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Using bioavailable nutrients and microbial dynamics to assess soil type and placement depth in reclamation

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ABSTRACT

Land reclamation following surface mining in the Athabasca oils sands region will be extensive, with various challenges specific to local reclamation cover soils. The high economic costs associated with pre-disturbance soil salvage and placement in reclamation necessitates judicious management and application of salvaged cover soils. Soil microbial community activity and bioavailable nutrient supply are largely overlooked in reclamation analyses despite their potential in providing a sensitive measurement of ecosystem function. This study evaluates these parameters by comparing two continuous cover soils, a coarse-textured forest floor mineral mix (FFM) and an organic matter-rich peat soil (PM) at Syncrude Canada's Aurora Soil Capping Study. Shallow (10 cm) and Deep (20–30 cm) placement depths of FFM and PM were compared to a control receiving no cover soil and a harvested jack pine site as a reference. Soil function was assessed by measuring bioavailable nutrient supply rates, soil respiration, phospholipid fatty acid analysis (PLFA), and community level physiological profiles (CLPP). Non-metric multidimensional scaling (NMS) was used to quantify functional similarity with reference conditions. NMS revealed the greatest similarity between FFM and the reference site for bioavailable nutrient supply, PLFA, and CLPP. Deep FFM application shared greatest PLFA similarity to the reference site, while Shallow FFM was more similar in CLPP. Shallow PM was more similar to reference conditions than Deep for all parameters measured, suggesting that shallow cover soil applications might be sufficient for the reclamation target. Soil respiration rates were greatest in FFM, followed by the reference site and PM treatments, with no difference attributable to placement depth. PM had greater nitrogen and sulfur availability, but was lower in phosphorus and potassium when compared to FFM and the reference site. Ecosystem function was more similar in cover soils that mimicked the reference site conditions as much as possible, which in this case meant shallow placement and material salvaged from upland forests.

1. Introduction

As of December 2013, the cumulative area disturbed by surface mining in the Athabasca oil sands region (AOSR) was 895 km^2 out of an estimated final footprint of 4800 km^2 (CAPP, 2015). Producers are required by law to reclaim this land to ‘equivalent land capability’ with locally common boreal species (Alberta Environment, 2016). With the removal of biological legacies, mining activities degrade land to a state of zero ecosystem function. Sub-surface geologic materials are generally unsuitable for plant growth and would require a lengthy period to restore ecosystem function if left alone, similar to primary succession following glacial disturbance (Bradshaw, 1997). Land reclamation attempts to mitigate these soil quality limitations primarily through the discrete salvaging of appropriate surface soil materials prior to mining. These materials, rich in soil organisms and organic matter, are distributed across landforms requiring reclamation. A number of soil reclamation cover designs and capping depths are possible depending on the types of surface and sub-surface materials salvaged, with the objective of mitigating the potential risk of sub-surface material (hydrocarbons, saline/sodic materials) and to provide a soil profile to expedite the re-establishment of targeted vegetative species and communities. In turn, this is expected to promote the re-establishment of sustainable ecosystem processes of a boreal forest landscape.

Given the costs associated with soil salvaging and material handling, there is incentive to understand the influence of placement depth of cover soils in delivering the requisite ecosystem function. Most of the latest research conducted on the effects of placement depth of reclaimed soils in the AOSR includes success of plant recruitment from soil propagule banks (Mackenzie and Naeth, 2010), tree rooting depths (Jung et al., 2014), and soil water movement (Naeth et al., 2011). Little consideration has been given to soil biology and its relevance to reclamation cover soil placement depth. Native coarse textured soils

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of the AOSR are occupied by jack pine ecosystems, with a significant lichen cover in the understorey, and have been shown to have thin soil horizonation and slow decomposition kinetics (Fyles and McGill, 1987).

Soil biogeochemical research on natural and reclaimed sites in the AOSR has included soil organic matter (SOM) quality (Norris et al., 2013; Turcotte et al., 2009), forest floor genesis (Sorenson et al., 2011), nutrient availability and uptake (MacKenzie and Quideau, 2010; Quideau et al., 2013), and microbial community structure and function (Dimitriu et al., 2010; MacKenzie and Quideau, 2012; MacKenzie et al., 2014). Microbial community function governs important ecosystem processes such as decomposition and nutrient cycling (Grayston and Prescott, 2005) and is therefore an integral component of determining reclamation success (Macdonald et al., 2012). Microorganisms metabolize organic compounds thus releasing nutrients into soil solution for plant uptake. Lately, soil microbial community responses to disturbance are receiving more attention in mine reclamation research globally (Harris, 2003; Mukhopadhyay et al., 2014), as well as in the AOSR (Swallow et al., 2009; Dimitriu et al., 2010; MacKenzie and Quideau, 2010; Sorenson et al., 2011). However, most criteria evaluating soil performance for the purpose of certification use chemical and physical parameters as proxies for biological health, and aim to optimize soil productivity rather than re-create diverse and functioning ecosystems (CEMA, 2006). Incorporating soil biological measurements into reclamation criteria could provide a sensitive measure of rehabilitated ecosystem function. The problem with widespread acceptance of these functional measures has been a way to evaluate them quantitatively across sites. We propose that a functional similarity index might be quantified by examining distance from reference sites in ordination space (Mukhopadhyay et al., 2014) and that this might provide a better measure of reclamation success than conventional agronomic measures of soil nutrient availability.

The objectives of this study were primarily to: 1) compare soil nutrient availability and microbial dynamics in the context of cover soil and placement depth in young reclaimed soils, and 2) assess functional similarity to a reference soil using distance in ordination space based on the attributes of the first objective. These objectives were addressed by comparing two surface soil depths of peat mix (PM) and forest floor mineral mixtures (FFM) to a control with no coversoil, and an undisturbed reference soil where a jack pine stand had re-established following timber harvesting. The provenance of each material led us to hypothesize that soil nutrient profiles and microbial community structure, function, and soil respiration in FFM would be most similar to the reference site. We also expected to find greater total microbial biomass and diversity, and nutrient profiles more similar to the reference site with shallow placements since undisturbed soils of the jack pine ecosystems in this region have shallow horizon development. Furthermore, soil nutrient imbalances were expected (MacKenzie and Quideau, 2010) due to dissimilarities in the origin of the reclamation material (peat forms under anaerobic conditions) and its placement in upland positions (aerobic).

2. Materials and methods

2.1. Study area

Syncrude Canada's Aurora North Mine is located 75 km north of Fort McMurray, Alberta, in the Boreal Forest Natural Region – Central Mixedwood Subregion (Cumulative Environmental Management Association 2006). Upland soils naturally present on this lease are predominantly coarse textured and mostly classified as Eutric Brunisols (Soil Classification Working Group, 1998; NorthWind Land Resources Inc., 2013) or Xeric Eutrocryepts (Soil Survey Staff, 2010). These soils support dry a/b ecosites (Beckingham and Archibald, 1996) consisting of mixed and pure stands of jack pine (*Pinus banksiana* Lamb.) and trembling aspen (*Populus tremuloides* Michx.). Upland soils are interspersed with imperfectly to very poorly drained Humic Fibrisols (Soil Classification Working Group, 1998) or Terric Sphagnofibrist (Soil Survey Staff, 2010) in lowlands, with black spruce (*Picea mariana* Mill.), birch (*Betula spp.*) and tamarack (*Larix laricina* Du Roi) as the dominant tree species (e to g ecosites, Beckingham and Archibald, 1996).

The Aurora Soil Capping Study (ASCS) was built to evaluate cover soil design and performance (placement depths and soil material types) using locally available coarse textured soils present in this region. The study is situated at an elevation of ~350 m on a lean oil sand overburden dump. In 2013, on-site weather stations measured annual rainfall of 319.6 mm. That same year, the average annual temperature was 2.5 °C with daily highs and lows during the sampling period of 33.7 and 6.2 °C, respectively (O'Kane Consultants, 2014).

Land reclamation in the AOSR generally uses a two-horizon design consisting of a continuous cover soil, underlain by subsoil (see Fung and Macyk, 2000). Typically, two broad categories of cover soil are available for use in reclamation: 1) peat mineral mix (PM), consisting of salvaged organic and mineral material from lowland bogs and fens; and 2) forest floor mineral mixture (FFM), salvaged as a composite of the forest litter layer (LFH horizon) and the uppermost mineral horizons (A and upper B horizons) of upland forest soils. Peat cover soil can range in composition from entirely peat to a peat–mineral mix depending on the nature of the underlying mineral material. The peat used in this study had almost no mineral content, but is still referred to as peat mix (PM).

In February 2012, reclamation treatments were created at an operational scale (approximately 1 ha each), using heavy haulers and bull dozers to spread subsoil and then continuous cover soils to desired thicknesses. Two depth treatments were considered for both cover soils, 10 cm for Shallow and 20–30 cm (FFM and PM, respectively) for Deep (see soil profiles Fig. 1). These were compared to a control where no cover soil was placed on the same sub-soil as in the other treatments (Fig. 1). Treatments, produced in triplicate, were randomized across the 36 ha study area along with 7 other treatments not examined here. Micro-topographic variability was minimized to reduce possible confounding effects introduced by microsites. Slopes on experimental units were < 2.5% grade and were drained by networks of ephemeral swales. In May 2012, jack pine, trembling aspen and white spruce (2–year-old nursery stock) were planted at approximately 2000 stems ha^{-1}. Finally, these treatments were compared to a reference site which was less than 5 km away and comprised of a recently harvested jack pine site with an undisturbed Xeric Eutrocryept soil profile (Fig. 1).

2.2. Field sampling

In June 2013, just over 1 year since soil placement and tree

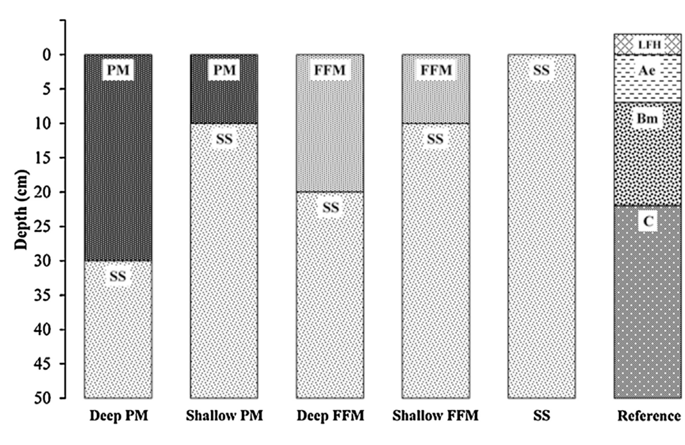

Fig. 1. Soil profiles for the selected treatments from the Aurora Soil Capping Study compared to a harvested reference site (n = 3).