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Soil microbial communities identify organic amendments for use during oil sands reclamation

M.L. Béasse [a], S.A. Quideau [a,*], S.-W. Oh [b]

[a] Department of Renewable Resources, 4-42 Earth Science Building, University of Alberta, Edmonton, AB T6G 2H1, Canada
[b] Department of Chemistry, Mokpo National University, Muan, Chonnam 534-729, Republic of Korea

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ABSTRACT

Most of the soil microbial community responsible for nutrient cycling in boreal forests is found in surficial organic horizons, often referred to as forest floor layers. In the Athabasca oil sands region of northern Alberta, Canada, reclamation of upland forests utilizes peat as an organic amendment due to shortages in forest floor materials. However, differences in physical and chemical properties between peat and forest floor raise the concern that the use of peat will fail to promote a soil microbial community consistent with sustainable forest ecosystems. As a strategy to maximize the limited supply of forest floor, this study investigated mixing both materials. Specifically, we determined the differences in microbial community composition and activity between fresh and stockpiled forest floor, peat and mixtures of both using basal respiration and phospholipid fatty acid (PLFA) analysis. Basal respiration increased with forest floor addition, but only responded to water content within the pure forest floor treatment. Mixing fresh peat and forest floor produced greater than additive respiration, and the overall PLFA profiles illustrated a microbial community more similar to the forest floor material than to the peat. This suggests a proportionally greater activity in the microbial community associated with the forest floor that is dominating the mixed treatment. Individual phospholipid indicators further demonstrated a distinct shift in their abundance going from the pure peat to the pure forest floor. Taken together, results provide evidence that mixing forest floor and peat provides benefits by increasing the water-holding capacity of the mixed material as compared to pure forest floor, while producing a microbial community more analogous to an upland forest community than to peat alone.

1. Introduction

Surface mining in the Athabasca oil sands region of northeastern Alberta, Canada, creates landscape scale disturbance, which removes the topsoil, parent geologic material, and overburden to a depth that often exceeds 80 m. Before this scale of excavation can begin, the mine site is drained, resulting in a lowering of the water table both on the mine site and adjacent property (Millennium EMS Solutions Ltd., 2005a). A new landscape is further created throughout the operation and reclamation of the mine site. The overburden excavation results in "bulking", an increase in volume per unit of soil that can reach 20%. This increase in volume produces topographic and surface expression changes that constitute a significant departure from the lowland peatlands characteristic of the pre-disturbance landscape. Recent mine approval estimates that the reclaimed area vegetated to upland forests will be double that of the original area (Millennium EMS Solutions Ltd., 2005b).

The different plant communities found in peatlands and upland boreal forests produce distinct litter compositions. Characterization of the molecular carbon structure of these litters using nuclear magnetic resonance (NMR) spectroscopy yields unique spectra that indicate quantifiable differences among them (Turcotte et al., 2009). Plant litter is the primary source of soil organic matter (Turcotte et al., 2009), and is also the primary driver of many biological processes occurring in the soil (Quideau et al., 2000). Hence, forest floor native to the target ecosystems would be the ideal source of organic amendment to cap the reconstructed soils. However, soil reclamation practices in the Athabasca oil sands region have primarily used peat to build soil fertility, due to the shortage of forest floor in the landscape undergoing mining. Widespread occurrence of organic soils on the landscape makes peat abundantly available and economical to salvage during the excavation of the mine site. Following a period of stockpiling, peat

* Corresponding author. Tel.: +1 780 4925397.
E-mail address: squideau@ualberta.ca (S.A. Quideau).

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is applied in a variety of ways depending upon the regulatory approval for each mining company, which includes different thicknesses and mixtures of the material.

Recent studies have used phospholipid fatty acid (PLFA) analysis, a chemical characterization of microbial cell membrane phospholipids, to investigate the composition of microbial communities in reconstructed soils (Dimitriu et al., 2010; Hahn and Quideau, 2012; Mackenzie and Quideau, 2012 Sorenson et al., 2011). Results of such studies demonstrate that microbial communities from peat-amended soils differ from natural boreal forests, and that time since reclamation is overridden by the influence of the reclamation material (Dimitriu et al., 2010). This raises the concern that the use of peat as an organic amendment may not support a soil microbial community consistent with upland forest development.

Since 1997, the Cumulative Environmental Management Association, an association of stakeholders in the Athabasca oil sands region, has explored the use of forest floor as an organic soil amendment for oil sands reclamation (Oil Sands Revegetation Committee, 1998). This material was investigated as a cost effective source for native upland forest plants, and has proven more successful than peat in establishing woody plants during field trials (Mackenzie and Naeth, 2007). The material is salvaged by scraping forest soils to a 10 to 30 cm depth, which creates a heterogeneous mixture of forest floor and underlying mineral substrate referred to as "forest floor mixture", or FFM material (MacKenzie and Quideau, 2012). Results from a recent study comparing peat- and FFM-amended plots suggest that forest floor puts both the microbial and plant communities of the reclaimed sites on a faster trajectory toward a natural forest than peat does (Hahn and Quideau, 2012). With the necessity to reclaim large areas, the best use of the limited forest floor material may be to combine it with the more abundant peat. However, so far, limited investigations have looked at how the two materials interact when mixed. MacKenzie and Quideau (2012) reported that the microbial community from a mixture of the two materials (forest floor and peat) showed no significant difference compared to pure forest floor, suggesting that the mixing of the two materials may be a viable option for reclamation.

The first objective of this study was to examine and compare the microbial communities from forest floor and peat materials, either sampled from undisturbed ecosystems, or following salvage and stockpiling. The second objective was to investigate how mixing of the two materials would influence their biodegradation and microbial communities. Thirdly, as moisture is an important environmental factor influencing soil microbial activity, experimental treatments were included to quantify the specific response of these organic amendments to different moisture levels.

2. Materials and methods

2.1. Site description and sample collection

The Athabasca oil sands region is located within the Wabasca Lowlands, an ecoregion of north-central Alberta which is characterized as a poorly drained, undulating lowland dominated by organic soils associated with fens and bogs (Ecological Stratification Working Group, 1995). The subregion is characterized by short, warm summers with 110 frost free days and a mean air temperature of 15.9 °C for the warmest month of the year (Natural Regions Committee, 2006). Winters are long and cold with a mean air temperature of −18.7 °C for the coldest month. The mean annual precipitation is 478 mm with an average of 336 mm falling during the growing season.

Four different materials were collected for this study, all within a 20 km radius around the Mildred Lake Plant Site (Syncrude Canada Ltd.), located 50 km north of the town of Fort McMurray (56°43′35″N 111°22′49″W). These included fresh materials sampled from two undisturbed natural sites, as well as aged materials sampled from two stockpiles. The fresh peat (FP) material was collected from a very-poorly drained site where a thick (>1 m) Histosol (FAO, 2006) had developed on top of a clay loam. Vegetation included black spruce (*Picea mariana* (Mill.) Britton) as the dominant tree species, and an understory dominated by low bush cranberry (*Viburnum edule* Michx.), bog birch (*Betula glandulosa* Michx.), and moss primarily composed of *Sphagnum* spp. The fresh forest floor layer (FF) was collected from an aspen (*Populus tremuloides* Michx.) dominated site with few white spruce (*Picea glauca* (Moench) Voss) trees. The soil at the site was classified as a Luvisol (FAO, 2006), with a texture of clay loam over clay, and was moderately well drained. Understory species included bearberry (*Arctostaphylos uva ursi* L.), and buffalo berry (*Shepherdia canadensis* (L.) Nutt.). The groundcover was dominated by Schreber's moss (*Pleurozium* spp.).

The stockpiled, i.e.; aged forest floor material (AF) and aged peat (AP) had been salvaged the previous winter from an aspen-dominated site and wooded fen, respectively, in areas scheduled to be mined near the Mildred Lake settling basin. These materials were selected as salvaged organic materials common to the area, which had undergone stockpiling, a common practice for oil sands operators. All materials were sampled by taking >10 samples from the sites and compositing them to yield a large representative volume of each.

2.2. Laboratory analyses

All samples were dried at room temperature, sieved to 4 mm, and carefully mixed to yield buckets of homogenized materials. Water holding capacity was determined on subsamples of each material ($n = 5$) using Puustjarvi's (1973) "soak and drain" method. Carbon content ($n = 3$) was determined by dry combustion using a Costech elemental combustion system (Model 4010; Valencia, CA). A 0.01 M $CaCl_2$, solution was used to measure pH ($n = 3$) using a 2:1 solution:sample ratio (Kalra and Maynard, 1991). Finally, three subsamples from each material were analysed as described in Turcotte et al. (2009) by nuclear magnetic resonance (CPMAS ^{13}C NMR) spectroscopy to describe their macromolecular composition. Five carbon types were identified based on their chemical shifts, including aliphatics (Alkyls) from 0 to 45 ppm, carbohydrates (O-Alkyls) from 45 to 112 pm, aromatics from 112 to 140 ppm, phenolics from 140 to 165 ppm, and carbonyls from 165 to 192 ppm.

2.3. Incubation experiment

Replicate samples ($n = 5$) of each material were incubated at three different water contents, corresponding to 30, 40 and 50% of water holding capacity. The materials included FF and FP from the natural sites, AF and AP from the stockpiles, as well as two mixed treatments consisting of equal parts of carbon from FF and FP (FF + P), and AF and AP (AF + P). This yielded a total of 90 samples for the incubation experiment.

The amount of material (g) needed for each replicate sample was calculated to correspond to an equivalent 4 g of organic carbon. All materials were mixed to a 2:1 ratio of sand to organic matter to optimize aeration (Campbell et al., 1993). Samples were incubated in 1 L glass mason jars for two weeks at room temperature to allow the microbial community to reactivate and come to equilibrium. Basal respiration was determined using a modified closed chamber and the CO_2 accumulation method (Hopkins, 2008). Flasks were watered daily by weight to maintain a constant water content throughout the 5-week incubation. Each