays a major role in the hydrolytic reaction of urea to form ammonium and carbon dioxide in the soil. Soil enzymes are highly sensitive to environmental changes and can therefore be used as indicators of functional processes related to vegetation establishment and soil quality. Thus, measurement of soil enzyme activities may provide an estimate of N cycling intensity (Dick et al., 1988).

A critical component of oil sands reclamation involves re-building the soil organic layer and accelerating soil profile development. This is often accomplished by large scale applications of organic matter. Two different types of organic matter commonly used as capping materials include the peat mineral soil mix (PMM) and LFH mineral soil mix (LFH), with the LFH including identifiable litter (L), fragmented and partially decomposed litter (F), and highly decomposed humus (H) material (MacKenzie and Naeth, 2007). The PMM is generally salvaged from lowlands within the mining footprint. The LFH is salvaged from upland boreal forest sites and typically includes Ae horizons from Luvisolic soils (Soil Classification Working Group, 1998) and fine roots and tree stumps (MacKenzie and Naeth, 2007).

The two organic materials have differing nutrient availabilities. The PMM has a high total N and low available N due to its high content of more recalcitrant organic carbon (C) which mineralizes slowly and results in high C:N ratios (Hemstock et al., 2010), a widely accepted indicator of N release and substrate availability (Mohanty et al., 2013). The LFH has a lower C:N ratio and provides a rich source of labile C and nutrients (MacKenzie and Naeth, 2010). Despite the high nutrient availability in LFH and the potential use of LFH as a reclamation material, its role in oil sands reclamation has not been thoroughly investigated. Despite past research in the oil sands region, more research is needed to help us understand as to how these two different OM sources, PMM and LFH, will perform relative to each other as organic capping materials in reclamation applications. Although some small scale preliminary studies have been conducted on N cycling and enzyme activities in PMM and LFH materials (McMillan et al., 2007; Dimitriu et al., 2010; Mackenzie and Quideau, 2012), no rigorous large scale, field-based investigations comparing LFH and PMM as alternative organic capping materials for oil sands reclamation have been conducted (Naeth et al., 2013). Because of their contrasting biological properties and nutrient availabilities with a more decomposed OM in LFH, we hypothesized that N availability and associated enzyme activities will be greater in LFH than in PMM in reconstructed sites in oil sands reclamation. Findings from this study will help to establish effective reclamation materials for soil quality improvement during ecosystem development in large scale reclamation applications.

2. Materials and methods

2.1. Research site

The research was conducted on Suncor Energy Inc., Lease 86/17, located 24 km north of Fort McMurray, Alberta (56°39′N, 111° 39′ W) in the central mixedwood natural subregion of the boreal forest region (Fung and Macyk, 2000). The area is characterized by long cold winters and short warm summers with a mean annual temperature of 0.7 °C from 1971 to 2000. Mean annual precipitation is 455 mm, which mostly falls as rain (342 mm) during summer (Environment Canada, 2003). Dominant tree species in natural forests in the region are trembling aspen (*Populus tremuloides* L.) and white spruce (*Picea glauca* L.) that exist in pure or mixed-wood stands (Fung and Macyk, 2000). The majority of soils have developed on glacial and glacial fluvial deposits. Gray Luvisolic soils (based on the Canadian system of soil classification, same below) are associated with till and lacustrine deposits, while Dystric Brunisols are associated with glaciofluvial outwash and eolian sands (Turchenek and Lindsay, 1982).

Air temperature and total precipitation data for the study period indicated that 2012 was slightly warmer and wetter than 2011. The mean average temperature was 14.6 °C in 2011 and 15.2 °C in 2012 during the sampling period (data not shown). The study site received 101 mm of precipitation in 2011 and 324 mm in 2012 during the sampling period (June–October) (Fig. 1) (O'Kane Consultants Inc.)

2.2. Experimental design and plot establishment

Research plots were established at Southeast Dump (56° 58′N 111° 22′W) at Suncor Energy Inc., between November 2007 and February 2008 (Brown and Naeth, 2014). Two rows of plots were arranged along a slightly east-facing slope in a completely randomized block design. The plot size was 10 m × 30 m. The plots were separated by a 5 m buffer. Half of the plots received freshly salvaged LFH and the other half received PMM following standard reclamation prescriptions. The LFH was applied at a depth of 20 cm, over 30 cm of mixed B and C horizon subsoil and 100 cm of

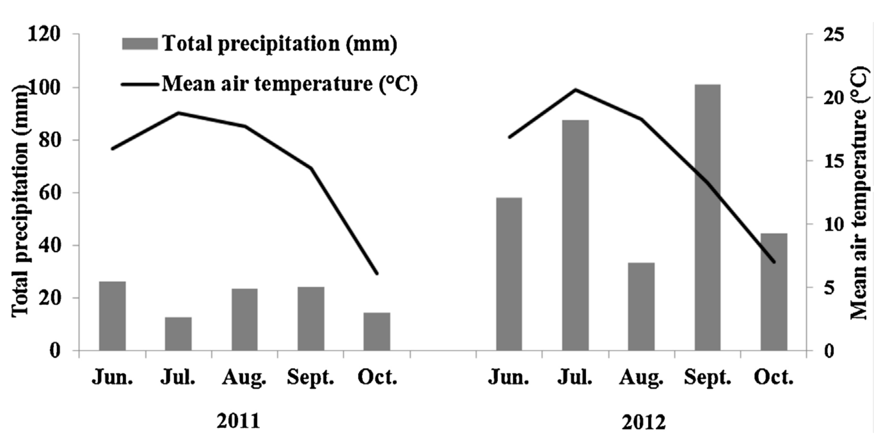

Fig. 1. Monthly precipitation (bars) and mean monthly air temperature (line) during sampling periods.