Mine Closure 2011 — A.B. Fourie, M. Tibbett and A. Beersing (eds)

doi:10.36487/ACG_rep/1152_19_Mackenzie

Surface soil handling on mines in the boreal forest – from textbook to operations

D.D. MacKenzie *Navus Environmental Inc, Canada*

M.A. Naeth *University of Alberta, Canada*

Abstract

Conservation of forest surface soil is critical for the development of self-sustaining forested ecosystems on post-mined land. Salvaging surface soil from upland boreal forests received little attention in the past and was often not required. Current research has shown forest surface soil provides an economical, diverse and abundant source of native propagules and an important source of nutrients and soil fauna. Salvage depth affects soil quality and potential for in situ propagules to emerge. Salvaging too deep will dilute the propagule and organic matter content of the forest floor with underlying mineral soil; however, salvaging too shallow may not provide sufficient root to soil contact for successful emergence of vegetative propagules. Optimal salvage depth will be impacted by various factors such as soil texture, source location and reclamation objectives. Salvaged surface soil should be directly placed, as stockpiling surface soil for even short periods of time reduces viability of most boreal plant species and causes substantial changes to soil chemical properties. The time between harvesting deciduous forests and soil salvage affects success of establishing deciduous trees; salvaging surface soil when trees have a sufficient amount of carbohydrate reserve in the root system can result in higher establishment rates. During salvage if too much mulch is incorporated with upland surface soil, viability of native propagules can be reduced. Optimal placement depth and distribution of surface soil is also dependent on many factors including salvage depth, substrate quality and reclamation objectives. Placement of coarse woody debris and/or straw on the surface soil creates microsites that aid in reestablishment of native plants. Data from field research at operational and plot scales are presented to support best practices. Various adaptive management practices developed from theory, research and operations to help reduce negative impacts on soil quality and viability of native propagules are discussed.

1 Introduction

Conservation of forest surface soil is critical for development of self-sustaining forested ecosystems on post-mined land. Surface soil provides an important source of native plant genetic material. Other properties of surface soil that make it a superior reclamation material to overburden, organic substitutes or amendments include nutrients, microbial populations, higher organic matter content, better structure and aeration, and lower resistance to root penetration and water infiltration (Power et al., 1979). Surface soil is essential for maintenance of nutrient cycles and productive forests (Fisher and Binkley, 2000). Surface soil contains an abundant source of macro and micro nutrients and provides a rich source of organic matter, propagules, microbial biomass and soil fauna (McMillan, 2005; Battigelli, 2006; MacKenzie, 2006, 2011; Brown, 2010). Research on upland surface soil for reclamation in the boreal forest is limited to studies in the Athabasca Oil Sands Region (Lanoue and Qualizza, 1999; MacKenzie, 2006; Battigelli, 2006; MacKenzie and Naeth, 2010; Brown, 2010; MacKenzie, 2011). For all studies cited, the use of upland surface soil in the Athabasca Oil Sands Region was beneficial for native plant establishment and improving soil quality. Emerging research from mines in the southern boreal region provide similar findings to that in the Athabasca Oil Sands Region (MacKenzie, 2010). On a smaller scale, direct placement of boreal forest surface soils on road sides helped restore native vegetation and reduced transport of weed species (Skrindo and Pedersen, 2004; Skrindo and Halvorsen, 2008).

The role of surface soil as a source of native plant seeds and vegetative propagules on mined lands has long been recognised and mines located in alpine, subtropical and temperate forests and grasslands have shown salvaging surface soils improves reclamation success of diverse, self-sustaining and productive plant communities (Tacey and Glossop, 1980; Smyth, 1997; Hall et al., 2010). In northeastern Alberta in the Athabasca Oil Sands Region, the importance of salvaging upland surface soil has been recognised. However, in the past, both perceived and real logistics and cost prevented use of salvaged surface soil as a reclamation material on a large scale (Ziemkiewicz et al., 1980). In other mines outside the Athabasca Oil Sands Region, surface soil with A horizons less than 15 cm may have not been salvaged, or salvaged to a depth (>30 cm) (Macyk and Drozdowski, 2008) that diluted the inherent beneficial properties of surface soil to a point where it is unrecognisable from underlying subsoil horizons. These practices were considered suitable for the standards at that time. However, growing awareness of sustainability and biodiversity from various stakeholders led to knowledge advancement in understanding forest surface soil and to a growing interest in alternative handling techniques for conservation and reclamation.

2 Salvage

2.1 Undisturbed surface soil properties

Surface soil in boreal forests is typically multi-layered and consists of an Ae (mineral) horizon overlain by a forest floor layer. The forest floor layer consists of dead plant organic matter in various stages of decomposition. The forest floor contains organic matter, macro and micro nutrients and the Ae horizon is a nutrient rich mineral soil (Fisher and Binkley, 2000). Surface soils developed from fine textured parent geologic material are more nutrient rich and support thicker forest floor layers than coarse textured surface soils (Beckingham and Archibald, 1996; Arocena and Sandborn, 1999; Mackenzie, 2011). Along a toposequence, nutrient content and forest floor and Ae horizon thickness increase down gradient (Huang and Schoenau, 1996; Little et al., 2002).

Surface soils contain an abundant and diverse source of seed and plant propagules, collectively known as propagules (Qi and Scarratt, 1998; Rydgren et al., 2004; MacKenzie and Naeth, 2010; MacKenzie, 2011). The majority of propagules in surface soils are in the organic layer and upper few cm of mineral soil (Strong and La Roi, 1983; Whittle et al., 1998). Seed densities in the upper 10 cm of surface soil can vary from 300 to 9,000 seeds m^{-2} (Hills and Morris, 1992). Seed bank densities are generally greater in nutrient rich forests (e.g. medium to fine textured luvisol) than in nutrient poor forests (e.g. coarse textured brunisol). Early to mid successional forest stands contain shade intolerant species and a large seed bank. As forest stands age the number of viable seeds decline (Hills and Morris, 1992). The species composition of the soil propagule bank is more similar to that of the above ground vegetation than that of the mineral soil (Rydgren and Hestmark, 1997). Seed and root distribution in soil is affected by particle size. Propagules are found deeper in coarse textured soils than in fine textured soils. Large pores in coarse textured soils allow seed dispersal deeper into the profile (Chambers et al., 1991) and roots penetrate deeper to obtain available nutrients and water (Schenk and Jackson, 2002).

2.2 Salvage depth

Increasing salvage depth of boreal forest surface soil may increase the underlying mineral soil salvaged, diluting the nutrient rich surface organic horizon with less nutrient rich underlying mineral horizon(s). Shallow salvage depths create a soil with higher organic carbon content and higher plant available macro and micro nutrients compared to greater salvage depths (MacKenzie, 2011). Some plant available nutrients (e.g. phosphorous in Bm horizon) may increase if soils are salvaged deeper. Shallow salvage does not imply only salvaging the forest floor, as incorporating some mineral soil is important for creating a new surface soil. The mineral horizon (Ae) of upland surface soil helps create a sustainable surface soil in the event of a forest fire and provides nutrients and a medium for roots to anchor.

Shallow salvage depths result in faster recruitment of native plant species from in situ propagules than deeper salvage (Tacey and Glossop, 1980; Rokich et al., 2000). Effects of salvage depth are also applicable to non-vascular plant species. Rochefort et al. (2003) found significantly greater establishment of Sphagnum capitula when spreading 0 to 10 cm of peatland surface soil compared to spreading deeper layers. Placement of boreal forest surface soil salvaged at shallow depths results in increased plant species, canopy cover and plant density compared to deeper salvage depths. Effects are more pronounced for fine textured soils (MacKenzie, 2011). Species richness, plant density and canopy cover significantly declined when salvage depth increased from 10 to 30 cm with a fine textured surface soil from a luvisol (MacKenzie, 2011).

Salvage depths up to 60 cm improved plant establishment compared to control plots that did not receive surface soils; however, abundance and richness of native species was significantly less than soils salvaged ≤ 30 cm (MacKenzie, 2011).

2.3 Season and timing

Seasonal weather conditions and pre-salvage operations (e.g. timber harvest, clear and grub operations, drainage) can change soil water content and depth of frost and snow on the surface. These factors affect quality of surface soil during salvage. Removing the forest canopy cover has a significant effect on the hydrologic cycle and soil physical properties (Fisher and Binkley, 2000). Clear cutting reduces water use by trees, but causes greater snow accumulation on the surface. Soil water content can increase substantially after trees removal and depth of frost penetration may increase. Salvaging during wet conditions can negatively impact physical, chemical and biological properties of soil, and handling wet soil increases soil bulk density and causes structural breakdown. Severe compaction can be difficult to ameliorate and can lead to reduced root growth. Equipment operation on wet soils increases rutting and can result in admixing upland surface soil with subsoil. Salvaging surface soil under dry, windy conditions may result in soil loss due to wind erosion. Admixing surface soil reduces organic matter content and is of greatest concern during soil salvage in wet conditions.

Salvaging surface soil with deep frost penetration increases the risk of incorporating deeper, potentially less suitable, mineral material if ripping is employed. Conversely, frost can prevent dozers from salvaging to desired depths and not all surface soil will be salvaged. Soil salvage during frozen conditions can reduce compaction to the subsoil layer and help reduce soil structure degradation. Snow mixed with surface soil increases the total volume of material handled and results in less accurate volume estimates. Incorporating excessive amounts of snow can saturate the soil after snowmelt, potentially leading to water erosion during high spring rainfall events.

Timing of tree harvest on areas where surface soil is to be harvested should be considered to optimise tree regeneration. Sprouting or suckering in trembling aspen and other boreal deciduous trees are most vigorous when total non-structural carbohydrate reserves are at their highest (Landhäusser and Lieffers, 1997, 2003; Frey et al., 2003). Winter logging usually promotes abundant suckering and best growth compared with spring or summer harvest (Peterson and Peterson, 1992). The time between tree harvest and soil salvage can have an effect on sprouting of trembling aspen. MacKenzie (2010) determined that harvesting trees the same fall or winter as the soil was salvaged resulted in significantly greater aspen establishment compared to salvaging soils five years after tree harvest. The time between timber harvesting and soil salvage had little effect on number of shrubs and herbaceous species that established from seed or vegetatively.

2.4 Woody debris

The ecological benefits of woody debris for boreal ecosystems is well known (Stevens, 1997). Woody debris can improve soil quality by creating microsites for microorganisms and mesofauna that are important in nutrient cycling, and improve seed catch of native plants. It may help severely degraded land regain ecological function by aiding and quickening recovery of mesofauna, microorganisms, soil nutrients, soil water and plant diversity (Brown, 2010). The majority of the literature describes the effects of woody debris from top application but not from after incorporating into the soil.

Incorporating too much woody debris into the surface soil during salvage can reduce viability of seeds and roots and/or germination and emergence of in situ propagules. Currently, there is no definitive threshold limit for what constitutes too much woody debris salvaged with surface soil, although there is assumed to be a critical value where increased woody debris can negatively impact soil quality by nutrient retention and composting caused by decay. Incorporating 15 to 20 cm of freshly mulched woody debris from a deciduous forest with 20 cm of luvisolic surface soil resulted in greater than 90% reduction in native species recruitment from in situ propagules compared to surface soil with no mulch (MacKenzie, 2010). Excessive amounts of woody debris incorporated into the surface soil likely created poor seed or root to soil contact causing poor germination and emergence of in situ propagules from in the surface soil.

2.5 Operations

Prescribed salvage depths should be based on pre-disturbance soil survey data and reclamation objectives. Salvage depth should result in an appropriate mix of forest floor and underlying soil material to preserve soil quality while maintaining a sufficient density of propagules for revegetation. Optimal salvage depths are site specific as undisturbed surface soils vary in depth and texture. The following guidelines are recommended when surface soil is stockpiled, and/or when there are no definitive plans for its use. For coarse textured soil, maximum salvage depth should be 15 cm or to the bottom of the Ae horizon, whichever is greater. For fine textured soil maximum salvage depth should be 30 cm or to the bottom of the Ae horizon, whichever is less. The change in colour from a light grey/white Ae horizon to a dark brown/brown Bt/Bm horizon is often a more practical guide for operators to use when salvaging surface soils; however, a depth needs to be applied when no Ae horizon exists. Shallow salvage depths should be targeted where reclaimed site productivity and/or plant species diversity are primary objectives. Deep salvage depths should be targeted where the primary objective is obtaining maximum reclamation material volume. Deeper salvage might be used to dilute propagule banks of undesired species, for example, where a salvage area has abundant competitive plant species such as marsh reed grass (*Calamagrostis canadensis*). If soils are salvaged deeper than optimal, longer time frames or additional management will likely be required to achieve comparable plant productivity and/or diversity.

Operational constraints may force operators to deviate from optimal salvage depths. Site conditions including soil water content, frost depth and visibility will influence effectiveness of salvage operations. Equipment operators typically use natural breaks, such as soil colour, within the soil profile as a tool for determining maximum salvage depth. However, guidance by experienced soil monitor(s) and/or more sophisticated equipment (laser or GPS guided) can help maintain a more consistent depth. Equipment operators can maintain a desired salvage depth during daylight better than at night; supplemental lighting can help improve night visibility.

3 Stockpiling

3.1 Stockpiling effects

Stockpiling negatively affects topsoil chemical, physical and biological properties; thus salvaged topsoil should be directly placed if possible. Stockpiling and associated disturbance from earth-moving equipment increases soil bulk density and reduces aggregate stability causing degradation in soil structure (Hunter and Currie, 1956). Over time, stockpiles become anaerobic below the surface, negatively affecting biological properties (Abdul-Kareem and McRae, 1984). Stockpiling reduces total nitrogen, available nitrogen and organic carbon content (Visser et al., 1984; Harris and Birch, 1987; Kundu and Ghose, 1997), and significantly reduces mycorrhizae and other microbial populations (Harris et al., 1989). Mycorrhizae share an important, beneficial relationship with plants, specifically in phosphorus nutrition and water uptake. Some studies suggest microbial populations of stockpiled topsoil return quickly once the soil is replaced (Williamson and Johnson, 1990). While stockpiled topsoil becomes biologically stagnant (specifically for aerobic microorganisms, seeds and roots), there is little evidence to suggest soils stockpiled in cool climates are stagnant in nutrients.

MacKenzie (2011) found stockpiling surface soil from northeastern Alberta for 16 months resulted in large increases in concentrations of iron, ammonium, manganese and other soluble ions; however, stockpiling did not substantially alter total nitrogen or organic matter. The majority of available nutrients (ammonium, phosphorous, potassium) and soluble ions (calcium, potassium, magnesium) increased with storage depth and time. The most noticeable effect from stockpiling was the dramatic loss in seed and root viability. Stockpiling resulted in a significant decline (up to 100%) in seed viability of 24 of 27 boreal species studied in both small and large stockpiles at depths below 1.0 m (MacKenzie, 2011). Constructing temporary stockpiles (e.g. <1 year) during frozen months prolonged seed viability; however, when stockpiles thawed, seed viability rapidly declined. Stockpiling was more detrimental to soil quality and seed viability in fine textured than coarse textured soils. Stockpiling effects within the Athabasca Oil Sands Region have only been studied for a short period of time and long term data will be required to make stronger conclusions about changes to soil quality over time.

3.2 Alternative stockpile design

Stockpiles should be selectively placed on areas protected from saturation, excessive compaction from equipment and contaminants, which reduce soil quality (Ghose, 2001). Stockpiling wet soils can increase soil degradation (Anderson et al., 1988; MacKenzie, 2011). Storage time should be minimised to prevent soil degradation and to preserve propagule viability. Constructing several small stockpiles instead of one large stockpile is better for maintaining long term quality of surface soils. Creating stockpiles of 1 to 3 m and maximum surface area can help reduce soil quality deterioration. Salvaging snow with surface soil has short term benefits, by reducing microorganism activity, when surface soil is stockpiled for less than one year. When the snow melts stockpiles become increasingly anaerobic. Too much snow incorporated with any type of stockpiled surface soil creates an unstable stockpile and may cause the material to become wet over time.

Periodic removal and placement (on post-mined land) of the upper surface layer of the stockpile can help preserve and create an additional source of propagules. Constructing stockpiles to create a propagule source involves repeated salvage of the upper surface layer of stockpiled soil, which contains the only significant source of viable propagules. During each re-salvage event, some of the upper layer is left on the surface of the stockpile. This residual soil contains viable propagules used for revegetating the stripped area. Newly established plants rebuild the propagule bank near the surface, creating another opportunity for salvage. To minimise soil quality degradation, appropriate equipment must be used and timing of salvage events needs to be considered. The time between each re-salvage period may vary from 3 to >5 years. Key factors affecting revegetation success include soil type, species present, amount of residual soil on the new surface, season re-salvage activities occur, compaction, surface roughness, adjacent weed seed source and weather. This practice has not been attempted; however, in theory a properly managed permanent stockpile could act as a propagule source.

4 Placement

4.1 Direct placement

Direct placement of soil containing viable propagules is one of the most economical ways of ensuring re-establishment of the diversity of species that exist in native ecosystems (Leck et al., 1989). However, if there is a potential for undesirable species in the seed bank (noxious weeds, competitive native or introduced species) to establish and out-compete desired species, direct placement may not be the best method to achieve reclamation objectives (e.g. commercial forest). Direct placement is preferred to stockpiling because seed viability, nutrients, organic matter and soil biota are difficult and costly to replenish once degradation occurs in stockpiles. Direct placement preserves viable propagules making them available for revegetation. Typical shrub densities obtained from surface soils salvaged from mid-seral deciduous stands in the boreal forest, replaced at depths > 10 to 20 cm range between 20,000 to over 100,000 stems per ha (MacKenzie, 2006, 2010, 2011). Number of plants emerging from direct placed surface soil depends on numerous factors such as salvage depth, stand age and type, disturbance history at the donor site, variations in year-to-year seed production and precipitation.

4.2 Placement depth

The effect of placement depth on establishing native plants is influenced by surface soil properties and distribution of propagules in the reapplied soil. Thin placement depths generally result in no difference in plant emergence and species richness compared to thick placement depths (Rokich et al., 2000; Holmes, 2001). At deep placement depths, seeds and vegetative parts are unable to emerge as they are buried deeper and have limited resources for growth such as carbohydrates and light (Benvenuti, 2003). Thick placement depths generally result in higher plant cover and/or productivity (Power et al., 1976; Redente et al., 1997). Mackenzie and Naeth (2010) found fine textured surface soil from an aspen/white spruce boreal forest applied at 20 cm had a significant greater canopy cover of woody and herbaceous plant compared to 10 cm. Coarse textured surface soil salvaged at 10 and 25 cm had a significant increase in woody and herbaceous plant canopy cover when placed at 20 cm versus 10 cm. Canopy cover of native boreal plants increased linearly with increasing placement depths of 0, 2, 5 and 10 cm using both fine and coarse textured soil (MacKenzie, 2011). Surface soil applied at thick depths created a rooting zone with higher organic matter and available micro and macro nutrients; this increased plant productivity and canopy cover (Mackenzie and Naeth, 2010; MacKenzie, 2011).

Thin placement depth of surface soil effectively redistributes a small quantity of donor soil over a larger area; however, it is more beneficial for regeneration of plants from seed. Spreading surface soil at thin depths using large dozers incorporates some substrate which the surface soil is applied over, which can dilute the organic rich surface soil. Use of smaller sized dozers does not overcome this problem and spreading surface soil with smaller equipment often causes unnecessary surface smoothing. Surface soils with high coarse woody debris are also harder to apply at thin depths. These operational constraints can be avoided by using excavators to spread the surface soil; however, this increases costs.

Chemical and physical properties of the substrate onto which surface soil is placed are important as substrate provides the environment in which roots physically stabilise plants and extract water and nutrients. Substrate properties can affect plant growth due to pore water chemistry, available water holding capacity, organic matter content, nutrient toxicities, nutrient deficiencies and thermal properties. Several substrates are available in the Athabasca Oil Sands Region, including peat mineral mix, fine textured parent material and coarse textured material. Each substrate differs in available water holding capacity, soil temperature and nutrient availability. When surface soil is applied to good quality substrates with few limitations to root growth, water and nutrient supply, differences between shallow and deep salvage depths in resulting canopy cover are few. When salvaged surface soil is placed on low quality substrates, upland surface soil salvaged from shallow depths (10 to 15 cm) resulted in increased canopy cover for most plant groups compared to surface soil salvaged from deeper salvage depths (20 to 30 cm) (MacKenzie, 2011).

Depth of placement should be based on reclamation objectives and optimal use of material if quantities are limited. Optimal placement depth to sustain a mature, productive forest may be different than the depth required for diverse wildlife habitat. Important considerations for restoring productive forests are available soil water and growing space for tree roots (Rodrigue and Burger, 2004). Deep soil positively influences mine soil productivity through increased rooting depth and greater water holding capacity (Torbert et al., 1988; Andrews et al., 1998). Soil placement depth for a less productive forested plant community might be thinner than that for commercial forest. For increased species diversity, placement depths should be varied from thin to thick (DePuit, 1984); however, if propagules are buried too deeply they may lie dormant and lose viability or germinate but never successfully establish. If soil is reapplied at shallow depths, propagules may emerge but available water and nutrients may limit successful plant establishment. A balance between maximising the area over which propagules are redistributed, while providing sufficient resources for successful plant establishment is needed. If adequate diversity within plant communities is a reclamation goal, topsoil should be reapplied at depths shallower than those necessary to maximise total diversity.

4.3 Distribution

A rough replaced surface soil is desirable for plant establishment as it promotes development of diverse plant communities. Rough surfaces create microsites that enhance native seed and spore catch, increase germination and emergence of in situ propagules and create localised changes in soil water. A rough surface can provide habitat for small animals and soil fauna prevent erosion. Incorporating a small amount of woody debris during salvage operations can help promote creation of rough surfaces; however, excessive amounts of woody debris can result in ineffective replacement of surface soil, and the negative effects previously mentioned.

Distribution of surface soil should be optimised when there are insufficient volumes available to replace across the post-mined landscape to be revegetated to forest. To optimise dispersal of native boreal plant propagules surface soil can be placed in multiple areas throughout the mine site, and away from the edge of mine lease boundaries. Establishing diverse, forested stands throughout the mine may enhance seed dispersal from birds and mammals on adjacent reclaimed areas with peat-mineral mix soil covers. Placing surface soil in several small islands may be preferable to placing one large island surrounded by peat-mineral mix because a greater edge to interior ratio will be created. This is desirable because it increases dispersal of native plant species seeds onto adjacent land not covered by upland surface soil. However, placing soil in very small islands may result in establishing vegetation being out-competed by aggressive plants from adjacent areas.

4.4 Amendments

Use of amendments (e.g. fertiliser, woody debris, mulch) on replaced boreal surface has not been widely studied. Generally, the use of fertilisers is not recommended or required if replaced soil nutrient concentrations are satisfactory. Skrindo and Halvaorson (2008) applied 30 kg ha^{-1} to surface soil and found no beneficial effect in natural revegetation. Fertilisation often increases growth and survival of tree and shrub species; however, it also increases growth of undesired, competitive herbaceous species which in turn increase shrub and tree mortality.

Brown (2010) determined that application of woody debris on reclaimed landscapes was beneficial because it increased species richness and decreased introduced species cover. Brown (2010) determined woody plant abundance was positively associated with coarse woody debris cover on a luvisolic soil in northeastern Alberta and found an increase in black spruce seedling establishment after spreading woody debris from black spruce trees. Application of woody debris resulted in nitrogen immobilisation and phosphorous leaching, but the extent was not determined. MacKenzie (2010) applied 300 m^3 of coarse woody debris per ha and 7 Mg per ha of barley straw mulch to a luvisolic soil in central Alberta. Coarse woody debris and straw mulch had no significant effect on woody plant density, herbaceous cover or species richness one year after placement. Using coarse woody debris from serotenous or semi-serotenous tree species can increase establishment of tree species from seed contained in cones. Use of straw for erosion control during reclamation activities has not been widely studied, but potential effects include introduction of undesired seed sources, possible plant growth inhibiting qualities and rate of breakdown.

5 Conclusions

Direct placed surface soils may be the most effective method for establishing diverse, native plant communities on post-mined landscapes in the boreal forest. The methods used to handle surface soil will influence how well plants establish from in situ propagules. Applied research has helped develop better soil handling practices. There is no single approach to salvage or placement and practices should be based on reclamation objectives. Achieving optimal salvage and placement depth may not always be achievable due to operational constraints; however, negative impacts from improper soil handing can be minimised through careful planning.

Acknowledgements

The authors thank Syncrude Canada Ltd., Suncor Energy Inc., Albian Sands Energy Inc., Canadian Natural Resources Limited, Imperial Oil Resources Limited, Total E&P Canada Ltd., Fort Hills Energy L.P. by its General Partner Petro-Canada Oil Sands Inc., Sherritt International Corporation and Capital Power Corporation for financial and operational support.

References

Abdul-Kareem, A.W. and McRae, S.G. (1984) The effects on topsoil of long term storage in stockpiles, Plant and Soil Journal, Vol. 76, pp. 357–363.

Anderson, T.R., Grundy, M.G. and Bell, L.C. (1988) Effect of stockpiling on two soils from the bowen coal basin and the ramifications for soil management in rehabilitation, in Proceedings Volume I, Environmental Workshop, A.C.T. Dixon (ed), September 1988, Australian Mining Industry Council, Darwin, Australia, pp. 256–272.

Andrews, J.A., Johnson, J.E., Torbert, J.L., Burger, J.A. and Kelting, D.L. (1998) Minesoil and site properties associated with early height growth of eastern white pine, Journal of Environmental Quality, Vol. 27, pp. 192–199.

Arocena, J.M. and Sanborn, P. (1999) Mineralogy and genesis of selected soils and their implications for forest management in central and northeastern British Columbia, Canadian Journal of Forest Soil Science, Vol. 79, pp. 571–592.

Barbour, L., Chanasyk, D., Hendry, J., Leskiw, L., Macyk, T., Mendosa, C., Naeth, M.A., Nichol, C., O'Kane, M., Purdy, B., Qualizza, C., Quideau, S. and Welham, C. (2007) Soil capping research in the Athabasca oil sands region, Vol. 1, Technology Synthesis, Draft.

Battigelli, J. (2006) Fact Sheet 36: soil arthropod communities on natural and reclaimed soils in the Athabasca oil sand region, in Soil Capping Reclamation Research, Volume 2: Fact Sheets.

Beckingham, J.D. and Archibald, J.H. (1996) Field guide to ecosites of northern Alberta, Northern Forestry Centre, Forestry Canada, Northwest Region, Edmonton, Alberta, Canada.

Benvenuti, S. (2003) Soil texture involvement in germination and emergence of buried weed seeds, Journal of Agronomy, Vol. 95, pp. 191–198.

Brown, R.L. (2010) Use of woody debris as an amendment for reclamation after oil sands mining, M.Sc Thesis, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada.

Chambers, J.C., Macmahon, J.A. and Haefner, J.H. (1991) Seed entrapment in alpine ecosystems: effects of soil particle size and diaspore morphology, Ecology, Vol. 72, pp. 1668–1677.

DePuit, E.J. (1984) Potential topsoiling strategies for enhancement of vegetation diversity on mined lands, Minerals and the Environment, Vol. 6, pp. 115–119.

Fisher, R.F. and Binkley, D. (2000) Ecology and management of forest soils, Third Edition, Jon Wiley and Sons, New York, USA.

Frey, B.R., Lieffers, V.J., Landhäusser, S.M., Comeau, P.G. and Greenway, K.J. (2003) An analysis of sucker regeneration of trembling aspen, Canadian Journal of Forest Research, Vol. 33, pp. 1169–1179.

Ghose, M.K. (2001) Management of topsoil for geologic environmental reclamation of coal mining areas. Environmental Geology, Vol. 40, pp. 1405–1410.

Hall, H.L., Barton, C.D. and Baskin, C.C. (2010) Topsoil seed bank of an oak-hickory forest in eastern Kentucky as a restoration tool on surface mines, Restoration Ecology, Vol. 18, pp. 834–842.

Harris, J.A. and Birch, P. (1987) The effects on topsoil storage during opencast mining operations, Journal of Science of Food and Agriculture, Vol. 40, pp. 220–221.

Harris, J.A., Birch, P. and Short, K.C. (1989) Changes in the microbial community and physico-chemical characteristics of topsoils stockpiled during opencast mining, Soil Use and Management, Vol. 5, pp. 161–168.

Hills, S.C. and Morris, D.M. (1992) The function of seed banks in northern forest ecosystems: a literature review, Ministry of Natural Resources, Sault Ste., Marie, Ontario, Canada, Forest Research Information Paper. No. 107.

Holmes, P.M. (2001) Shrubland restoration following woody alien invasion and mining: effects of topsoil depth, seed sources and fertilizer addition, Restoration Ecology, Vol. 9, pp. 71–84.

Huang, W.Z. and Schoenau, J.J. (1996) Forms, amounts and distribution of carbon, nitrogen, phosphorous and sulfur in a boreal aspen forest soil, Canadian Journal of Soil Science, Vol. 76, pp. 373–385.

Hunter, F. and Currie, J.A. (1956) Structural changes during bulk soil storage, Journal of Soil Science, Vol. 7, pp. 75–80.

Kundu, N.K. and Ghose, M.K. (1997) Shelf life of stock-piled topsoil of an open cast coal mine, Environmental Conservation, Vol. 24, pp. 24–30.

Landhäusser S.M. and Lieffers, V.J. (2003) Seasonal changes in carbohydrate reserves in mature northern Populus tremuloides clones, Trees, Vol. 17, pp. 471–476.

Landhäusser, S.M. and Lieffers, V.J. (1997) Seasonal changes in carbohydrate storage and regrowth in rhizomes and stems of four boreal forest shrubs: applications in Picea glauca understorey regeneration, Scandinavian Journal of Forest Research, Vol. 12, pp. 27–32.

Lanoue, A. and Qualizza, C. (1999) Lfh and shallow mineral horizons as inoculants on reclaimed areas to improve native species catch, Environmental Affairs, Syncrude Canada Ltd., Fort McMurray, Alberta, Canada, Preliminary Results Report, 32 p.

Leck, M.A., Parker, T.V. and Simpson, R.L. (1989) Ecology of soil seed banks, Academic Press Inc., San Diego, California, USA.

Little, T.I., Pluth, D.J., Corns, I.G.W. and Gilmore, D.W. (2002) Post-fire forest floor development along toposequences of white spruce-trembling aspen mixedwood communities in west-central Alberta, Canadian Journal of Forest Research, Vol. 32, pp. 892–902.

MacKenzie, D. (2006) Assisted natural recovery using a forest soil propagule bank, M.Sc Thesis, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada.

MacKenzie, D. (2010) Reclamation of a Coal Mine Using Direct Placed Forest Surface Soil, presented at the Canadian Land Reclamation Association Conference, 24–26 February, 2010, by Navus Environmental Inc., Red Deer, Alberta, Canada.

MacKenzie, D. (2011) Reclamation using upland surface soils from boreal forests in the oil sands, PhD Thesis, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada (unpublished).

MacKenzie, D. and Naeth, M.A. (2010) The role of the forest soil propagule bank in assisted natural recovery after oil sands mining, Journal of Restoration Ecology, Vol. 18, pp. 418–427.

Macyk, T.M. and Drozdowski, B.L. (2008) Comprehensive report on operational reclamation techniques in the mineable oil sands region, created for the Cumulative Environmental Management Association, Fort McMurray, Alberta, Canada.

McMillan, R.A. (2005) Forest floor as an amendment in oil sands reclamation, MSc. Thesis, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada.

Peterson, E.B. and Peterson, N.M. (1992) Ecology, management and use of aspen and balsam poplar in the prairie provinces, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Canada, Special Report 1.
Power, J.F., Ries, R.E. and Sandoval, F.M. (1976) Use of soil materials on spoils-effects on thickness and quality, North Dakota Farm Research, Vol. 34, pp. 23–24.
Power, J.F., Sandoval, M. and Ria, R.E. (1979) Topsoil-subsoil requirements to restore North Dakota mined land to original productivity, Mining Engineering, Vol. 31, pp. 708–1712.
Qi, M.Q. and Scarratt, J.B. (1998) Effect of harvesting method on seed bank dynamics in a boreal mixedwood forest in north western Ontario, Canadian Journal of Botany, Vol. 76, pp. 872–883.
Redente, E.F., Mclendon, T. and Agnew, W. (1997) Influence of topsoil depth on plant community dynamics of a seeded site in northwest Colorado, Arid Soil Research and Rehabilitation, Vol. 11, pp. 139–149.
Rochefort, L., Quinty, F., Campeau, S., Johnson, K. and Malteret, T. (2003) North American approach to the restoration of sphagnum dominated peatlands, Wetlands Ecology and Management, Vol. 11, pp. 3–20.
Rodrigue, J.A. and Burger, J.A. (2004) Forest soil productivity of mined land in the midwestern and eastern coalfield regions, Science Society of America Journal, Vol. 68, pp. 833–844.
Rokich, D.P., Dixon, K.W., Sivasithamparam, K. and Meney, K.A. (2000) Topsoil handling and storage effects on woodland restoration in western Australia, Restoration Ecology, Vol. 8, pp. 196–208.
Rydgren, K. and Hestmark, G. (1997) The soil propagule bank in a boreal old-growth spruce forest: changes with depth and relationship to aboveground vegetation, Canadian Journal of Botany, Vol. 75, pp. 121–128.
Rydgren, K., Okland, R.H. and Hestmark, G. (2004) Disturbance severity and community resilience in a boreal forest, Ecology, Vol. 85, pp. 1906–1915.
Schenk, H.J. and Jackson, R.B. (2002) The global biography of roots, Ecological Monographs, Vol. 72, pp. 311–328.
Skrindo, A.B. and Halvorsen, R. (2008) Natural revegetation on forest topsoil and subsoil along roadsides in boreal forest, Applied Vegetation Science, Vol. 11, pp. 483–490.
Skrindo, A.B. and Pedersen, P.A. (2004) Natural revegetation of indigenous roadside vegetation by propagules fom topsoil, Urban Forestry and Urban Greening, Vol. 3, pp. 29–37.
Smyth, C.R. (1997) Early succession patterns with a native species seed mix on amended and unamended coal mine spoil in the rocky mountains of southeastern British Columbia, Canada, Arctic and Alpine Research, Vol. 29, pp. 184–195.
Stevens, V. (1997) The ecological role of coarse woody debris: an overview of the ecological importance of coarse woody debris in B.C. forests, Research Branch, B.C. Ministry of Forests, Victoria, B.C., Canada, Working Paper 30/1997.
Strong, W.L. and La Roi, G.H. (1983) Rooting depths and successional development of selected boreal forest communities, Canadian Journal of Forest Research, Vol. 13, pp. 577–588.
Tacey, W.H. and Glossop, B.L. (1980) Assessment of topsoil handling techniques for rehabilitation of sites mined for bauxite within the Jarrah Forest of Western Australia, Journal of Applied Ecology, Vol. 17, pp. 195–201.
Torbert, J.L., Tuladhar, A.R., Burger, J.A. and Bell, J.C. (1988) Minesoil property effects on the height of ten year old white pine, Journal of Environmental Quality, Vol. 17, pp. 189–192.
Visser, S., Fujikawa, J., Griffiths, C.L. and Parkinson, D. (1984) Effect of topsoil storage on microbial activity, primary production, and decomposition potential, Plant and Soil Journal, Vol. 82, pp. 41–50.
Whittle, C.A., Duchesne, L.C. and Needham, T. (1998) Soil seed bank of a jack pine ecosystem (Pinus banksiana), International Journal of Wildland Fire, Vol. 8, pp. 67–71.
Williamson, J.C. and Johnson, D.B. (1990) Determination of the activity of soil microbial populations in stored and restored soils at opencast coal sites, Soil Biology and Biochemistry Journal, Vol. 22, pp. 671–675.
Ziemkiewicz, P.F., Takyi, S.K. and Regier, H. (eds) (1980) Proceedings: workshop on reconstruction of forest soils in reclamation, Alberta Land Conservation and Reclamation Council Report # RRTAC 80-4, Edmonton, Alberta, Canada.