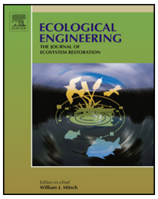
Ecological Engineering 64 (2014) 240–249

Contents lists available at ScienceDirect

Ecological Engineering

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



Textural interfaces affected the distribution of roots, water, and nutrients in some reconstructed forest soils in the Athabasca oil sands region

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ARTICLE INFO

Article history:
Received 5 August 2013
Received in revised form 8 November 2013
Accepted 20 December 2013
Available online 28 January 2014

Keywords:
Fine root
Land reclamation
Overburden
Tailings sand
Textural discontinuity

ABSTRACT

Re-constructed soils in the reclaimed landscape in the Athabasca oil sands region (AOSR) usually consist of an upper amendment layer (cover soil) and a substrate layer below. The cover soil used is typically peat-mineral mix (PMM) and the substrate can be materials such as tailings sand (TS) and fine-textured overburden (OB) materials. Abrupt changes in soil properties between the cover soil and the lower substrate layer create the so-called textural interface that can restrict water and nutrient movement and subsequently affect root growth. To assess the effect of the textural interface on the distribution of roots, water, and nutrients, we collected soil samples from the 10–5, 5–2, and 2–0 cm layers above and 0–2, 2–5, and 5–10 cm layers below the interface (zero at the interface) from nine sites each of PMM/TS and PMM/OB that were planted to lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) trees, respectively. Fine root (<2 mm) biomass (FRB) decreased logarithmically ($p < 0.01$) through the interface. The greatest decrease was found between 5–2 and 2–0 cm above the interface in TS due to lack of capillary rise of water and at the interface in OB due to compaction of fine-textured OB material. Based on stepwise regression analysis, volumetric water content and NH_4-N or DON explained the variation of FRB in TS while electrical conductivity (EC) was the main parameter explaining FRB in OB. Our results indicate that management practices need to consider the influence of textural discontinuity or textural interface on the distribution of fine roots, water and nutrients and for water and N availability in TS and salt stress in OB as potential limiting factors for improving tree growth in the reclaimed/reconstructed landscape in the AOSR.

1. Introduction

Abrupt changes in soil texture in a soil profile create boundaries or textural interfaces between soil layers. The so-called textural interface or discontinuity can restrict water and nutrient movement (Li and Liu, 2011) and can subsequently affect root growth (Eapen et al., 2005). Soil profiles with a textural interface could be classified into two types: a fine-textured layer over a coarse-textured one and the reversed textural arrangement of soil layers. Permeability typically reduces at the interface in both types of layer configurations through a reduction in the rate of water movement through the interface (Jury and Horton, 2004; Li et al., 2013). When a fine-textured soil layer with principally micropores overlies a sandy layer, percolation water is stagnant just above the textural interface, as water cohesion and capillary pressure in micropores prevent water from infiltrating into macropores of the coarse-textured lower layer (Boateng, 2007). This capillary barrier phenomenon has been used to prevent water that infiltrated into the cover layer from getting into a lower layer in landfills (Qian et al., 2010) and to increase water availability in the rooting zone above the capillary barrier (Ityel et al., 2011). Similarly, water easily accumulates above the interface between an upper coarse-textured soil and a lower clayey and/or compacted soil, because water infiltrates very slowly into the lower layer (Verbist et al., 2007). Water availability in the layer above the interface again increases in this scenario (Li and Liu, 2011), but poor drainage may induce locally reduced (or anaerobic) conditions and decrease nutrient availability (Brady and Weil, 2008). Therefore, water movement across the textural interface can become limited and the distribution of water and nutrients can be distorted in such soil profiles.

The Athabasca oil sands region (AOSR) in Alberta, Canada, is the world's second largest reserve of recoverable oil (Humphries, 2008). Unlike conventional crude oil extraction, open-pit mining of oil sands has disturbed and will continue to disturb a large amount of surface land area. Such disturbances include the removal

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http://dx.doi.org/10.1016/j.ecoleng.2013.12.037

of vegetation and soil. Alberta's Environmental Protection and Enhancement Act requires that all mines must be reclaimed to the equivalent land capability of the area prior to surface mining (Powter et al., 2012). To fulfil that requirement, it is important to reconstruct soils that are capable of supporting sustained tree growth, with potential growth limiting factors minimized. As fine roots perform water and nutrient uptake, fine root biomass (FRB) has been used to indicate environmental changes and stand characteristics (Jung and Chang, 2013; Vanguelova et al., 2007). FRB has also been reported to be significantly correlated with tree growth (Finér et al., 2007). Therefore, FRB may be used as an indicator of ecosystem development in the reclaimed landscape.

The first step in land reclamation in the oil sands mining areas is soil re-construction (Naeth et al., 2011). Reconstructed soils in the AOSR usually consist of an upper layer of amendments of peat or peat-mineral mix (PMM) and lower layers of substrates such as tailings sand (TS) and/or fine-textured overburden (OB) materials (Rowland et al., 2009). The PMM is a mixture of salvaged peat and surface mineral soils and has an appropriate combination of micro- and macropores that help with both drainage and water storage (Hejduk et al., 2012) while TS and OB mainly contain macro- and micropores, respectively. Therefore, differences in the pore structure between the amendment and substrate layers may distort the distribution of water and nutrients and subsequently influence root growth across the interface. For example, soil profiles with the amendment over TS may have advantages in drainage, but water and nutrient movement by capillary rise across the interface is likely limited due to lack of micropores in the TS layer. Given the low water and nutrient holding capacity of TS (Barbour et al., 2007), potential water and nutrient deficiency may suppress root growth below the interface. Furthermore, water availability decreases in the amendment layer and may become a limiting factor for tree growth as capillary rise does not occur in a TS type soil profile. In soil profiles with the PMM over fine-textured OB, the hydraulic conductivity of the fine-textured OB is expected to be much lower than that of the PMM (Barbour et al., 2007), meaning that water infiltrated into the PMM would be mainly stored in the amendment layer as drainage through the interface would be restricted. In addition, when the OB layer is compacted, it would have high soil strength and root extension beyond the interface would be limited (Khan et al., 2012). Therefore, the textural interface between the amendment and OB layers can be a barrier for root growth as well.

In this study, we tested the hypothesis that the distribution of FRB and nutrients in reconstructed soil profiles is affected by the textural interface in reclaimed soils in the AOSR. We also investigated the impact of the textural interface on soil properties and factors affecting FRB distribution in reclaimed soils. We expect that this study will provide information that can help improve land reclamation practices in the AOSR.

2. Materials and methods

2.1. Site description

This research was carried out on one of the Suncor Energy Inc. leases located at about 22 km north of Fort McMurray in the AOSR. A portion of this land was reclaimed from open-pit mining sites to upland forests. The research area was located in the humid continental climate zone having short warm summers and long cold winters; the mean annual temperature is 0.7 °C with 67% mean annual humidity and the mean annual precipitation is 455.7 mm with an average of 342.2 mm occur as rainfall during the growing season (Environment Canada, 2010). The reclaimed soils have been re-established with PMM as amendments above reclamation substrates such as TS and OB materials. Lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) were the only tree species planted in TS and OB sites, respectively, in the studied reclaimed areas. Tree age was different from site to site (Table 1). The understory plant communities on TS sites were dominated by *Rosa acicularis* (prickly rose), *Rubus idaeus* (raspberry), *Melilotus* spp. (sweet clover), *Taraxacum officinale* (dandelion), and *Agropyron trachycaulum* (slender wheat grass), while *Salix* spp. (willow), *Alnus crispa* (green alder), sweet clover, dandelion, and *Calamagrostis canadensis* (bluejoint grass) were the dominant species on OB sites. We set up eighteen research plots 10 m × 10 m in size in the reclaimed areas, with nine plots constructed with PMM over TS and the other nine plots constructed with PMM over fine-textured OB (Table 1). The thickness of the amendment ranged from 11 to 48 cm (Table 1). The nine sites in each site type encompassed a site productivity gradient from low to high based on visual inspection of tree performance and later confirmed by tree growth increment measurements (Duan et al., unpublished data).

2.2. Sampling and analyses

Each plot was surveyed in 2011 and soil samples were collected by horizon from a soil pit dug in each plot. To measure bulk density (BD), soil samples were collected with a 100 cm^3 steel ring sampler and oven-dry mass of the soil in each sampler was determined. Total carbon (C) and nitrogen (N) contents were determined with a Carlo Erba NA 1500 elemental analyzer (Carlo Erba Instruments, Italy). Soil texture was analyzed using the hygrometer method (Gee and Or, 2002).

Within each plot, soil samples were collected in September 2012 from the top 10 cm of the amendment with a bi-partite root auger (Eijkelkamp, the Netherlands) at 25 cm from the trunk of three randomly selected trees. Fresh samples were weighed and crushed to pass through an 8-mm sieve. Fine roots (<2 mm diameter) of the tree species were picked up on the sieve, rinsed with running water, dried at 70 °C in an oven, and weighed. Three sub-samples were collected from the soil that had passed through the sieve and weighed. FRB in the sub-samples was determined. The total FRB is the sum of the two fine root samples described above. Diameter at breast height (130 cm above ground) (DBH) and height of each tree in the plots were measured in September 2011 and 2012. Aboveground tree biomass (AB) in each plot in 2011 and 2012 was calculated with DBH and height-based allometric equations (Lambert et al., 2005) and the difference between aboveground tree biomass in 2011 and 2012 was regarded as the annual increment of aboveground tree biomass (IAB). The gravimetric soil water content for the soil samples was determined in a forced-air oven at 105 °C and volumetric soil water content (VWC) was calculated from bulk density and gravimetric water content.

Another soil sampling was carried out in August 2012 to determine the distribution of FRB, water content, and nutrient concentrations through the textural interface. We collected soils from 10–5, 5–2, and 2–0 cm above (in the amendment layer) and 0–2, 2–5, and 5–10 cm below (in the substrate layer) the textural interface at the same location from which we collected the top 10 cm of the amendment in each plot (described above). In this sampling, the zero point was set at the textural interface. Root biomass and soil water content were determined as described above. Soil pH, electrical conductivity (EC), and concentrations of soluble cations including Ca^{2+}, Mg^{2+}, K^+, Na^+, and Al^{3+} were determined after extraction with deionized water at 1:2 of soil to water ratio (v:v, same below) and filtration; a 1:4 ratio was used for the PMM sample from site 15 due to the high organic matter content at this site (Table 1). A Perkin Elmer Elan 6000 quadrupole