UNIVERSITY OF ALBERTA

Early Stages Of Calcareous Soil Reclamation Along The TMX-Anchor Loop Pipeline In Jasper National Park

By

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

Master of Science

Land Reclamation and Remediation

Department of Renewable Resources

Fall 2010
Edmonton, Alberta

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ABSTRACT

Research assessed early stages of calcareous soil reclamation along the TMX-Anchor Loop pipeline through Jasper National Park. Calcareous soils are low in nutrients and highly prone to erosion after disturbances. Four sites were established in each of five calcareous soils, and divided into three pipeline right-of-way areas; work, trench and spoil. Ten amendment treatments, established within each right-of-way areaincluded a control and combinations of wood chips, fertilizer and compost with some plots having amendments incorporated. Wood chip treatments decreased availability of soil nutrients, with small plants contributing to high vegetation densities and low cover. Compost treatments increased soil nutrients and aided large plant establishment, creating lower plant densities and higher cover. Light application rates were most successful, with higher native plant densities and cover in relation to heavy application rates, which encouraged robust non-native plants. Pipeline right-of-way areas had no overall impact on early reclamation success.

ACKNOWLEDGEMENTS

Many people have played a role in this accomplishment. I am thankful to all who have read over a page, provided insight or support, been there to listen and had the patience to endure with me!

Thank you to my supervisor, Dr. M. Anne Naeth, for the continued support, insight and ideas. Without your push I would likely not have started on this journey and definitely not finished it!

Great thanks go out to TERA Environmental Consultants and Kinder Morgan Canada for financial and technical support for this research. Thank you to the people of Jasper National Park for assistance.

To my committee members, Dr. David Chanasyk and Dr. Scott Chang, your input and assistance are greatly appreciated. Thank you for dedicating your valuable time to reviewing and providing constructive criticism throughout this process.

Huge thanks to Sarah Wilkinson for your patience, time, planning and organization throughout my work. Thank you to Ingrid Hallin for your superior field planning and organization.

Thank you to my field assistants, Courtney Anderson, Heather Archibald, Helene Marcoux, Steve Rome, Darin Sherritt and Lance Steinke. Your help, ingenuity and ability to put in endless field hours are greatly appreciated! To the students of the Naeth Grad Lab, your knowledge and friendship is greatly appreciated.

A special thanks to my friends and family for your love, support, patience and understanding. Mom, your distractions during visits home were the only way I managed to stay sane over the last few years! Dinners, care packages and an ear always willing to listen are gifts greater than you will ever know. Dad, thank you for the support in every way possible that you have provided. You are the reason I am mechanically inclined and capable of hands on work and problem solving! I love our ‘work talks’ that provided so many fantastic ideas, creative solutions and helped to develop a strong backbone! Jess and Elyce, you have both provided the greatest mental de-stressers ever during long phone conversations, lazy nights at home and the quirkiest senses of humour I have ever witnessed! To my roomies, thank you for understanding that I wasn’t being antisocial if the door was closed, and for providing outrageous entertainment when you knew that I needed a break. I will always look back on our ‘educational talks’ with a huge smile! To all my other friends and family that always have a word of encouragement – thank you.

Thank you Micheal. You believed I would eventually finish and no matter how frustrated I was, you always knew how to make me believe it too! Your insight and support has been amazing.

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CHAPTER 1: INTRODUCTION

1. BACKGROUND

Kinder Morgan Canada, in 2006, was granted approval for construction of the TMX Anchor-Loop Pipeline through Jasper National Park to meet the growing demand of Canada's western shipping routes for crude oil produced in Alberta. The pipeline right-of-way traverses five calcareous soil series in the park, which pose problems for reclamation due to their chemical and physical characteristics. They become unstable and prone to erosion after disturbance; chemical reactions and a high pH create nutrient deficiencies for plants.

This research was initiated to examine methods for reclamation and stabilization of calcareous soils along the pipeline right-of-way in Jasper National Park. The research will help to increase awareness of calcareous soils, improve their reclamation potential and limit their further deterioration after pipeline and other disturbances.

1.1 The TMX Pipeline

In the early 1950s, the original TMX pipeline was built to carry petroleum products across the Rocky Mountains (Kinder Morgan Canada Ltd. 2007a). This pipeline was operating at full capacity and had been modified to compensate for increased crude oil production and the need to transport it. To accommodate the growing volumes of petroleum products from the expanding oil sector, Kinder Morgan proposed the TMX-Anchor Loop as an expansion to the original pipeline (Figure 1), which was approved by the National Energy Board on November 23, 2006. Fisheries and Oceans Canada, Parks Canada and Environment Canada signed off on the Cumulative Effects Assessment Act screening report on June 14, 2007.

Alternate pipeline routes proposed to avoid disturbance of Jasper National Park and Mount Robson Provincial Park were not considered feasible (National Energy Board 2006). Routes to the north or south would have crossed a portion of Banff National Park or Willmore Wilderness Area where no previous linear disturbances had occurred. To go around all sensitive and protected areas of the Rocky Mountains would have involved extensive extra pipe which was not economically feasible. The original 1950s Trans-Mountain pipeline route was approved at a time when environmental considerations were not emphasized. The route was chosen because of the low elevation Yellowhead pass, making access and construction less complicated. The Jasper National Park section of the route had been approved in 1951 by a Government of Canada Order in Council with a clause allowing for "future consideration of looped pipelines as may be proposed". In 1952, a British Columbia Order in Council approved construction through Mount Robson Provincial Park. These previous agreements helped grandfather construction of the new TMX Anchor-Loop pipeline through ecologically sensitive park areas.

The project involved construction and operation of 158 km of a 91 cm diameter pipeline from the Hinton Pump Station to a location near Rearguard, British Columbia, through Jasper National Park and Mount Robson Provincial Park (National Energy Board 2006; Tera Environmental Consultants and University of Alberta 2007). The right-of-way, varying from 15 to 18 m in width along most of the pipeline, followed the existing Trans Mountain pipeline for 56 % of its length and other linear rights-of-way (highways, roads, power lines, abandoned railway grades) for 43 % of its length.

Pipeline construction began in Jasper National Park in August 2007 and final cleanup was completed by the end of April 2008, with only localized reclamation projects remaining (Kinder Morgan Canada Ltd. 2007b). Construction and cleanup was completed in Mount Robson Provincial Park in October 2008. The pipeline was put into service on October 30, 2008, increasing capacity of the TMX system from 260,000 to 300,000 barrels per day (Kinder Morgan Canada Ltd. 2008).

1.2 Regulatory Framework

Several regulatory bodies were involved in approval, construction and monitoring stages of the TMX-Anchor Loop pipeline. The federal environmental assessment coordinator for the project was the Canadian Environmental Assessment Agency.

The National Energy Board, Canadian Transportation Agency, Fisheries and Oceans Canada, Parks Canada Agency and Transportation Canada were also involved in various aspects of the regulatory process (Canadian Environmental Assessment Agency 2007).

An environmental assessment was required by section 5 of the Canadian Environmental Assessment Act based on the scope of the project and permits required by other regulating agencies (Canadian Environmental Assessment Agency 2008). The National Energy Board, through section 52 of the National Energy Board Act, issued a certificate for construction of the pipeline when "...the Board [was] satisfied that the pipeline is and will be required by the present and future public convenience and necessity..." (National Energy Board 1990). Subsection 101(3) of the Canada Transportation Act states that "...the agency may, on application, authorize the construction of a suitable road crossing, utility crossing or related work, or specify who shall maintain the crossing" (Transport Canada 1996).

Fisheries and Oceans Canada were involved by section 35(2) of the Fisheries Act stating that authorization is required to "...[cause] alteration, disruption or destruction of fish habitat by any means or under any conditions..." (Department of Justice Canada 1985). Transport Canada's Navigable Waters Protection Act (section 5(1)(a)) outlines "no work shall be built or placed in, on, over, under, through or across any navigable water..." without approval by the minister prior to construction (Transport Canada 1985). Other legislation and regulations apply to specific construction areas such as permits for individual stream crossings from Transport Canada's Navigable Water's Act and Parks Canada permits for off highway and over snow vehicle travel.

Subsection 5(1) of the National Parks Building Regulations and subsections 11(1) and 18(1) of the National Parks General Regulations require a building permit for any topsoil removal, excavation or construction of a building within a national park (Department of Justice Canada 2007a). They require permits "...to take flora or natural objects for scientific purposes from a park or to remove natural objects for construction purposes..." and "...to take water for domestic, business or railway supply purposes within a park..." (Department of Justice Canada 2007b).

1.3 Management Objectives and Desired End Results

Parks Canada provided management objectives and desired end results for the project. These are discussed in the following paragraphs (Tera Environmental Consultants and University of Alberta 2007).

Vegetation success on the right-of-way and temporary work areas was defined. Native herbaceous ground cover was required to meet the density requirement of 10 plants (native) per m^2 in 90 % of a m^2 in any 10 by 10 m area, and the combined cover of mulch (plant litter) and live native plants needed to be $\geq$ 80 % ground cover. Alternatively cover could be to a density and / or percent emulating surrounding natural undisturbed vegetation of the same or equivalent ecosite, to avoid artificial enhancement, but support restoration of ecological integrity in appropriate agreed upon situations. Vegetation needed to maintain cover and density without fertilizers beyond the cessation of expected residual effects.

Soils of the right-of-way and temporary work areas were required to provide historic natural undisturbed growing conditions and continue natural undisturbed rates and patterns of biomass and nutrient cycling and other ecological functions. For previous stockpile or storage areas, restoration was required to baseline conditions compatible with the above noted historic conditions as the ultimate target. No acceleration of soil erosion rates was allowed, beyond predisturbance levels in the project area and on specific soil conditions. The latter included extreme calcareous sites and sites with little or no topsoil, steep slopes, poor water availability or high wind exposure. No destabilizing of dune environments beyond the (by definition) dynamic nature of dunes was allowed. Restoration success would be defined as areas that emulated the surrounding natural undisturbed vegetation of the same or equivalent ecosite, accepting that this may take several years to achieve.

2. SITE HISTORY AND DESCRIPTION

Aboriginal tribes including the Shuswap and Cree were the first known inhabitants of the Rocky Mountain region (Jasper Chamber of Commerce 2008, Jasper National Park 2008). The first recorded non-aboriginal visit to the

Athabasca Valley was in 1810 by surveyor David Thompson. His trip was quickly followed by movement into the area by Iroquois guides and fur traders and development of a pack trail through Tete Jaune Pass. Travel through the mountains increased with the rumour of gold in British Columbia and many overland travellers moved through the Yellowhead pass. In 1865, Dr. John Rae surveyed the pass to determine the potential for a rail line through the mountains. By 1900, the Grande Trunk railway was committed to the construction of a second transcontinental railway which reached the town of Jasper in 1911. The Dominion Government recognized 13,000 km of the mountain region as Jasper Forest Park in 1907 and in 1930 the Canadian government established Jasper National Park as it is today.

The Rocky Mountains are located in the eastern system of the Cordilleran Region (Clayton et al. 1977). In Canada, this region extends from the Pacific Ocean to the interior plains, north to the Alaskan border and south to the 49^{th} Parallel. The eastern system consists of the Rocky Mountains and Yukon Mackenzie Mountains. The Rockies are 129 to 161 km wide and 1,448 km long, paralleled along the entire length by 25 to 60 km of foothills. Peak elevation varies from 1,830 m to greater than 3,660 m with the highest, Mount Robson, 3,956 m. This mountain range was created by thrust faults of Paleozoic limestone and quartzite and is traversed by the Liard and Peace River systems. Jasper National Park spans over 10,800 km^2 of the eastern slopes of the Rocky Mountains in western Alberta (Figure 2), ranges in altitude from 985 m to nearly 3,800 m and includes montane, sub-alpine and alpine subregions (Parks Canada 2007).

Jasper National Park has a continental climate, characterized by short, warm summers and long, cold winters (Parks Canada 2007) (Table 1). The Pacific Ocean and prevailing west winds play a major role in climate changes year round. Ocean winds move water rich clouds over the mountain ranges, depositing large amounts of precipitation in the highlands. The dry winds then move northeast through the Athabasca valley and often result in wind erosion on bare slopes. When north and east winds are prominent, an Arctic front moves in and temperatures drop.

Brunisols, Regosols and Gray Luvisols along with exposed parent material make up most of the soils in the montane, subalpine and alpine areas of Jasper

National Park (Holland 1983). The pipeline route traverses the Devona, Talbot and Hillsdale 1 soil series, which are expected to be difficult to revegetate due to a combination of calcareous chemistry (pH > 8) and coarse texture. Talbot and Devona soils occur in the eastern portion of Jasper National Park and are characterized by a thin veneer of silts and fine sands that is highly susceptible to wind erosion (Figure 3).

These soil series are very calcareous throughout the profile (Table 2) and usually developed on active sand dunes or calcareous silts and fine sands overlying gravelly fluvial or till material. The extremely calcareous surface condition and highly erodible nature are expected to make restoration efforts difficult where these soil types are encountered. Devona, Talbot and Hillsdale 1 soils are traversed for approximately 23 km along the TMX-Anchor Loop Route within Jasper National Park and Mount Robson Provincial Park (Tera Environmental Consultants and University of Alberta 2007). Other strongly to extremely calcareous soils include Hinton and Vermilion Lakes 1, encountered for 7 km along the route in Jasper National Park. Well established topsoil horizons in some of these soils may mitigate strongly to extremely calcareous conditions.

Alpine rangelands occur above the tree line at high elevations on sites with low soil nutrients, low soil water and an extremely short growing season (Elias 2002). Trees and large woody species are absent (Clayton et al. 1977) and vegetation consists of stunted, deformed trees shorn off by wind and snow (krummholz stands), willow and heather shrublands and alpine grasslands. Grasslands are comprised of very short plants including alpine blue grass (*Poa alpina* L.), alpine fescue (*Festuca brachyphylla* Schult. ex Schult. & Schult. f.), alpine timothy (*Phleum alpinum* L.), stone field lichens and low lying rhizomatous sedges.

Subalpine areas, most common on eastern slopes and uplands, are dominated by coniferous species. These species usually include engelmann spruce (*Picea engelmannii* Parry), alpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and lodgepole pine (*Pinus contorta* Dougl.) (Clayton et al. 1977). Lodgepole pine is the seral community, while engelmann spruce and alpine fir comprise climax communities. Exposed sites may have climax communities of limber and white bark pines and alpine larch. Moist, depressional areas throughout the subalpine have willow, bog birch and sedge meadows. Grasslands are limited to steep southern slopes and well drained riparian areas, and are maintained by frequent fires (Holland 1983).

In Jasper National Park montane ranges are limited to the warm, dry Miette and Athabasca valleys (Parks Canada 2007). They are dominated by white spruce (*Picea glauca* (Moench) Voss), blue douglas fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco.), lodgepole pine (*Pinus contorta* Loudon) and trembling aspen (*Populus tremuloides* Michx.) (Clayton et al. 1977). Aspen at lower elevations, and lodgepole pine at higher elevations, are seral plant communities that depend on fire. The douglas fir overstory is the modal community in the Alberta montane; it is highly productive when young but productivity drops as it matures. Young communities have less competition for light and nutrients in the understory which is often dominated by bunch grasses. Understory in a mature douglas fir stand is less productive due to competition and is dominated by shade tolerant species such as hairy wildrye (*Elymus innovatus* Beal) and pine grass (*Calamagrostis rubescens* Buckley). Rocky outcrops often have limber pine (*Pinus flexilis* James) (Holland 1983, Elias 2002). Species in the research area before pipeline construction are listed in Table 3.

3. PIPELINES

Pipeline refers to the pipe that is used for transporting fluid goods and the infrastructure required to move these products through the line. Infrastructure may include valves, pump stations, compressors, metering and delivery stations and other components necessary for the operation of the line. Pipelines are considered one of the safest and most efficient methods for long distance transportation of crude oil, natural gas, refined products, water and other products from their production and extraction locations to refineries and markets (Canadian Energy Pipeline Association 2007b).

The earliest pipelines were constructed about 500 BC in China using bound bamboo shoots to transport brines and natural gas (Canadian Energy Pipeline Association 2007b). Construction in Canada began in the early 1900s, with the longest pipeline running 270 km from Bow Island to Calgary. In 2006 the Canadian Energy and Pipeline Association, whose members transport 97 % of the crude oil and natural gas produced in Canada, estimated that 413,400 m^3 of crude oil and 480 million m^3 of natural gas were transported through more than 100,000 km of pipeline in Canada each day.

3.1 Standard Disturbances and Reclamation

Pipeline disturbances affect large, narrow tracts of land across the planet. In Canada, construction of a pipeline requires approval from the National Energy Board and must follow various other regulating bodies that may apply to pipelines of specific lengths, running through sensitive areas or otherwise related to pipeline construction areas.

After a pipeline has been approved and land access obtained, most pipeline installations follow the same basic construction steps (National Energy Board 2003). The proposed right-of-way is surveyed and pre-construction assessments are completed to determine if any sensitive areas, environmental concerns or construction challenges are present along the right-of-way. The pipeline is usually constructed in segments and specialized crews are staggered along it depending on stage of construction. These crews move progressively down the line as each section is completed.

Existing fences are opened or moved and trees are cleared (National Energy Board 2003). Large timber is often salvaged and small brush is chipped or burned. Topsoil and subsoil are stripped separately and stored in separate stockpiles on the spoil side of the right-of-way. The ground is graded to provide a safe, level work surface. As the trench is dug, sections of pipe are laid and welded together (Figure 4). Joints are checked for weld integrity and wrapped to prevent corrosion and weathering. The pipe is lowered into the trench and the trench backfilled with subsoil. Topsoil is replaced and the pipe is pressure tested with water for leaks. The right-of-way is cleaned and permission is requested from the National Energy Board to put the line into production.

Reclamation is required after pipeline construction. Reclamation techniques and equipment vary with right-of-way size, location, climate and other site specific factors. After pipeline burial, topsoil is replaced and the site is recontoured to restore drainage. Erosion control is implemented on slopes and other susceptible areas and sites are revegetated with an appropriate seed mix. Fences along the right-of-way that were moved or opened for construction are replaced or closed. Monitoring for pipeline slumping, erosion, compromised plant growth or diminished crop yield occur for several years to minimize environmental impact.

Moose Mountain pipeline, with 90 % located in Kananaskis Country recreation area, faced similar conditions as the TMX-Anchor Loop pipeline. The pipeline was constructed near Bragg Creek, Alberta beginning in 1981 and carries sour gas from fields to a compressor station. Objectives for 50.5 ha requiring reclamation were erosion control, controlled right-of-way access, minimized aesthetic impact and enhanced habitat. Topsoil and subsoil were stripped separately, stockpiled and replaced (Shell Canada Resources Limited 1980). Where inadequate for two lift stripping, subsoil and topsoil were mixed if nutrients would not be reduced. Compacted areas were scarified and seeded after soil was replaced. Brush mulch was used to improve erosion control and seedling establishment in areas with steep slopes and overland flow. Straw and commercial mulches were used with tackifiers if there were insufficient natural materials. Erosion control mats were installed in critical areas. Drainage was controlled with french drains, ditch plugs, cross ditching and recontouring. Siltation at stream crossings was reduced with minimized traffic, right angle approaches to banks and straw bales. Fertilizer improved low soil nutrients, facilitating plant establishment. Revegetation techniques included hydroseeding with tackifiers, mixes of quick establishing grass species adapted to local conditions, shrub stem cuttings and seedlings.

3.2 Pipeline Impacts

Pipeline construction affects large tracts of land and a single line may cross many soil types, plant communities and streams. A few pipelines cross the Alberta section of the Rocky Mountain range while numerous lines operate in the foothills and into the mountain range (Canadian Energy Pipeline Association 2007a). The pipelines have been constructed by companies including Pembina, TransCanada and Kinder Morgan. Soil, vegetation and environmental factors can greatly influence pipeline reclamation success and must be considered for each pipeline along its route.

Soil physical and chemical properties can be greatly influenced by pipeline construction. Research in construction and reclamation techniques, amendment applications and management strategies can help establish ways to alleviate the problems associated with pipeline construction impacts. De Jong and Button (1973) found little nutrient regime effect in the upper 15 cm across the pipeline right-of-way, with increased nutrients below 30 cm on the trench due to topsoil admixing. Culley et al. (1982) found detrimental influences on soil physical and chemical properties in the first year following construction. They found soil mixing, decreasing organic matter and nitrogen availability, and compaction occurred on fine to medium textured soil but usually not on coarse textured soils. Landsburg (1989) found pipeline construction had little influence on agricultural soil quality. Under optimum construction conditions (dry), she found no effect on soil physical properties on the work area Ap horizon, although it had elevated soluble salts on the spoil side due to admixing. She found no effect on physical or chemical properties in pasture land. Shallow topsoil stripping helped to preserve soil organic carbon (Wruck 2004).

The type of soil along a pipeline right-of-way can change as the pipeline moves across the landscape which can have a significant effect on pipeline reclamation. Solonetzic soils often have increased salts and pH at the soil surface of the trench area, especially on newly installed pipelines (De Jong and Button 1973; Landsburg 1989) with values returning to normal over time (De Jong and Button 1973). Naeth et al. (1987) found that with time, greater natural amelioration of pipeline construction induced changes occurred with soil chemical properties than with soil physical properties. They estimated that soil will take approximately 50 years to regain 50 % of its original organic matter. Permeability and aeration of solonetzic soil Bnt horizons improved as construction decreased bulk densities; this led to increased yields on the trench, especially for older pipeline disturbances (De Jong and Button 1973). Little evidence of detrimental soil chemical or physical changes as a result of pipeline construction were observed on cultivated chernozemic soils by De Jong and Button (1973). Boreal soil recovery from pipeline construction is not well documented. Soil admixing during construction increased pH, EC, soluble sulphates and exchangeable Ca and N in the upper 20 cm, but these properties tended towards normal ranges within 2 to 3 years following construction (Soon et al. 2000a). Soil organic carbon and total nitrogen was reduced after construction, with total nitrogen increasing slightly in the next two years (Soon et al. 2000b).

Pipeline construction and subsequent operation can influence soil temperature regimes throughout pipeline operation. Naeth et al. (1993) found construction activities altered soil texture, bulk density and water content. These soil changes along with the continual release of heat from compressed fluids being transported along the line contributed to changes in soil temperature regimes. Temperature was less affected at the soil surface than in subsoil and was concluded to have contributed to limited plant growth.

Pipelines can have a significant effect on surface and ground water. Berm construction over trenches to reduce subsidence, results in temporary right-of-way water ponding during snow melt and heavy rainfall events by blocking the overland flow of water (Naeth et al. 1988). Soil water in the upper 50 cm can increase with values returning to background conditions within ten years following disturbance (Naeth et al. 1988). Compaction can occur across the right-of-way, resulting in reduced water retention and infiltration rates which also self corrected within three years of construction (Soon et al. 2000b). Stream crossings during pipeline construction can be very sensitive, especially in fish bearing streams. Sediment is often released, creating suspended and then excessive deposited sediments, which can cause short term detrimental effects to downstream aquatic life and habitats by altering streambank conditions, reducing benthic invertebrates and fish populations. Recovery of downstream areas usually occurs within a year after construction (Anderson et al. 1995; Reid and Anderson 1999). At the site of the crossing, streambank conditions may be improved through proper construction and management (Reid and Anderson 1999).

Revegetation success along a pipeline right-of-way can vary greatly. Pipeline construction initially decreased crop yields which improved within five years; detrimental effects lasted longer for row crops with little impact on alfalfa (Culley et al. 1982, Culley and Dow 1988). Neilson et al. (1990) reported decreased corn silking and plant heights in the first year after construction but yield was not affected. Barley yield decreased the first year after construction but increased in the following two years. Soon et al. (2000b) found little residual soil or vegetation yield effect was evident two years after pipeline construction in boreal soils.

Natural recovery was successful in multiple studies but required appropriate conditions. Natural recovery was successful in boreal forest reclamation when paired with careful soil salvage during construction because of the large contribution of seed and propagules in the seed bank (Salisbury 2004). Seed banks in native prairie tended to aid in rapid ground cover but consisted mostly of non-native species (Petherbridge 2000). Natural recovery was successful on various pipeline disturbances in native fescue grasslands if construction techniques included minimal disturbance; recovery was too slow on larger disturbances to be considered feasible (Elsinger 2009).

Plant species composition was affected by pipeline right-of-way area where rhizomatous grasses were more successful than tufted grasses on areas with greater disturbance such as the trench, while work and spoil areas had higher plant species diversity (Ostermann 2001). Native legumes struggled to recover after pipeline construction and those that did establish decreased over time. Bare ground decreased over time and eleven to twelve years post construction, bare ground was approaching 0 %. Seeding native or agronomic species helped ameliorate soil conditions if grazing was managed to allow later seral species to establish and thrive; without grazing management the seeded community persisted (Elsinger 2009). Once established on the right-of-way, non-native, aggressive species such as *Bromus inermis* Leyss. (smooth brome grass) persisted after pipeline construction, threatening native plant community diversity and reducting dominant native species (Parker 2005). Seeding resulted in higher native grass and total vegetation covers and densities but lower forb covers and densities than natural recovery (Wruck 2004).

Neilson et al. (1990) found winter pipeline installation was less detrimental than fall installation. Topsoil stripping had little effect on canopy cover and plant density (Wruck 2004). Sod salvage methods provided successful reclamation of rough fescue communities in a study by Petherbridge (2000), who also showed that minimal disturbance combined with topsoil conservation techniques will decrease the time required for reclamation. Construction conducted without topsoil stripping influenced revegetation by creating admixed soil conditions.

Ostermann (2001) showed grazing had little effect on species composition but it increased density on some sites and decreased cover over all. Elsinger (2009) showed that on various aged pipelines, repetitive or heavy grazing negatively influenced soil and plant characteristics while occasionally increasing species richness. As grazing pressure increased, revegetation success decreased.

4. CALCAREOUS SOILS

Calcareous soils are defined in the Canadian System of Soil Classification and by the Soil Science Society of America (Agriculture and Agri-Food Canada 1998, Soil Science Society of America 2008). They contain sufficient free calcium carbonate ($CaCO_3$) and other carbonates to effervesce visibly or audibly when treated with 0.1 M cold hydrochloric acid, and contain from 10 to 1000 g kg^{-1} $CaCO_3$ equivalent.

Calcareous soils occur worldwide, typically in arid and semi-arid climates (Figure 5). They are usually formed on glacial till, eolian and glaciolacustrine surface deposits or limestone bedrock. In Jasper National Park, limestone bedrock and glacial drift are the most common origins for calcareous soils (Dumanski et al. 1972, Wittenben and Lacelle 1986, Lacelle 1990). Calcisols, defined by the Food and Agriculture Organization as soils with substantial accumulation of $CaCO_3$, occur on approximately 324 million hectares of land in Africa, Australia, Europe, north, south and central America and north, central, south and southeast Asia. Calcareous soils, not classified as calcisols because they exhibit other more prominent characteristics, are not included in this estimate; therefore it does not accurately represent the land area influenced by calcareous soil (Land and Plant Nutrition Management Service 2000).

4.1 Calcareous Soil Properties and Associated Reclamation Challenges

Calcareous soil particle size and bulk density create conditions highly susceptible to wind erosion. Wind moves soil via long distance transport, saltation and rolling (Russel 1973), with saltation causing the most damage to soils and vegetation. Saltation occurs when medium sized particles (0.1 to 0.5 mm) are picked up by the wind, carried short distances just above the soil surface (up to 1 m) and dropped back onto the soil. The momentum carried by the particles when they are dropped is transferred to the soil at the contact location causing a spray of soil particles into the air, increasing the amount of soil affected by moving air. Saltation is the most common type of erosion on calcareous soils because these particle sizes are most common. Disturbance of these calcareous soils during pipeline construction increases the ratio of medium sized particles to fine and coarse particles by breaking up soil clods, further encouraging soil erosion (Ruellan 1972). Water content and mulch or vegetation covers are the best guards against wind erosion.

Water erosion is often classified as chemical, physical or rain splash. Rain splash occurs when loose, exposed soil material is hit by falling precipitation and is moved. Chemical erosion usually occurs where soluble rock, such as limestone, is found and involves the dissolution and transport of material in solution. Physical erosion occurs when moving water has enough velocity to pick up and move soil particles. This is a greater risk on bare soils, steep slopes and on soils where permeability is decreased. (Canadian Encyclopedia 2010)

Plant establishment and growth are difficult in calcareous soils due to high pH, low nutrient availability and high bicarbonate and calcium (Maynard et al. 1997). Iron and calcium carbonate react to form insoluble iron oxides, resulting in iron chlorosis and iron deficiencies in plants (Loeppert et al. 1984). Phosphorous becomes unavailable because of phosphate ion adsorption to carbonate minerals (Thorne and Seatz 1955, Talibudeen 1981) or insoluble calcium-phosphate mineral formation in highly concentrated calcium soils (Talibudeen 1981, Kinzel 1983, Marion et al. 1993). Nitrogen deficiencies occur with increased nitrate and increased nitrification in soils with basic pHs (Martikainen 1984, Sahrawa et al. 1985, von Mersi et al. 1992, Priha and Smolander 1995). Calcium and potassium imbalances result in potassium deficiencies, especially in douglas fir and lodgepole pine (Clement et al. 1977, Ulrich 1983, Bonneau 1992, Smith and Wass 1994a). Manganese, zinc, copper and boron can be deficient (Talibudeen 1981, Marschner 1995) due to decreased solubility, formation of precipitates (Thorne and Seatz 1955, Marschner 1995) and increased adsorption to calcium carbonate minerals (Udo et al. 1970, Mesquita and Vieira e Silva 1996).

Rooting zone cementation in calcareous soils occurs if carbonates precipitate, alone or with other anions and adsorb to the soil, coating soil particles and filling pore space (Oyanarte et al. 1994, Curran 1999, Rattan 2002). Cultivation or other disturbances can encourage crust formation by degrading soil structure (Ruellan 1972). This may limit plant growth but should not be a problem on the trench where soil was lifted out, peds were broken and then the soil was replaced. This cementation may be of concern on the work area due to machinery compaction.

4.2 Calcareous Soil Reclamation Research

The Food and Agriculture Organization of the United Nations and the United Nations Development Programme held a regional seminar on reclamation and management of calcareous soils in 1972 in Cairo, Egypt. The seminar focused on the Near East (Afghanistan, Iran, Iraq, Jordan, Pakistan, Sudan, Saudi Arabia, etc.) and the challenges faced in these areas due to calcareous soils (Food and Agriculture Organization 1973). The challenges, related to nutrient deficiencies in calcareous soils, and the need to find a greater land base for agriculture for sustaining eastern populations. Reclamation and management techniques focused on the issues in that part of the world, but can be applied to calcareous soils across the planet.

Little research has been conducted in North America to address the challenges and concerns associated with reclamation of calcareous soils. Documents addressing the issue of nutrient availability exist, but are largely concerned with agricultural production on calcareous soils that have been created by a disturbance or those with saline-sodic properties rather than naturally occurring calcareous soils.

Lack of available nutrients is the focus of most reclamation research on calcareous soils. Phosphorous is the most limiting nutrient due to fixation, reducing efficiency to less than 20 % (Spinks and Barber 1947, Tisdale et al. 1993). Phosphorous is not readily available for plant uptake because higher soil pH creates reactions between phosphate ions and carbonate minerals forming insoluble $CaPO_4$ minerals (Thorne and Seatz 1955, Talibudeen 1981, Kinzel 1983, Marion et al. 1993).

Several potential solutions for phosphorous deficiencies in calcareous soils have been proposed. Mycorrhizal fungi associations create organic acid secretions that help dissolution of carbonate minerals (Malajczuk and Cromack 1982, Callot et al. 1985) and phosphorous can be more efficiently extracted when plant roots release organic acids, lowering pH and improving dissolution (Ström et al. 2005). Adding carbon to calcareous soils increased microbial biomass and available phosphorous (Bünemann et al. 2008). Fluid monoammonium fertilizers provide phosphorous that is less likely to become fixed in the soil compared to granular monoammonium fertilizers, resulting in increased crop production (Lombi et al. 2004). Sludge amendments, used for calcareous soil reclamation, reduce soil pH just enough to improve phosphorous nutrient availability and uptake (O'Connor et al. 1986). Phosphorous induced zinc deficiencies are also a problem as lack of phosphorous increases zinc adsorption, decreasing availability (Saeed 1977); so improving phosphorous availability will aid zinc uptake.

Insoluble sulphur in some calcareous Canadian soils was up to 42 % and unavailable to plants due to co-precipitation with carbonates (Roberts and Bettany 1985). Reaction with hydrogen ions released insoluble sulphur showing pH plays an important role in sulphur availability in calcareous soils (Hu 2005).

Soil pH limits nutrients other than phosphorus and sulphur. Iron and manganese react with carbonates forming insoluble iron oxides and precipitating carbonate minerals (Loeppert et al. 1984, Thorne and Seatz 1955, Marschner 1995); manganese, copper and zinc undergo adsorption reactions with calcium carbonates (Udo et al. 1970, Mesquita and Vieira e Silva 1996). Ryan and Hariq (1983) used chelates of manganese, zinc and copper to increase availability to plants. Less is known about nitrogen deficiencies in plants growing in calcareous soils but Stams and Marnette (1990) showed that nitrification is greater on calcareous soils than non-calcareous soils. High soil solution calcium concentrations may decrease potassium uptake (Thorne and Seatz 1955) and induce potassium deficiencies (Clement et al. 1977, Ulrich 1983, Bonneau 1992).

Many studies have been conducted on waste sulfuric acid as an amendment for calcareous soils. Yahia et al. (1975) showed addition of sulfuric acid from copper smelters to calcareous soils, especially those affected by sodium, improved water infiltration rates up to an optimum application rate of 5 to 15 tonnes ha^{-1}. Sulfuric acid application improved nutrient availability by decreasing soil pH, solubilising $CaCO_3$ and improving availability of insoluble nutrients in the soil (Linderman et al. 1991). Nutrient availability further improved when an organic amendment such as cattle manure was added as an additional nutrient source (Cates et al. 1982). Crusting was prevented by applications of sulfuric acid and gypsum (Amezketa et al. 2005), which also helped to solve the problem of using large scale industrial wastes. Elemental sulphur, produced as a large scale waste by some industries, may provide enough acidification to improve nutrient availability (Kalbasi et al. 1988, Singh and Chaudhari 1997, Kaplan and Orman 1998).

Other amendments have been considered for reclaiming calcareous soils and often involved disposal of industry wastes. Robbins et al. (1996) attempted to use irrigated cheese whey, which is high in calcium, magnesium, sodium and potassium, and found it helped decrease soil pH but was only beneficial for salt tolerant species because salt sensitive species suffered from foliar burn. Amendments with rapid initial release of nutrients, such as chicken manure and sewage sludge, were best for increasing crop production (Costa et al. 1989). Bentonite improved infiltration rates and water holding capacity on sandy calcareous soils (Al-Omran 2002). Sewage sludge was used by Brofas et al. (2000) for reclamation of calcareous bauxite mine spoil reclamation, with increased plant biomass, foliar cover and plant density over the first four growing seasons and by Moral et al. (2002) with a continual increase in available nutrients over 150 days. Composted urban waste used by Gallardo-Lara (2006) had similar results for lettuce and barley crops.

4.3 Amendments to Address Reclamation Challenges

Organic matter is often lost during soil disturbance either through dilution of topsoil with subsoil, topsoil erosion or stockpiling. Amendments, as suggested by previous calcareous soil research, are necessary for improving nutrient availability and soil stability. They are used on disturbed sites to quickly increase soil organic matter, add nutrients and improve soil physical properties (Land Resources Network Ltd. 1993). Only the amendments used for the current calcareous soil research sites are described below. These amendments were chosen based on the restriction of bringing foreign material into Jasper National Park, and for their erosion control and potential nutrient additions to the soil.

Fertilizers are used worldwide as a source of plant nutrients to supplement soil fertility. Most fertilizers contain nitrogen, phosphorous, potassium and sometimes sulphur. World food production has increased by 75 % since the 1950s from increased yield and not increased land use (Troeh and Thompson 1993). Approximately half of this yield increase is due to fertilizer use.

Compost can be derived from many sources including plant parts, manure, sewage sludge, animal bedding and household garbage. When applied to soil as an amendment, municipal solid waste compost can influence soil pH, increase soluble salts, electric conductivity, cation exchange capacity, organic matter and available nutrients (Land Resources Network Ltd. 1993). Soil aeration and pore volume increase and soil density decreases with the incorporation of compost. There is a potential for heavy metal contamination in the soil, but most metals are strongly bound to organic matter and are unavailable in the soil. Municipal solid waste composted with wood chips may have high carbon to nitrogen ratios.

Wood waste is commonly used as a soil amendment or mulch and is composed of approximately 50 % carbon, 44 % oxygen, 6 % hydrogen and trace amounts of nitrogen (Land Resources Network Ltd. 1993). This composition creates a high carbon to nitrogen ratio. Wood chips are useful but application method can alter effectiveness. Large chips are more effective as mulch than soil amendment and even small chips may provide few nutrients unless incorporated into the soil. All wood chip applications will increase water retention, decrease erosion and weed emergence and immobilize available nutrients such as nitrogen. Incorporation can benefit soil by increasing aeration and tilth. Wood chips decompose slowly, at approximately 25 % over five years, and do not stimulate soil organism activity. Applying wood waste to the soil can decrease soil pH, soluble cations and electric conductivity while increasing sodium adsorption ratio.

5. RESEARCH OBJECTIVES AND HYPOTHESES

The overall research objective is to evaluate selected soil amendments and revegetation procedures that will most effectively and quickly reclaim calcareous soils along a pipeline right-of-way in Jasper National Park. The research will focus on the critical early establishment period in the first growing season.

Specific objectives are as follows.

- Evaluate fertilizer, compost and wood chips amendments to determine which provides the most suitable substrate conditions for native plant species and minimizes erosion potential on newly disturbed soils.
- Evaluate two compost application rates and two methods of application for compost and wood chip amendments to determine which provides the most initial benefit to soil physical and chemical properties and improves native vegetation establishment while minimizing labour and cost.

The following are the hypotheses for the TMX research project on calcareous soil reclamation based on previous knowledge of plant-soil interactions and amendment use.

- Soils series will exhibit similar responses to individual soil amendments.
- Wood chip treatments will provide better erosion control than compost or fertilizer treatments.
- Heavy compost application will provide better erosion control than light application.
- Incorporating amendments will decrease their ability to aid in wind erosion control but will increase their water erosion control potential and nutrient availability.
- Heavy application of compost will provide the greatest soil nutrients, resulting in increased establishment success.
- Fertilizer application will aid in early establishment of native plant species, especially in wood chip plus fertilizer treatments.

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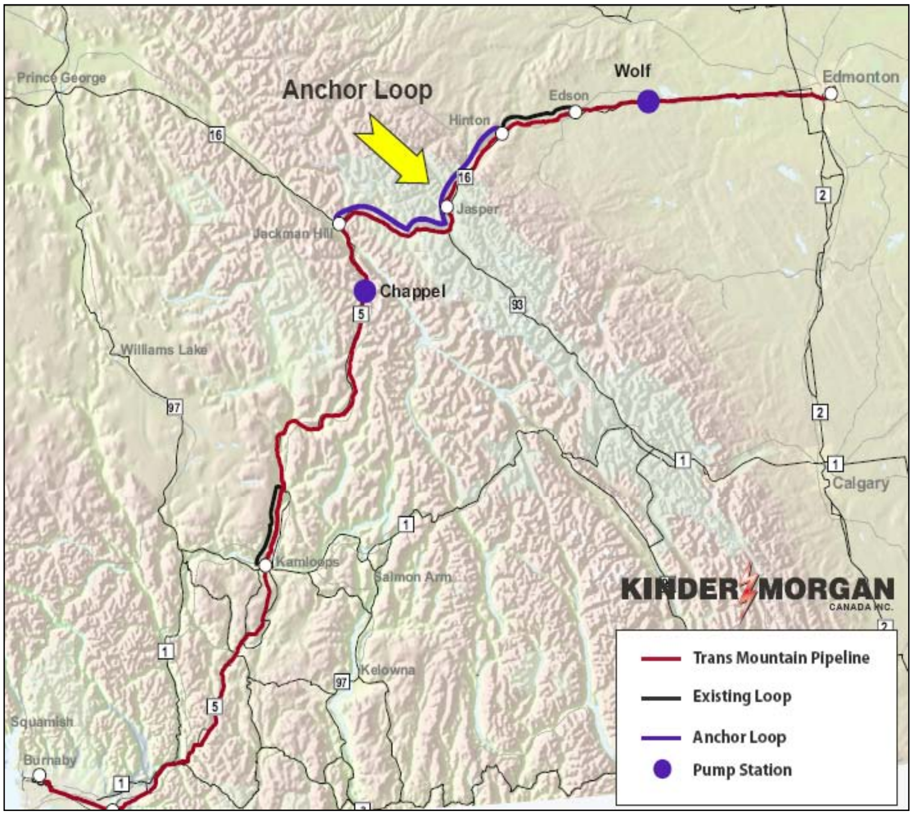

Figure 1. Map of the old TMX pipeline, the new TMX-Anchor Loop project and new pump stations (Kinder Morgan Canada, TMX 2006).

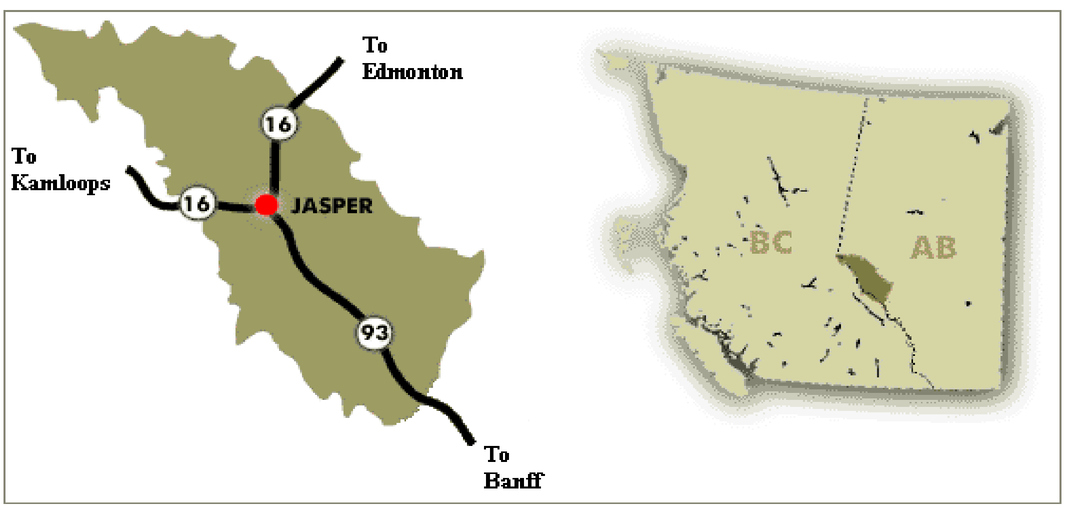

Figure 2. General Jasper National Park location (Adapted from Canadian Rockies 2008).

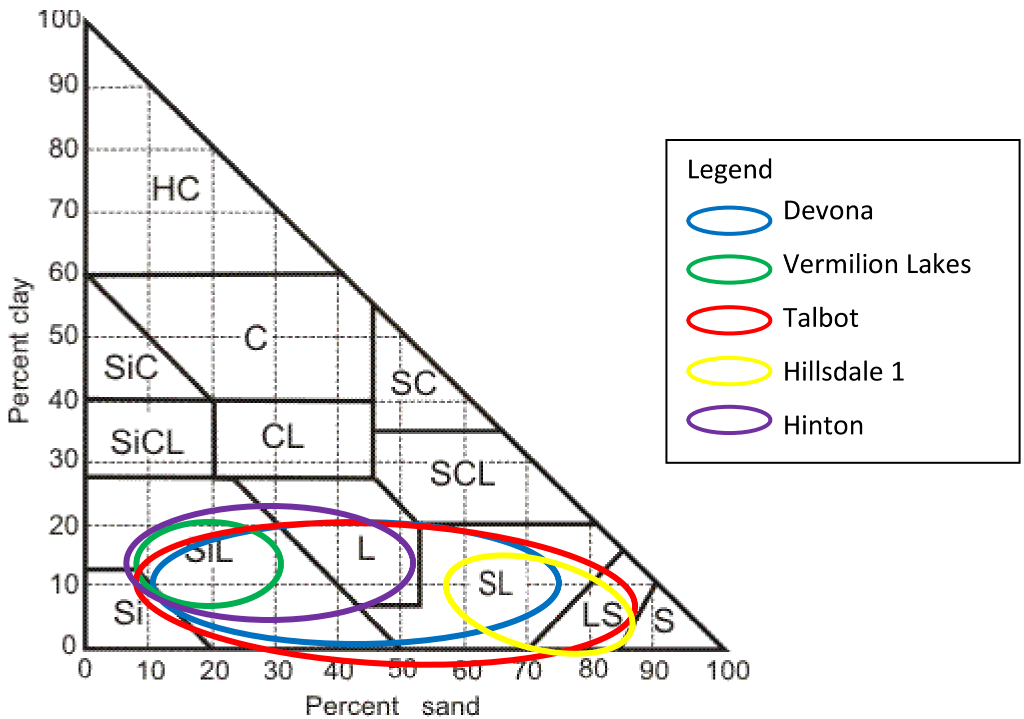

Figure 3. Five calcareous soil unit textural ranges plotted on a texture triangle.

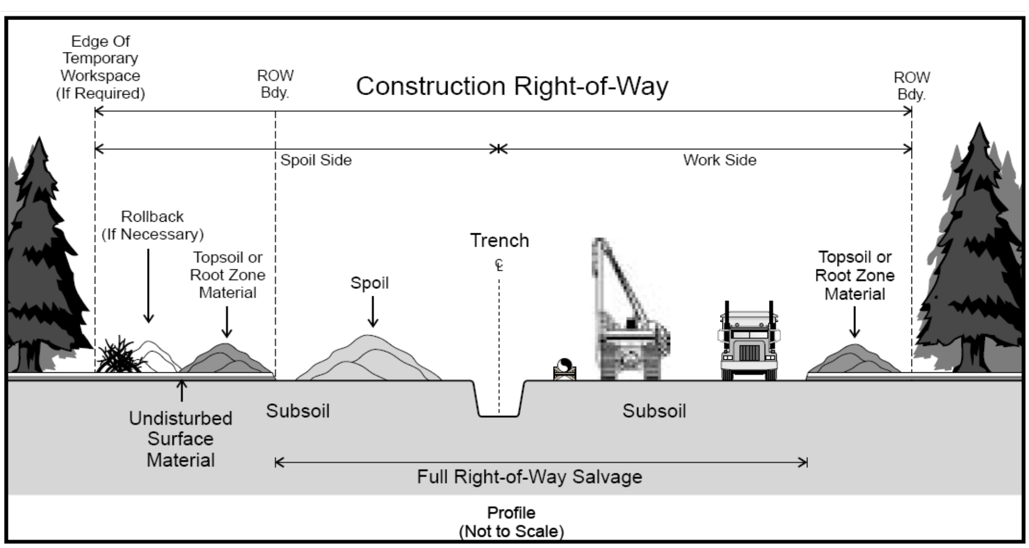

Figure 4. Diagram of basic disturbance by pipeline construction (Kinder Morgan Canada Ltd. 2007a).

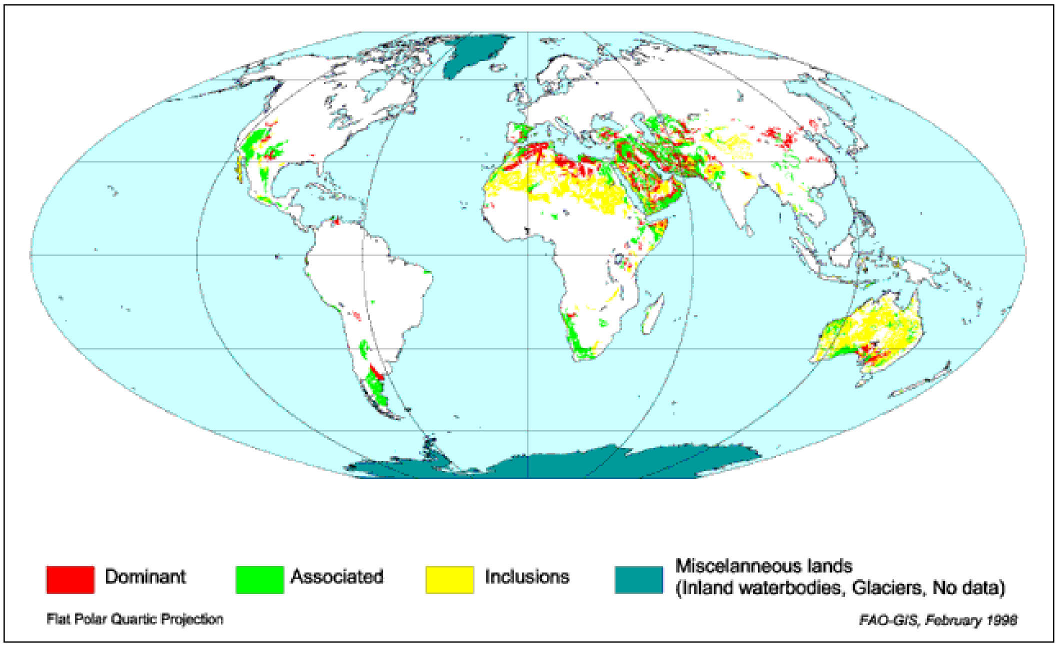

Figure 5. Global distribution of calcisols, associated calcareous soils and inclusions (Land and Plant Nutrition Management Service 2000).

Table 1. Canadian climate normals from 1971 to 2000 for Jasper (Environment Canada 2002).

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Air Temperature (^oC)	-9.8	-6.3	-1.2	4.3	9.1	12.8	15	14.5	9.8	4.5	-4	-9.2
Precipitation (mm)	26.9	16	17.6	18.8	29.9	55	60.1	59.1	37.3	28.7	24.5	24.8
Snowfall (cm)	30.5	18.3	16.9	8.6	1.4	0.3	0	0.2	1.9	8	21.6	30.3
Rainfall (mm)	4.5	2.8	5.1	12	28.7	54.7	60.1	59	35.9	22.1	8.3	3.4
Snow Depth (cm)	23	24	15	2	0	0	0	0	0	0	5	16
Wind Speed (km h^{-1}) SW	9.2	9.1	8.3	8.6	8.5	8.1	7.9	7.3	7.6	8.5	8.7	9.1
Relative Humidity (%) 0600 h	81.4	80.9	80.8	80.2	80	81	83	87	86.8	82.3	83.5	82.3
Relative Humidity (%) 1500 h	70.9	61.5	49.9	38.5	38.3	40.5	41.8	44.2	47.1	50.8	66.7	74.3

Table 2. Calcareous soil series descriptions (TERA Environmental Consultants and University of Alberta 2007).

Soil Series	Soil Classification	Parent Material	Texture	Topsoil Depth (cm)	Calcareous Surface
Devona	Calcareous orthic, Calcareous cumulic regosol	Eolian	Silt loam to very fine sandy loam	13-22	Extremely
Vermilion Lakes	Calcareous rego gleysol	Fluvial	Silt loam	0-22	Strongly to very strongly
Talbot	Calcareous orthic, Calcareous cumulic regosol	Eolian / fluvial or till	Silt loam / gravelly sandy loam to gravelly loamy sand	9-35	Extremely
Hillsdale 1	Calcareous orthic, Calcareous cumulic regosol	Fluvial fan	Very fine sandy loam to gravelly loamy sand	0-25	Strongly to very strongly
Hinton	Calcareous melanic brunisol	Eolian / till	Loam to silt loam / stony loam	10-90	Strongly to extremely

Table 3. Common plant species occurring on calcareous soil sites from predisturbance data collection on the pipeline right-of-way.

Scientific Name	Common Name
Amelanchier alnifolia Nutt.	Saskatoon
Antennaria alpina(L.) Gaertn.	Alpine pussytoes
Arctostaphylos uva-ursi (L.) Spreng.	Common bearberry
Artemisia frigida Willd.	Pasture sage
Aster conspicuus Lindl.	Showy aster
Astragalus americanus (Hook.) M.E. Jones	American milk vetch
Carex phaeocephala Piper	Head like sedge
Castilleja miniata Douglas ex Hook.	Indian paintbrush
Chrysopsis villosa (Pursh) Nutt. ex DC.	Golden aster
Cornus canadensis L.	Bunchberry
Cornus sericea Michx.	Red osier dogwood
Equisetum arvense L.	Common horsetail
Fragaria virginiana Mill.	Wild strawberry
Gaillardia aristata Pursh.	Brown eyed susan
Galium boreale L.	Northern bedstraw
Hedysarum boreale Nutt.	Northern sweet vetch
Juniperus communis L.	Common juniper
Juniperus horizontalis Moench	Creeping juniper
Koeleria macrantha (L.) J.A. Schultes f.	June grass
Lilium philadelphicum L.	Wood lily
Maianthemum canadense Desf.	Lily of the valley
Maianthemum stellatum (L.) Link	Star flower soloman’s seal
Mertensia paniculata (Aiton) G. Don	Alpine bluebell
Pentaphylloides floribunda (Pursh) A. Love	Shrubby cinquefoil
Picea glauca (Moench) Voss	White spruce
Pinus contorta Loudon	Lodgepole pine
Poa alpina L.	Alpine bluegrass
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen
Rosa acicularis Lindl.	Wild rose
Shepherdia canadensis (L.) Nutt.	Canada buffaloberry
Smilacina racemosa (L.) Desf.	False soloman's seal
Solidago multiradiata Aiton	Northern goldenrod
Stipa viridula (Trin.) Barkworth	Green needle grass
Trisetum spicatum (L.) Richt.	Spike trisetum
Vaccinium membranaceum Douglas ex Torr.	Mountain huckleberry
Vicia americana Muhl.	American vetch
Zigadenus elegans (Pursh)	Mountain death camas
Zigadenus venenosus S. Watson	Death camas

CHAPTER 2: EARLY STAGES OF CALCAREOUS SOIL RECLAMATION ON THE TMX-ANCHOR LOOP PIPELINE IN JASPER NATIONAL PARK, ALBERTA, CANADA

1. INTRODUCTION

The need to move increasing quantities of Alberta crude oil to Canada's west coast required that the Rocky Mountains be traversed by pipeline. The TMX-Anchor Loop pipeline crosses five calcareous soil series through Jasper National Park. Calcareous soils are challenging to reclaim and little research has been conducted on their reclamation.

Calcareous soils are low in available nutrients and have high erosion and cementation potential after disturbances. Plant establishment and growth are affected by high pH, low nutrient availability and high bicarbonate and calcium concentrations (Maynard et al. 1997). Iron and calcium carbonate react to form insoluble iron oxides resulting in iron chlorosis and iron deficiencies in plants (Loeppert et al. 1984). Phosphorous becomes unavailable due to phosphate ion adsorption to carbonate minerals (Thorne and Seatz 1955, Talibudeen 1981) or insoluble calcium-phosphate mineral formation in highly concentrated calcium soils (Talibudeen 1981, Kinzel 1983, Marion et al. 1993). Nitrogen deficiencies are associated with increased nitrification in soils with basic pH (Martikainen 1984, Sahrawa et al. 1985, von Mersi et al. 1992, Priha and Smolander 1995). Calcium and potassium imbalances result in potassium deficiencies, especially in douglas fir and lodgepole pine (Clement et al. 1977, Ulrich 1983, Bonneau 1992, Smith and Wass 1994a) and manganese, zinc, copper and boron can be deficient (Talibudeen 1981, Marschner 1995) due to decreased solubility, formation of precipitates (Thorne and Seatz 1955, Marschner 1995) and increased adsorption to calcium carbonate minerals (Udo et al. 1970, Mesquita and Vieira e Silva 1996).

Sulfuric acid application to calcareous soils decreased pH, solubilized $CaCO_3$ and increased availability of nutrients in insoluble forms (Linderman et al. 1991). Elemental sulphur, a large scale waste from some industries, provided enough acidification to improve nutrient availability (Singh and Chaudhari 1997, Kalbasi et al. 1988, Kaplan and Orman 1998). Adding sulfuric acid from copper smelters, especially to soils affected by sodium, increased water infiltration rates up to an optimum application rate of 5 to 15 tonnes ha^{-1} (Yahia et al. 1975). Irrigated cheese whey decreased soil pH (Robbins et al. 1996) and bentonite increased infiltration rates and water holding capacity on sandy calcareous soils (Al-Omran 2002). Sewage sludge for reclaiming calcareous bauxite mine spoil increased plant biomass, foliar cover and plant density (Brofas et al. 2000) and provided a continual increase in available nutrients over 150 days (Moral et al. 2002). Costa et al. (1989) suggested amendments with rapid initial release of nutrients, such as chicken manure and sewage sludge, to increase crop production.

Soil properties can be significantly influenced by pipeline construction. De Jong and Button (1973) found little effect on nutrient regime in the upper 15 cm across a pipeline right-of-way, with increased nutrients below 30 cm on the trench due to topsoil admixing. Culley et al. (1982) found soil mixing, decreased organic matter and nitrogen availability and compaction on fine to medium but not coarse textured soil. Shallow topsoil stripping helped preserve soil organic carbon (Wruck 2004). Solonetzic soils often had increased salts and pH at the surface of the trench, especially on newly installed pipelines (De Jong and Button 1973; Landsburg 1989) with values returning to normal over time (De Jong and Button 1973). Soil water in the upper 50 cm increased, returning to background conditions within ten years following disturbance (Naeth et al. 1988). Compaction occurred across the right-of-way resulting in reduced water retention and infiltration rates which also self corrected within three years of construction (Soon et al. 2000b). Naeth et al. (1987) found that with time, greater natural amelioration of pipeline construction induced changes occurred with soil chemical properties than with soil physical properties. They estimated soil would take approximately 50 years to regain 50 % of its original organic matter.

Revegetation success was also affected by pipeline construction. Crop yields decreased but improved within five years; effects lasted longer for row crops with little impact on alfalfa (Culley et al. 1982, Culley and Dow 1988). Soon et al. (2000b) found little yield effect evident two years after pipeline construction in boreal soils. Ostermann (2001) found rhizomatous grasses were more successful than tufted grasses on the highly disturbed trench, while work and spoil areas had higher diversity. Few native legumes established, then decreased over time.

Eleven to twelve years post-construction, bare ground was near zero. Seeding with native or agronomic species helped ameliorate soil conditions if they were managed for later seral species establishment; without grazing management the seeded community persisted indefinitely (Elsinger 2009). Non-native, aggressive species, such as *Bromus inermis* Leyss. (smooth brome grass), persisted long term, threatening native plant community diversity and reduction of dominant native species (Parker 2005). Seeding resulted in higher native grass and total vegetation cover and density but lower forb cover and density than natural recovery (Wruck 2004).

Soil amendments were considered necessary to improve reclamation potential of calcareous soils along the TMX-Anchor Loop pipeline right-of-way. Since the calcareous soils occurred in a national park, amendments needed to be locally available in Jasper National Park or approved by the park for use. Wood chips from the clearing of the pipeline right-of-way before construction commenced, MSW compost from the Town of Jasper and a pipeline prescribed fertilizer were utilized on the calcareous soil plots for this research.

2. RESEARCH OBJECTIVES

The objective of this research was to determine appropriate techniques for calcareous soil reclamation along the TMX-Anchor Loop pipeline in Jasper National Park. Challenges included addressing nutrient deficiencies and erosion problems while utilizing only locally available amendments or amendments approved for use in a national park to create natural conditions along the pipeline right-of-way. Specific research objectives were as follows.

- Evaluate fertilizer, compost and wood chips amendments to determine which provides the most suitable substrate conditions for native plant species and minimizes erosion potential on newly disturbed soils.
- Evaluate two compost application rates and two methods of application for compost and wood chip amendments to determine which provides the most initial benefit to soil physical and chemical properties and improves native vegetation establishment while minimizing labour and cost.

3. MATERIALS AND METHODS

3.1 Research Site Description

The research site was located in Jasper National Park on the eastern slopes of the Rocky Mountains of western Alberta in montane subregions (Parks Canada 2007) (Figure 1). Jasper National Park has a continental climate, characterized by short, warm summers and long, cold winters (Table 1) (Parks Canada 2007).

Montane ranges are limited to the warm, dry Miette and Athabasca valleys (Parks Canada 2007). They are dominated by white spruce (*Picea glauca* (Moench) Voss), blue douglas fir (*Pseudotsuga merziesii* var. *glauca* [Beissn.] Franco.), lodgepole pine (*Pinus contorta* Loudon) and trembling aspen (*Populus tremuloides* Michx.) (Clayton et al. 1977). Trembling aspen at lower elevations, and lodgepole pine at higher elevations, are seral plant communities and depend on fire for development. Rocky outcrops are often vegetated with limber pine *Pinus flexilis* James (limber pine) (Holland 1983, Elias 2002).

Five calcareous soil series of theTalbot, Devona, Hillsdale 1, Hinton and Vermilion Lakes soil series occur along the pipeline route. These soils usually develop on active sand dunes or calcareous silts and fine sands overlying gravely fluvial or till material and are very calcareous throughout the profile (Table 2). Devona, Talbot and Hillsdale 1 soils occur for approximately 23 km along the TMX-Anchor Loop Route within Jasper National Park and Mount Robson Provincial Park; Hinton and Vermilion Lakes 1 soils occur for 7 km along the route in Jasper National Park (Tera Environmental Consultants and University of Alberta 2007). Well established topsoil horizons in some of these soils may mitigate strongly to extremely calcareous conditions (Table 2).

3.2 Site Reconnaissance

A field reconnaissance survey was conducted July 9 to 14, 2007 to select research sites and collect pre-construction soil and vegetation data. Each of the five calcareous soil series along the pipeline right-of-way were assessed for spatial diversity and topographic characteristics and four study sites were chosen for each soil unit using detailed alignment sheets of the proposed right-of-way.

Areas with the soil series of interest were located on maps and sites were spaced along the pipeline based on occurrence frequency (Figure 2). Sites were marked with GPS and soil and vegetation in the area were assessed.

Soil was sampled with a dutch auger for most laboratory analyses and a Star Quality forest soil sampler (60 cm x 5 cm) for bulk density. Samples were taken at 0 to 15, 15 to 30 and 30 to 50 cm depth increments on proposed work, trench and spoil locations of the right-of-way. Samples were sealed in labelled plastic bags and stored in a cooler for 4 days until sent to ALS Laboratory for analyses. Analyses included organic carbon, inorganic and total carbon, carbonate (CO_3), bulk density, total organic nitrogen, available nitrogen, phosphorous, potassium, sulphur, particle size and detailed salinity (Table 3). Penetration resistance measurements were taken with a Star Quality center cone penetrometer at 5 and 15 cm at the same sites and general locations as the soil cores.

Vegetation was visually assessed using three 1 m^2 quadrats randomly located on the proposed work, trench and spoil areas of the right-of-way for a total of nine quadrats per site; 36 per calcareous soil. Total cover, cover by plant species, litter and bare ground were estimated. Plant species not identified were collected for later identification in the laboratory. All species found during vegetation assessments are listed in Table 4.

3.3 Experimental Design and Treatments

The experimental design was a split split plot, including 5 soil series, 3 pipeline right-of-way locations and three amendments. Within each of the 5 research sites (corresponding to soil unit), thirty 1.5 m^2 plots were constructed from June 14 to 18, August 24 to 29 and September 17 and 18, 2008; 10 in each of the 3 sections of the pipeline right-of-way (work, trench, spoil stockpile) for a total of 598 plots (two fertilizer plots were not set up because of site size restrictions) (Figure 3). The plots on each site were randomly assigned one of ten soil amendment treatments: control, fertilizer, wood chips incorporated, wood chips incorporated with fertilizer, wood chips unincorporated, wood chips unincorporated with fertilizer, compost heavy application, compost heavy application incorporated, compost light application, compost light application incorporated. Each treatment was present only once for each right-of-way section. On September 19 and 20, 2008, each plot was broadcast seeded at a rate of 18 kg ha^{-1} with a prescribed calcareous soil seed mix created by Parks Canada staff, TERA Environmental staff and Dr. M.A. Naeth of the University of Alberta for the calcareous areas along the pipeline (Table 5). A 27-26-0 fertilizer was applied by hand broadcasting on June 2 and 3, 2009 as vegetation began to emerge.

A pipeline right-of-way contains distinct areas. The work area, which is most highly compacted, provides space for machinery, travel and other construction activities. Soil is excavated from the trench area into which the pipeline is lowered and then covered. This area has the highest admixing and is at greatest risk for soil slumping after construction. Soil horizons and structure are removed, making soil physical properties on the trench the most degraded of the right-of-way. The spoil area is used for stockpiling excavated soil, and sometimes pipe, and undergoes the least damage during pipeline construction. Each site was divided into these areas and amendment treatments applied to each (Figure 3).

Aged municipal solid waste (MSW) compost from the town of Jasper (analysis results in Table 6) was applied as two heavy and two light applications, with one of each incorporated to a depth of 10 cm and the others unincorporated. Heavy treatments were applied at a depth of 2.52 cm (19.5 kg $plot^{-1}$); light treatments were applied at a depth of 0.84 cm (6.5 kg $plot^{-1}$). Rates were determined based on product availability, practicality for large scale application, erosion control and sufficient nutrients for vegetation establishment. These rates were converted to a volume per plot for efficient field application. Amendments were added to the pails without packing, poured onto the appropriate plots, then hand raked evenly over the surface. After being spread, incorporated amendments were dug and turned into the soil with a shovel to a 10 cm depth, then raked to obtain an even surface. Compost treatments were expected to add soil nutrients and increase soil organic carbon. The heavy application was expected to provide more wind erosion control than the light application; incorporation was expected to provide less control of wind erosion but increase control of water erosion and increase nutrient availability and organic matter to the soil in the rooting zone.

Wood chips, stockpiled over winter before use, were retained from the right-of-way clean up of slash piles and applied to the soil surface at a depth of 1.68 cm

(10.5 kg plot^{-1}). This rate was determined the same way as the compost treatments based on availability, erosion control properties and manageable volume per plot. Two plots treated with wood chips were incorporated in the same manner as the compost. One of the incorporated plots and one of the unincorporated plots were fertilized in spring 2009. The incorporation intended to reduce plants rooting directly in the wood chips which could compromise long term survival because of reduced soil-root contact. Incorporation was expected to decrease decomposition time, providing organic carbon to the soil at a faster rate. Wood chips were expected to provide high water erosion control because they would slow runoff and provide protection from wind.

Fertilizer was broadcast by hand on June 2 and 3, 2009. Although valuable for erosion control and long term nutrient cycling, the wood chip treatments may increase C:N ratio and immobilize available nutrients. Fertilizer was expected to add nutrients and balance C:N ratio. A 27-26-0 (nitrogen, phosphorus, potassium) slow release fertilizer was applied at a rate of 135 kg ha^{-1} in keeping with the pipeline company's prescribed practice.

3.4 Soil Sampling and Measurements

Soil penetration resistance was measured with a CN-973 cone penetrometer with a 15^{o} semi angle cone with a 12 mm diameter June 22 to 27, 2009. Dial measurements were recorded in psi and a calculation was used to convert raw data to MPa data (see calculation in Appendix). Five readings were taken at each of three depths (5, 10, 15 cm) in each plot. Values were averaged to determine penetration resistance for each depth for each plot. Observations were made for evidence of soil crusting during penetrometer measurements, and involved looking for a surface layer of soil that could be lifted in one piece or was resistant to pressure by the penetrometer or sampler's hand, but none that would impede germination or plant growth were observed.

Soil was sampled from June 22 to 27 at 0 to 5 cm and 5 to 15 cm depths in the most south east corner of each plot, approximately 25 cm from the outer plot edge (Figure 4). Due to the rocky conditions of many sites, samples were collected using a trowel marked for 5 and 15 cm depths. Samples were placed in sealed plastic bags, stored in coolers until field sampling was complete, then stored in a refrigerator for 4 days. Due to financial constraints, the two depth samples from each plot were combined into one 0 to 15 cm sample then taken to the Calgary ALS Laboratory for analyses. Samples were analyzed for pH, organic and inorganic carbon, total carbon and nitrogen, available nutrients and calcium carbonate equivalents using standard methods (Table 3).

Three soil water measurements were taken at each plot using a ThetaProbe ML2x probe from June 22 to 27, 2009 and were located along the north edge, south east and south west corners of each plot (Figure 4). Measurements were taken to the probe depth of 15 cm. Values were averaged to provide one soil water measurement for each plot.

Erosion pins, consisting of 15 cm steel spikes with tops painted neon green to increase ease of relocation, were installed flush with the soil surface on each plot on June 2 and 3, 2009 and visual evidence of erosion was noted. Erosion was assessed during each subsequent field visit (June 22 to 27, August 31 to September 11, 2009) and included noting any soil deposition on plot stakes and plants and locating and measuring rills.

3.5 Vegetation Assessments

On June 2 and 3, 2009, preliminary vegetation assessments were conducted, including visual assessments of whole plot cover, non-native species and any differences among treatments on each site.

From August 31 to September 11, 2009 vegetation was assessed in 1 m^2 quadrats located in the center of each plot to minimize edge effects. Visual estimates were made of total live vegetation, litter, bare ground, rocks, animal feces and cover by individual plant species. Density was determined by counting individual plants of each species within the 1m^2 area. The tallest and shortest plants of each species were measured by stretching the plant to its maximum height in the case of plants with upright growing structures (e.g. grasses) and as they were on the plot for prostrate type plants (e.g. vegetative dandelions). Where multiple plants occurred, an estimate of average height was made based on the most commonly occurring height for each species within the plot.

Presence of flowering or seed producing plants for each species was recorded. Plant health was determined by assigning each species a rating of good (no signs of stress or damage), fair (mostly healthy with some minor signs of stress or damage to some plants of a species) or poor (dying or severely damaged plants or signs of stress occurring on all plants of a species). Herbivory was rated as 0 (no evidence of herbivory), 1 (minor evidence of herbivory, not affecting plant health) or 2 (herbivory evident on all plants of a species, enough herbivory to damage plant health). Anything that could affect the vegetation assessment within or near a plot was noted; the most common evidence was manual removal of weeds in six of the twenty sites by restoration crews before vegetation assessments were complete. (Table A1)

Plots containing large numbers of individual plants too numerous to count were assessed using two 0.1 m^2 quadrats and extrapolating the data to a 1 m^2 area. These quadrats were stratified based on visual assessments of the entire plot species density and cover. One quadrat was randomly placed within each of the stratified areas and assessments were carried out for species density and cover, while plant heights, health, seed production and total vegetation cover were assessed within 1 m^2 quadrats. Values from the two 0.1 m^2 quadrats were averaged for each species; densities were multiplied by ten and cover values were divided by ten to get the closest estimate of density and cover in these plots. The factor of ten was used because ten 50 cm by 20 cm 0.1 m^2 quadrats fit into a 1 m by 1 m quadrat. This technique was used on 33 of the 597 plots assessed (one plot was missed during data collection). (Table A2)

3.6 Site Photographs

Site photographs were taken during plot construction (June 14 to 18, August 24 to 29 and September 17 and 18, 2008) and during final vegetation assessments (August 31 to September 11, 2009). Individual plot photos were taken during preliminary vegetation assessments (June 2 and 3, 2009) and during final vegetation assessments (August 31 to September 11, 2009). Areas exhibiting evidence of erosion, human or animal disturbance or other interesting observations were photographed. Pictures were used for recalling site conditions and clarifying any discrepancies that arose after field work was completed.

3.7 Statistical Analyses

Soil data were tested for normality and homogeneity of variance for each soil parameter using Shapiro-Wilk's test for normality and Levene's test for equality of variance prior to analysis with emphasis placed on equality of variance (Zar 1999). Although most data met the assumption of normality, the homogeneity of variance tests often failed. Assumptions are often not met in biological data due to inherent differences in soil nutrients, microtopography and environmental variability (Reynolds et al. 1997, Farley and Fitter 1999). To analyze all soil parameters with the same method, data that did not meet assumptions were scrutinized by comparing means and standard error for each parameter, looking for overlapping values, logical groupings and single outliers.

To further support parametric analyses, analyses were run on all original data and then on ranked data for each parameter using SPSS18 and with ANOVA as a non-parametric Scheicher Ray Hare test (Dytham 2003). Results for the original data were compared with the ranked data and in most cases ranking did not alter results or made little sense when compared with raw data. Small sample sizes make effective testing of normality and equality of variance extremely difficult therefore all original data were used in the analyses (Finney 1989). Robust univariate ANOVA analyses (Dytham 2003) were used to compensate for variations in normality and homogeneity. Tukey's multiple comparison post-hoc tests were used to detect mean differences for factors with significant effects for all soil parameters (Zar 1999). P-values of 0.05 were used in all cases to determine significant differences.

Prior to analyses of canopy cover and density data, species were divided into four groups based on plot sums of total plants, seed mix species, native species (not including those in the seed mix) and non-native species. Data were tested using Shapiro-Wilk's test for normality and Levene's test for equality of variance prior to analysis with emphasis placed on equality of variance (Zar 1999). Most data did not meet assumptions of normality or homogeneity. Non-parametric Scheicher Ray Hare tests (Dytham 2003) were conducted on totals for native seeded species, native non-seeded species, non-native species and total species for canopy cover and density data. Whitney Mann U post hoc tests were used to detect mean differences for factors with significant effects (Zar 1999). P values of 0.05 were used in all cases to determine significant differences.

Individual seed mix species were analysed using a qualitative approach as the data contained numerous zeros and could not be statistically analysed effectively. Individual species in the seed mix were analysed using mean and standard error analyses, with graphing to provide a visual explanation of trends.

4. RESULTS AND DISCUSSION

4.1 Soils

Other than penetration resistance, soil properties were not significantly different among pipeline work, trench and spoil areas (Table A3). Amendments had a significant effect on soil properties, varying among the five calcareous soils. Pipeline area and amendment interactions were significant in a few cases. Soil nutrient and carbonate leaching, amendment decomposition rate and soil penetration resistance were likely influenced by the climate conditions of the 2009 growing season; characterized by higher than average temperatures and lower precipitation than normal for the Jasper area. Pre-disturbance data are summarized in Table 7; post-disturbance data are summarized by soil, pipeline area and amendment in Tables 8, 9 and 10.

4.1.1 Soil chemical properties

Disturbance and reclamation had no effect on sodium adsorption ratio, which averaged 0.22 (0.10 to 0.59) after pipeline construction and 0.23 (0.01 to 0.40) before construction (Table A4). Values below 4 are not considered detrimental to vegetation or soil structure and in the eastern slopes region where the TMX-Anchor Loop pipeline is situated, soils are considered good if sodium adsorption ratio is below 2 (Macyk et al. 1987, Naeth et al. 1991).

Electrical conductivity ranged from 0.39 to 3.56 dS m^{-1} and averaged 0.94 dS m^{-1} (Tables 11, A6). Only 17 of 598 soil samples had values over 2 dS m^{-1}. Of these 11 were on compost treatments and 6 were on control, fertilizer and incorporated woodchips treatments; 5 were on Hillsdale soils. Values prior to pipeline construction ranged from 0.33 to 0.86 dS m^{-1} and averaged 0.47 dS m^{-1}. Although maximum values after pipeline construction were higher than pre-disturbance, averages were below 4 dS m^{-1}, indicating construction did not have adverse effects on electrical conductivity. None of the calcareous soils were above 4 dS m^{-1}, which is considered saline in agricultural soils. Reclaimed eastern slopes soils are rated good when electrical conductivity is below 2 dS m^{-1} and fair between 2 and 4 dS m^{-1}.

Post disturbance soil pH ranged from 6.2 to 7.9, averaging 7.2 in all treatments, slightly lower than pre-disturbance which ranged from 7.1 to 8.2 with an average of 7.7 (Tables 11, A6). Heavy compost treatment's pH was lowest, followed closely by low compost treatments. Wood chips treatments had slightly increased pH; fertilizer and control plots had the highest values. Incorporation of amendments decreased pH in compost treatments and increased it in wood chips treatments. Acceptable soil pH for most plants is between 6 and 8, with the optimal range for agronomic crops between 6.5 and 7 (McKenzie 2003). Although less is know about optimal pH range for native species, pH should not be an issue for any of the plant species expected on the site.

The calcareous nature of a soil is measured in calcium carbonate ($CaCO_3$) equivalents due to variability in calcareous parent material; deposits are never pure $CaCO_3$ and include $MgCO_3$, CaO and MgO. Calcareous soils contain 10 to 1,000 g kg^{-1} of $CaCO_3$ equivalent (Agriculture and Agri-Food Canada 1998, Soil Science Society of America 2008). Calcareous soils along the TMX pipeline averaged 35.6 % $CaCO_3$ equivalent ranging from 13.5 to 60.9 % (Table A7). Prior to pipeline construction, $CaCO_3$ equivalents were slightly lower, from 3.0 to 52.6 % and averaging 25.1 % (Table 7). $CaCO_3$ equivalents < 2 are considered good for the region, 2 to 20 are fair, 20 to 70 are poor and > 70 are unsuitable (Macyk et al. 1987). Pre and post construction values fell into fair and poor categories. Pipeline areas did not differ in $CaCO_3$ equivalents, although amendment treatments were significant on all soils except Talbot. Devona, Hillsdale, Hinton, Talbot and Vermilion Lakes ranged from 37.5 to 41.0 %, 37.9 to 46.8 %, 27.5 to 30.2 %, 39.1 to 42.8 % and 21.7 to 27.4 %, respectively. Heavy compost applications consistently had the lowest values, improving the soil by decreasing $CaCO_3$ equivalents. Other treatments varied with soil type.

Pre-disturbance total carbon ranged from 2.0 to 22.0 %, organic carbon from 0.8 to 21.0 % and inorganic carbon from 0.3 to 6.3 %, with means of 6.4, 3.4 and 2.9 %, respectively(Tables 8, 9, 10). After pipeline and plot construction, total carbon was 5.9 to 17.5 %, organic carbon 1.7 to 14.5 % and inorganic carbon 1.5 to 7.2 %, with means of 9.7, 5.5 and 4.2 %, respectively (Table A8). Total carbon differed among soils, at 10.2 to 11.6 % for Devona, 9.1 to 10.8 % for Hillsdale, 8.5 to 10.1 % for Hinton and 7.5 to 9.0 % for Vermilion Lakes.

Inorganic carbon varied little, yet all soils except Talbot had significant treatment effects (Tables 12, A9). Devona averaged 4.4 to 4.9 %, Hillsdale 4.5 to 5.6 %, Hinton 3.2 to 3.6 % and Vermilion Lakes 2.5 to 3.2 %. Pipeline area by amendment interactions were significant for Vermilion Lakes soils but showed no pattern. Values for all soils ranged from 2.3 to 3.3 %, 0.8 to 3.5 % and 2.6 to 3.4 % for spoil, trench and work areas, respectively. Spoil and work areas did not have a significant range of values while the trench had a much larger range.

Organic carbon was significantly different among soil series, increasing nearly 2 % with heavy compost (Tables 12, A9). Averages ranged from 5.3 to 7.2 % for Devona, 3.5 to 6.1 % for Hillsdale, 5.0 to 6.0 % for Hinton and 4.3 to 6.6 % for Vermilion Lakes. Devona heavy compost and incorporated heavy compost were 6.8 and 7.2 % while all other treatments were 5.3 to 6.1 %. This trend was consistent among soils. An increase of 2 % organic carbon is biologically significant, especially in the first year after plot establishment (Zinati 2001).

4.1.2 Soil plant nutrients

Little soil nitrogen is available to plants, making it the most often supplied nutrient in fertilizers. In temperate climates like Jasper, 1 to 5 % of soil organic nitrogen is available to plants each year. Over fertilization with nitrogen can be detrimental, promoting rapid vegetative growth at the expense of flower and seed production (Troeh and Thompson 1993). Nitrogen is available to plants as nitrate (NO_3^-) or ammonium (NH_4^+) (McKenzie 2003). Pre-disturbance total nitrogen ranged from 0.05 to 0.77 % and averaged 0.18 % with 1.6 to 47.8 mg kg^{-1} of available nitrogen, averaging 4.2 mg kg^{-1}. After pipeline construction total nitrogen increased, ranging from 0.13 to 0.76 % and averaging 0.32 %, as did available nitrogen, ranging from 1.0 to 360.0 mg kg^{-1} and averaging 21.0 mg kg^{-1}. Total nitrogen ranges were small with none above 0.5 %, although all soils had significant treatment differences. Compost had highest total nitrogen.

Available nitrate was significantly affected by amendments (Tables 13, A9). Devona, Hinton, Talbot and Vermilion Lakes soils had lowest nitrate in wood chips, control and fertilizer treatments; light compost treatments were intermediate and heavy compost treatments highest. Hillsdale soil had a smaller range of values and higher variability, with wood chips treatments lowest, followed by incorporated and unincorporated light compost, control and unincorporated high compost treatments. Highest available nitrogen was in fertilizer and incorporated heavy compost treatments. Incorporated compost treatments had higher available nitrogen than unincorporated counterparts, while incorporation of wood chips usually decreased nitrate availability, due to increased decomposition rates in compost and immobilization in wood chips. For example, on Devona soils controls averaged 11.1 mg kg^{-1} while wood chips treatments ranged from 2.9 to 5.2 mg kg^{-1}. Fertilizer alone did not significantly increase available nitrogen compared to control treatments. Available nitrogen had significant pipeline area by amendment treatment interactions for Hinton soils; trench and work areas had higher available nitrogen in compost treatments (heavy compost > light compost), and lowest in wood chips treatments. There were no significant differences between spoil area treatments, although they followed the same pattern.

Most soil phosphorous is tied to large organic molecules making it unavailable to plants. $H_2PO_4^-$ is available but readily adsorbed to iron and aluminum in the soil. H_2PO_4 and HPO_4^{2-}, in acidic and alkaline soils, respectively, have extremely low solubility (Troeh and Thompson 1993). Available phosphorous ranged from 0.1 to 6.0 mg kg^{-1} and averaged 0.6 mg kg^{-1} before pipeline and plot construction, increasing to 96.4 mg kg^{-1} with 0.5 to 1,220.0 mg kg^{-1} ranges after.

Available phosphorous was significantly affected by amendment treatments, being most influenced by compost treatments (Tables 13, A9). Wood chips and control treatments were generally the same with fertilizer treatments slightly higher. Light compost treatments were intermediate and heavy compost treatments were highest. Compost incorporation usually increased available phosphorous, while wood chips incorporation had little effect.

Potassium is utilized by plants in its K^+ form. Most soils contain 1 to 5 kg ha^{-1} potassium in solution and young soils, dry soils and calcareous soils rarely respond to potassium fertilizers because they have not lost much of their supply (Troeh and Thompson 1993). Pre-disturbance available potassium ranged from 31.0 to 402.0 mg kg^{-1} and averaged 98.3 mg kg^{-1} and increased post-disturbance to 50.4 to 730.0 mg kg^{-1} and an average of 217.7 mg kg^{-1}. Potassium increased after construction and plot establishment from 0.1 to 37.0 mg L^{-1} and a mean of 4.6 mg L^{-1} to 5.5 to 198.0 mg L^{-1} with a mean of 38.0 mg L^{-1}. Soil potassium, magnesium, calcium and sodium were and analysed as mg L^{-1}. These values can be converted to mg kg^{-1} by multiplying cation values by the corresponding base saturation (see example calculation in appendix).

Available potassium was highest in heavy compost treatments and lowest in control or fertilizer treatments for all soils. Wood chips and light compost treatments had different orders of magnitude but did not have large ranges compared to heavy compost treatments. Unincorporated and incorporated heavy compost treatments were 252.8 and 258.3 mg kg^{-1}, 324.2 and 313.9 mg kg^{-1}, 456.2 and 427.3 mg kg^{-1}, 207.7 and 268.6 mg kg^{-1}, 317.7 and 351.4 mg kg^{-1} for Devona, Hillsdale, Hinton, Talbot and Vermilion Lakes, respectively. All other treatments ranged from 129.4 to 185.3 mg kg^{-1}, 141.7 to 202.6 mg kg^{-1}, 215.0 to 305.7 mg kg^{-1}, 107.1 to 177.7 mg kg^{-1}, 181.1 to 257.6 mg kg^{-1}.

Heavy compost treatments had the highest potassium for all soils followed by light compost treatments for Devona, Hillsdale and Hinton soils (Tables 13, A10). Wood chips treatments for these three soils were similar, with control and fertilizer treatments having the least potassium. Talbot and Vermilion Lakes soils had little difference in potassium between light compost and wood chips treatments, and had lowest values in control and fertilizer treatments. Soil potassium was significantly different for pipeline area by amendment treatment interactions for Hinton soils. Compost treatments had highest soil potassium for all pipeline areas. Spoil had the smallest range between treatments and the lowest overall values (26.7 to 63.0 mg L^{-1}) while the trench had highest overall values and the largest ranges (34.2 to 120.8 mg L^{-1}).

Sulphides have low solubility in soil but are easily oxidized to sulphates and used by plants as SO_4^{2-} in the soil and SO_2 from the air (Troeh and Thompson 1993).

Available sulphates ranged from 3.0 to 49.0 mg kg^{-1} and averaged 6.6 mg kg^{-1} pre-disturbance, increasing to a range of 2.2 to 312.0 mg kg^{-1} with an average of 19.4 mg kg^{-1} following pipeline construction and plot establishment.

Available sulphates were significantly different among treatments for all soils except Hillsdale, with highly variable ranges among soils and amendment treatments. Differences between pipeline areas were not significant. Values ranged from 6.4 to 20.6 mg kg^{-1} for Devona, 8.2 to 33.7 mg kg^{-1} for Hillsdale, 10.3 to 43.0 mg kg^{-1} for Hinton and 6.7 to 25.2 mg kg^{-1} for Vermilion Lakes (Tables 13, A10). There were no general trends among soils or treatments, suggesting natural soil nutrient variability was a greater influence than amendment treatments for available sulphur.

Calcium is rarely deficient and can buffer soil pH to around 8 (Troeh and Thompson 1993). Pre-disturbance calcium ranged from 12.0 to 156.0 mg L^{-1} with an average of 54.7 mg L^{-1} (Table 7) and increased to a range of 62.9 to 513.0 mg L^{-1} with a mean of 135.4 mg L^{-1} after disturbance. Hinton was the only soil with significant differences among treatment areas. Wood chips treatments were lowest in calcium ranging from 102.7 to 107.5 mg L^{-1}, followed by control and fertilizer treatments at 114.9 and 120.7 mg L^{-1}, respectively. Light compost treatments were higher and heavy compost treatments had highest calcium concentrations with a maximum mean of 161.4 mg L^{-1} for incorporated heavy compost treatment. (Table A11)

Magnesium is often deficient in soils (Troeh and Thompson 1993). Pre-disturbance magnesium increased from 4.0 to 59.0 mg L^{-1} with a mean of 26.4 mg L^{-1} (Table 7) to a range of 9.6 to 232.0 mg L^{-1} with a mean of 43.8 mg L^{-1} after pipeline construction and plot establishment. Magnesium was highly variable with soils, ranging from 21.1 to 106.9 mg L^{-1}, but amendment treatments had similar trends. Heavy compost treatments were highest in magnesium, followed by light compost, fertilizer and control treatments. Wood chips treatments had lowest magnesium. In almost every case, incorporation of wood chips and compost increased magnesium compared to unincorporated. (Table A11)

Sodium is a non-essential element but can partially substitute for potassium which, with magnesium, is often deficient (Troeh and Thompson 1993). Pre-disturbance sodium ranged from 3.0 to 19.0 mg L^{-1} averaging 7.9 mg L^{-1} (Table 7) while post-construction ranged from 3.1 to 40.4 mg L^{-1} and averaged 11.4 mg L^{-1}. Sodium ranged from 9.3 to 14.4 % for Devona, 5.3 to 13.0 % for Hillsdale, 8.7 to 20.4 % for Hinton and 11.1 to 16.2 % for Vermilion Lakes. All soils, with the exception of Vermilion Lakes, were significantly different. Wood chips treatments had lowest sodium, with no pattern for other treatments. (Table A11)

4.1.3 Soil physical properties

Penetration resistance varied among soil types, mostly due to rocky conditions (Tables 14, 15, A4, A12), especially on two Hillsdale1 and all four Vermilion Lakes sites where soils were extremely rocky. Five measurements were taken on each plot; when rocks were encountered and restricted the number of measurements, blanks were left in the data and those plots had fewer numbers to determine mean penetration resistance. Overall penetration resistance ranged from 0.3 to 6.0 MPa, 0.9 to 6.3 MPa and 1.1 to 6.3 MPa with means of 1.6 MPa, 2.6 MPa and 2.9 MPa at 5 cm, 10 cm and 15 cm, respectively. Verbist et al. (2007) cited measurements exceeding 3 MPa as the limit for root restriction and 4 MPa is suggested by Naeth et al. (1991) as plant limiting. In 216 plots penetration resistance was between 3 and 4 MPa and on 151 plots exceeded 4 MPa, with most of these occurring at depths of 10 or 15 cm. Vegetation still established on most of these sites, although growth may be restricted in later growing seasons as plant roots attempt to extend past 5 cm depths.

Penetration resistance on pipeline areas was significantly different on Devona soils at all depths, increasing from spoil to trench to work areas. Penetration resistance increased with depth on all five soils except on Hillsdale spoil and trench areas where the trench penetration resistance was higher than on the work area. Treatment effects were significant for all soil types at 5 cm and on Hillsdale soils at 15 cm, the latter due to rocky conditions. At 5 cm penetration resistance was lower for incorporated than unincorporated treatments, with differences less evident on Vermilion Lakes because of the rocky nature of the soil and on Talbot soils, where all penetration resistance data was low. Unincorporated wood chip and heavy compost treatments had lower penetration resistance than control, fertilizer and unincorporated light compost treatments at

5 cm, likely due to less resistance from thick amendments than bare soil. Area by treatment interactions for penetration resistance were significant for Talbot soils at 10 cm and Hillsdale soils at 15 cm, but without a common pattern. Penetration resistance would further decrease during a year with higher precipitation.

Volumetric soil water content, within the upper 15 cm of the soil, ranged from 0.8 to 30.1 % with an average of 11.6 % (Tables 11, A13). Most values were below 25 %; any above 20.0 % were on heavy compost or wood chip treatments or on Vermilion Lakes sites where measurements occurred during drizzling rainfall. Soil water was significantly different for all soils except Devona, with ranges of 6.1 to 11.5 %, 8.8 to 13.7 %, 12.2 to 16.2 % and 8.5 to 14.8 % for Hillsdale, Hinton, Talbot and Vermilion Lakes soils, respectively. Regardless of soil, incorporated amendments had lower soil water than their unincorporated counterparts. Control and fertilizer treatments were highest and there was little difference between heavy and light compost applications. These results would likely change with higher precipitation. It is likely that the amendments absorbed much of the water making it unavailable to plants.

Soil base saturation averaged 72.9 % and ranged from 34.7 to 153.0 % after construction and ranged from 31.3 to 250.0 % and averaged 75.6% before construction, showing that even though the maximum decreased dramatically, little overall change occurred with pipeline construction. Base saturation did not vary significantly among pipeline areas, but was significant between treatments in Hillsdale and Vermilion Lakes soils. Incorporated and unincorporated heavy applications of compost had the highest overall base saturation, followed by the four wood chip treatments, the light compost, control and fertilizer treatments. Although significant, the range of values for Hillsdale and Vermilion Lakes across amendment treatments was 53.95% for fertilizer, 69.12 % for heavy compost, 62.14 % for the control and 76.48 % for incorporated heavy compost treatments.

Erosion pins did not provide adequate information on effectiveness of amendments for controlling erosion. Most pins did not show any measureable change in soil levels due to erosion over the summer months. Only pins influenced by disturbances such as animal tracks and weed removal showed measurable differences in soil height. Fall installation prior to snowfall and snow melt may have provided measurable erosion data.

Visual observations of soil collection on plot stakes and standing vegetation showed that soil was moving off the research plots. The small size and close proximity of the plots made it impossible to determine from which amendment treatment the soil had originated. Evidence of wind erosion was present on each of the research sites but identifying the ability of individual amendments to control erosion was not possible. Amendment incorporation would likely decrease water erosion by creating a rough, less compacted surface that would slow water movement and increase infiltration. Wind erosion would likely increase on incorporated treatments because soil is exposed to the air instead of protected from wind as in unincorporated treatments. Further research is required to determine the most appropriate methods of erosion control on calcareous soils.

4.2 Vegetation

Vegetation growth was poor on most of the treatments likely due, in part, to the 2009 growing season which had very little precipitation and higher than average air temperatures (Figure 5 and Figure 6). Diversity was high for a first year of growth, with a total of 126 species of grasses, forbs, shrubs and trees found on the sites. Most species did not occur on every plot and some only occurred on one of the twenty sites. For analysis and discussion efficiency, species data were categorized into three groups including non-seeded native species, seeded native species and non-native species. Seeded native species were analysed separately from other native species to assess seed mix and seed bank emergence. Qualitative analysis was conducted on the individual species in the prescribed seed mix to help describe seed mix success. Lists of all species found during vegetation assessments are listed in Tables 16, 17, 18.

4.2.1 Seed mix success

Koeleria macrantha and *Trisetum spicatum*, each accounting for 15 % of the seed mix, produced high numbers of small plants after the first growing season. Due to small plant sizes and early stages of growth and maturity they were extremely difficult to differentiate in the field and were combined for more accurate analysis. These two species had the highest and most consistent density and canopy cover of the seeded species (Tables 19, 20, A14, A15). Only compost treatments with large sized grass and annual introduced species did not conform to this pattern because the larger individuals out-competed the smaller seedlings for water and light in these nutrient rich plots.

Seed mix density percentages were calculated by dividing the density of each individual seeded species by the total density of all seeded species per plot, providing an estimate of how well each seeded species performed (Table 21, 22). In most treatments, 60 to 90 % of the total seeded species density was *Koeleria macrantha* or *Trisetum spicatum*, although values ranged from 21.5 to 93.8 %. These values must be interpreted relative to the 30 % combined seed mix composition for the two species. All other seeded species had much lower densities and covers across treatments. *Stipa viridula* made up 20 % of the seed mix density while contributing 0 to 21.1 % of the seeded species density with most treatments having less than 10 %.

Festuca idahoensis seed was the largest component of the seed mix at 25 %, although most treatments had less than 5 % seeded species density with the highest value being 13.3 %. On many treatments *Festuca saximontana* was more prevalent than *Festuca idahoensis*, suggesting a mistake in the seed mix or a more suitable habitat for the former.

The seed mix included 15 % *Agropyron spicatum* which ranged from 0.9 to 63.9 % seed mix density with higher values on Hillsdale, Hinton and Vermilion Lakes soils; Devona and Talbot soils usually had below 10 % of the seed mix density attributed to *Agropyron spicatum*. Higher densities for all soils were on wood chips treatments, with none over 10.2 % and most below 5 % for compost treatments. *Agropyron trachycaulum* and *Agropyron subsecundum* combined for a 5 % total of the seed mix. They performed well considering the low seed mix percent and provided a range of 0 to 46.7 % of the total density of seeded species, with over a fifth of the plots (usually compost or fertilizer treatments) exceeding 5 % of the total seed mix density. *Agropyron violaceum* made up the final 5 % of the prescribed seed mix and accounted for less than 5 % of the seed mix percent density; in many plots no *Agropyron violaceum* plants were found.

Compost treatments had highest cover of seeded species with average to high densities (Table 21, 22). Fertilized treatments performed better than control and unfertilized wood chips treatments with average to low cover and medium to high densities. Wood chips treatments had little cover but high densities of small plants (many not past three to four leaf stage) and seedlings. Winter survival of many of these plants is not expected, due to low carbohydrate reserves.

4.2.2 Plant density

Plant density varied among pipeline right-of-way areas but there was no overall trend among the five soil series (Table 23). Devona, Hillsdale and Talbot soils had the lowest densities on the pipeline work area; Hinton and Vermilion Lakes soils had lowest densities on the trench area. Spoil areas had highest densities for Devona, Hinton and Vermilion Lakes, with the remaining two soils having highest densities on the pipeline trench.

Plant density was significantly different among amendment treatments across all soils and vegetation classes (Tables 25, A16). Seeded and non-seeded native species contributed most to the total density, with non-native species making up only a small proportion.

Seeded native species had highest density on fertilized and control treatments followed by light compost (incorporated and unincorporated) and fertilized wood chips treatments (Tables 25, A16). Fertilized wood chips treatments had higher densities than their unfertilized counterparts. Incorporation of wood chips had little effect on density. High density on fertilizer, control and wood chips treatments were often the result of many young plants and seedlings on a single plot. Light compost treatments had higher density than heavy compost treatments and incorporation of compost usually increased density. Incorporated and unincorporated compost treatments had the lowest plant densities except where there was very little growth on an entire site. In these cases, heavy compost treatments often had highest plant densities. Low densities in heavy compost treatments were likely because each individual plant was large in size and therefore fewer plants could exist. Plants on light compost treatments were smaller than those on heavy compost treatments, but substantially larger than seedlings and young plants on wood chips, fertilizer and control treatments.

Native species that were not included in the seed mix likely emerged from the soil and amendment seed banks or were moved in by wind or animal dispersion.

Fertilizer and control treatments had similar plant densities to wood chips treatments, with the exception of fertilized wood chips treatments that were occasionally higher than the others. These fertilized wood chips treatments often had higher densities than their unfertilized counterparts. Light compost treatments had higher densities than heavy compost treatments and incorporation of compost further increased density. The two light compost treatments had the highest densities, along with unincorporated wood chips and incorporated, fertilized wood chips treatments. Although densities for these treatments were highest, plants were taller and more mature on light compost treatments and were quite small on wood chips treatments. Volunteer native species had similar densities across all treatments.

Non-native species had low densities compared to native species. Compost treatments had slightly higher densities than the other six amendment treatments, followed by fertilizer, control and wood chips treatments. Densities were low across all treatments but there were significant differences in maturity and size between compost and the other six amendment treatments. Compost treatments had larger plants, many of which were producing seed, than the other treatments where smaller plants either had not reached seed production stages or were producing very few seeds.

4.2.3 Canopy cover

Pipeline right-of-way areas showed some differences in canopy cover (Table 24). Mean cover decreased from spoil to trench to work areas on all soils except Vermilion Lakes, which were rocky soils that had little difference in penetration resistance between the work areas. Therefore, the decrease in cover across the work areas is likely the result of higher penetration resistance and thus increased difficulty for plant roots to penetrate and anchor in the soil.

Seeded and non-seeded native species constituted most of the cover except in compost treatments where non-natives were a major cover contributor (Tables 26, A17). This is especially evident in heavy compost treatments.

Seeded species provided the most cover on incorporated and unincorporated light compost treatments and incorporated heavy compost treatments. All other amendment treatments had low cover with little variability. In some instances, fertilized treatments had higher cover compared to control, wood chips and unincorporated heavy compost treatments. Amendment incorporation almost always increased cover of seed species in compost treatments but had little effect in wood chips treatments.

Non-seeded native species generally combined to provide higher cover than the total cover provided by seeded native species in all treatments except in light compost treatments. Although non-seeded species were often smaller in size, this result is likely due to the large number of non-seeded species in comparison with the eight species included in the seed mix. Compost treatments, and in a few cases fertilized wood chips treatments, had higher cover of non-seeded native species than all other amendment treatments. Wood chips treatments normally either had very little cover or moderate cover provided by many small plants. Incorporation of amendments often decreased the number of non-seeded native species.

Non-native species thrived on compost treatments, in many cases becoming large, seed producing plants. Low compost treatments usually had a higher cover of seeded native species than non-native species while heavy compost treatments usually had a higher cover of non-native species than native species. Non-native species cover was extremely low for all wood chips treatments and in some cases, especially when not incorporated or fertilized, non-native species were not found on wood chips treatments. Amendment incorporation effect was less obvious for non-native species compared to native species but increased cover in compost treatments and decreased cover in wood chips treatments.

4.2.4 Plant health and herbivory

Plant heath was consistently good across all soils, pipeline areas and amendment treatments. Some plants were rated fair or poor but these cases were for individual plants and were often due to herbivores or damage due to trampling. Too few plants were affected to tie the poorer health conditions to soil characteristics or other growing condition factors

Herbivory was of little concern throughout the first growing season. Very little browsing or insect herbivory was noticed throughout the vegetation assessments.

Where ungulate browsing was seen, select plant species (usually *Festuca saximontana* Rydb.) were chosen and damage was not detrimental to overall success. Insect herbivory was limited with the exception of aphid infestations on young *Rosa acicularis* Lindl. on one site. Affected plants were stunted and in poor health but overall plot success was not negatively affected and infestations were limited to only a small number of plants.

5. AMENDMENT EVALUATION

Soil parameters for control treatments were used to characterize un-amended site conditions after pipeline construction. All soil and vegetation data for other treatments were compared to this control to determine amendment influence on these soil and vegetation properties.

Treatments with only fertilizer had higher available nitrates and available phosphorous, slightly elevated pH and, along with control treatments, had the highest soil water. Soil potassium was lower on fertilized plots than all other amendment treatments. Control and fertilizer treatments often had moderate vegetation density and cover, surpassing three of the four wood chips treatments; the exception was unincorporated wood chips treatments that had been fertilized. Plants were generally taller and more robust on fertilized than control treatments. Fertilizers are readily available, easy to apply and can be customized to provide the nutrients required on a site.

Soil nutrients, with the exception of soil potassium, were immobilized in wood chips treatments with concentrations often lower than in control treatments. These treatments had slightly higher pH than compost treatments and slightly lower pH than control and fertilizer plots but still fell within the acceptable soil pH range. Incorporation of wood chips treatments had little influence on soil chemical properties but decreases penetration resistance and slightly increased soil organic carbon and magnesium. Low available nitrates were further reduced when wood chips were incorporated into the soil. Fertilization of wood chip treatments had little effect on soil properties but slightly increased plant density and cover. Wood chip treatments provided an effective barrier for non-native species emergence from the seed bank. Non-native species density and cover were greatly reduced compared to the other six amendment treatments. This mulch effect was evident with native species emergence, decreasing densities and cover for all native propagules in the seed bank with the exception of *Picea glauca* (Moench) Voss. and *Arctostaphylos uva ursi* (L.) Spreng. Wood chip treatments likely provided some erosion control by creating a barrier between the soil and wind and by slowing water movement to improve infiltration. However, the small plants with undeveloped root systems in these treatments likely did not contribute much to soil stabilization in this first growing season.

Soil and vegetation parameters responded most favourably to compost treatments. Soil organic carbon, nutrients and available nutrients increased on compost treatments while pH and $CaCO_3$ equivalent decreased. Vegetation cover increased dramatically with compost. Plants were larger and many produced seed heads in the first growing season, providing an additional seed source for the upcoming season. Light compost treatments had similar cover, increased species diversity, decreased sizes of non-native species while still providing moderate plant densities compared to heavy compost counterparts. Incorporation of compost treatments improved soil and plant benefits but, although incorporation would likely decrease water erosion and possibly increase wind erosion, it is unclear what extent amendment incorporation played on erosion control capability. Rooting of the more robust plants on compost treatments likely provided increased soil stability to aid in erosion reduction.

Erosion control capabilities of amendment treatments could not be determined in this short study period. Although erosion was not extremely detrimental on the small plots used in this study, it would be an important factor to determine for large scale projects and applications.

Compost is not the most economical or readily available soil amendment for most reclamation projects but the dramatic improvement in conditions and vegetation establishment indicate that readily available nutrients are necessary for successful early reclamation on calcareous soils. Based on cost, availability and differences in plant and soil response to heavy and light compost treatments, light applications would be a better use of scarce resources. In National Parks compost may not be available internally and may not be allowed in the park.

6. PRACTICAL APPLICATIONS

Reclamation of disturbed soils can be assisted by carefully chosen amendments that aid in ameliorating limiting conditions for soil chemical and physical properties and in turn, vegetation establishment. Nutrient addition to disturbed calcareous soils is necessary for vegetation establishment and is further improved by slight decreases in soil pH. An amendment such as compost that provides an immediate nutrient source and a long term slow release source with the added benefit of decreasing soil pH, resulting in higher availability of nutrients, seems to be the most efficient method for successful early vegetation establishment on reclaimed sites.

Less obvious effects of amendment applications, such as slight pH adjustments that seem biologically insignificant, may influence soil chemistry in a way that greatly impacts the final success of the treatment.

Determining appropriate amendment rates for any disturbed site is important. Higher application rates, along with often not being economically feasible, are not always the most beneficial from a biological perspective. In this study, a larger area could be more successfully reclaimed with smaller volumes of compost amendment than larger volumes.

7. CONCLUSIONS

Fertilizer increased available nitrogen and phosphorous compared to control and wood chips treatments. Fertilizer on wood chips treatments had little effect on soil properties compared to unfertilized counterparts but showed slight increases in plant cover and density.

Wood chips decreased soil pH and nutrients with the exception of sulphates which had little change and available potassium which increased compared to control and fertilizer treatments; plant density was high, consisting of many small seedlings with little overall cover.

Compost treatments were most effective for improving first year growing conditions for native species. They had the greatest influence on soil chemical properties, increasing nutrients and carbon concentrations, with the exception of available sulphur, and decreasing pH and $CaCO_3$ compared to all other amendment treatments. Compost supported increased vegetation cover and decreased plant density compared to all other treatments.

Heavy compost treatments had a greater influence on soil chemical properties than light compost treatments. Heavy treatments, although associated with slightly higher plant cover and lower plant density, had lower species richness than light treatments and were predominantly covered by large non-native species. In comparison, lower rates of compost had higher seeded and non-seeded native species cover and smaller less dominant non-native species.

Incorporation of amendments led to lower soil penetration resistance and soil water content. Effects of compost and wood chips on pH were amplified by incorporation. Incorporated compost treatments had a further increase in available nitrogen and phosphorous while incorporation of wood chips decreased available nitrogen.

Light applications of compost provided nutrients for seeded and non seeded native species to thrive without being overtaken by non-native species, while being more economic and attainable considering the amount of compost likely to be available for a large scale reclamation project. Incorporation of light compost treatments increased nutrients but had little overall effect on vegetation in the first growing season. Incorporation is therefore deemed unnecessary as it increased time and labour requirements for application. After considering all soil and vegetation responses to soil amendments, light application compost without incorporation was the most effective study treatment for the early reclamation of disturbed calcareous soils.

Pipeline right-of way areas had little influence on the reclamation of calcareous soils. Penetration resistance increased in most cases from spoil to trench to work areas, and perhaps impeded vegetation growth slightly in the first growing season, resulting in small decreases to canopy cover and overall density on the work area. Soil types showed differences in many soil chemical properties with little difference in physical properties.

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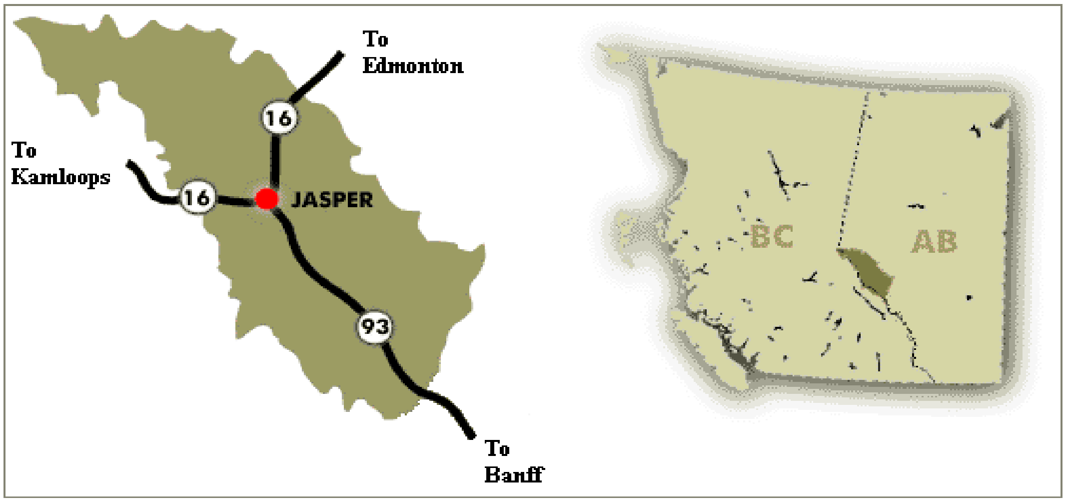

Figure 1. General Jasper National Park location (Adapted from Canadian Rockies 2008).

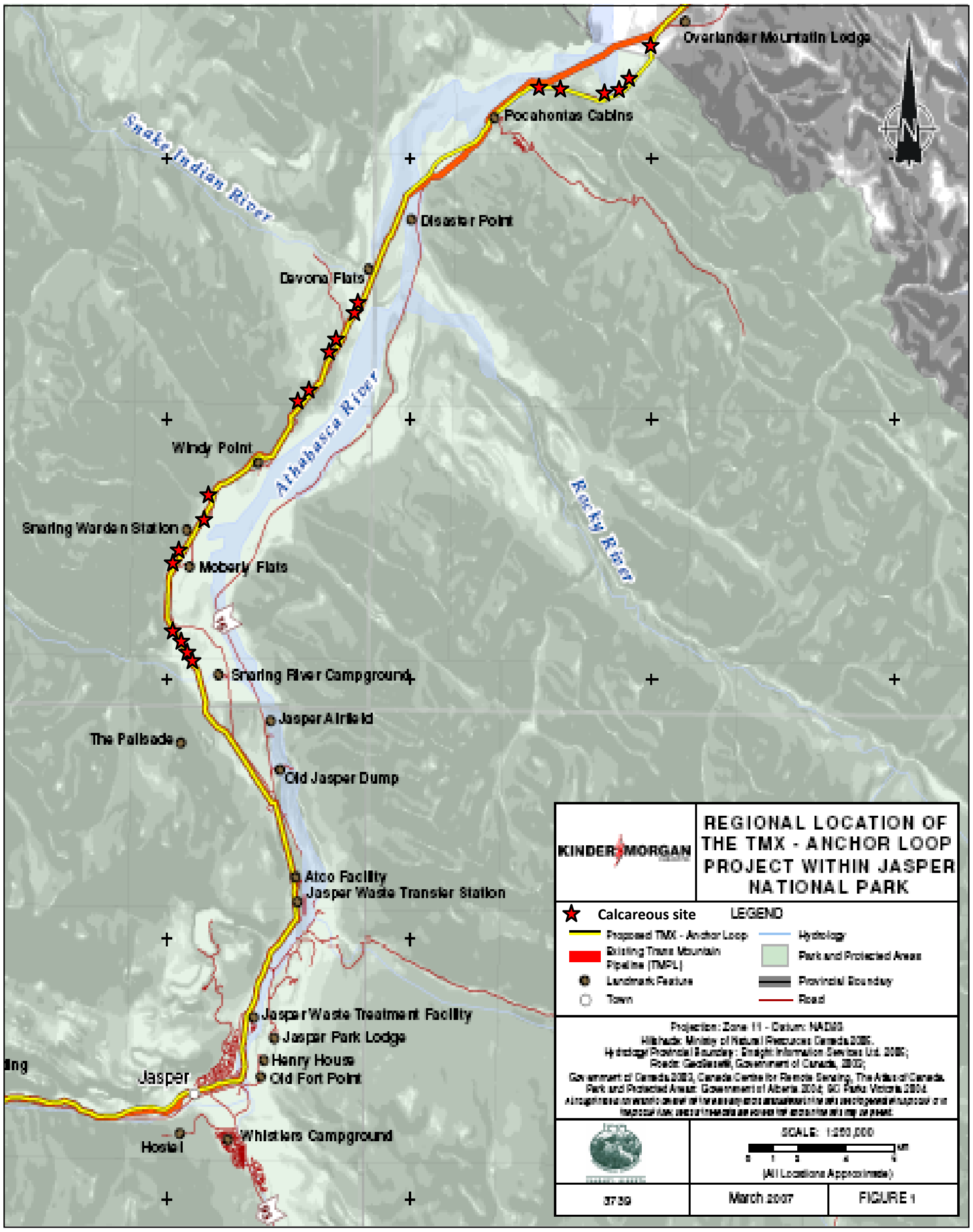

Figure 2. Aerial map of the pipeline right-of-way showing calcareous soils chosen for the research (Kinder Morgan Canada Inc 2007c).

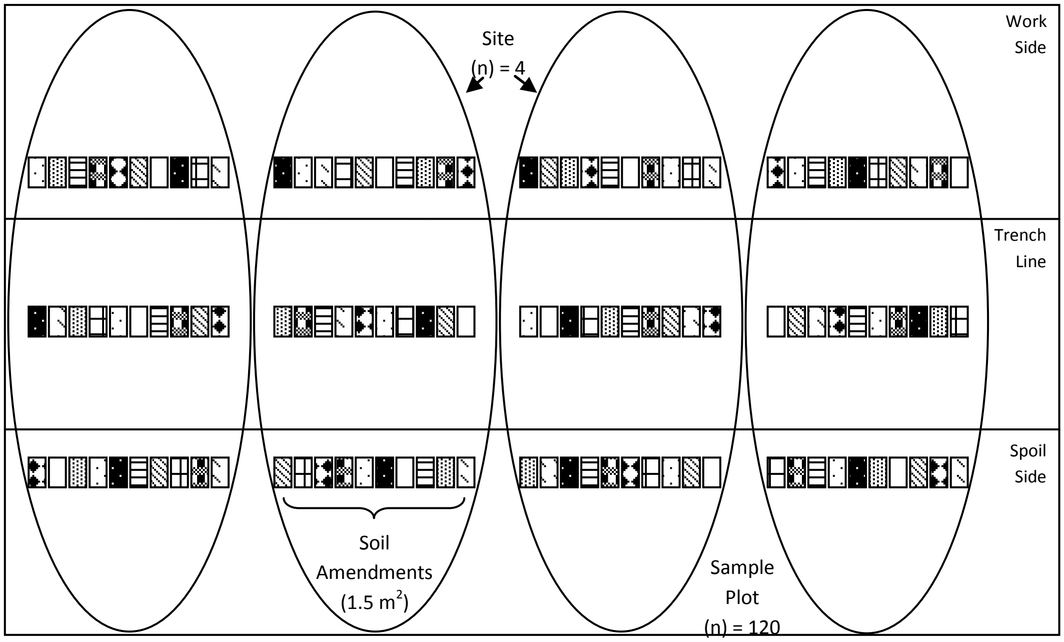

Figure 3. Schematic plot design showing the four study sites for a soil series and experimental plot layout along the pipeline right-of-way.

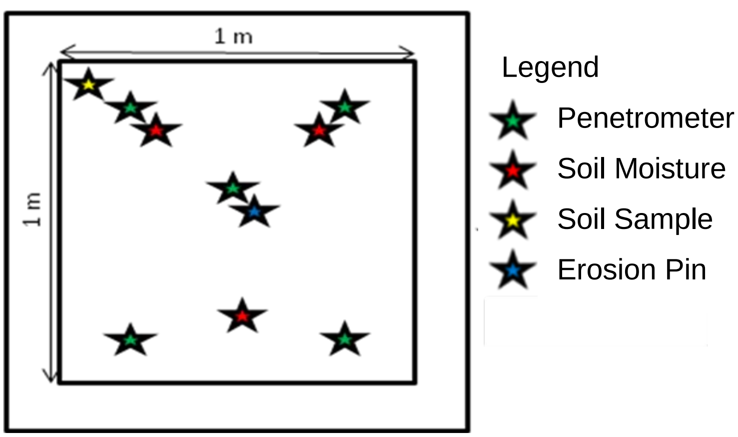

Figure 4. Soil and vegetation sampling locations within each plot.

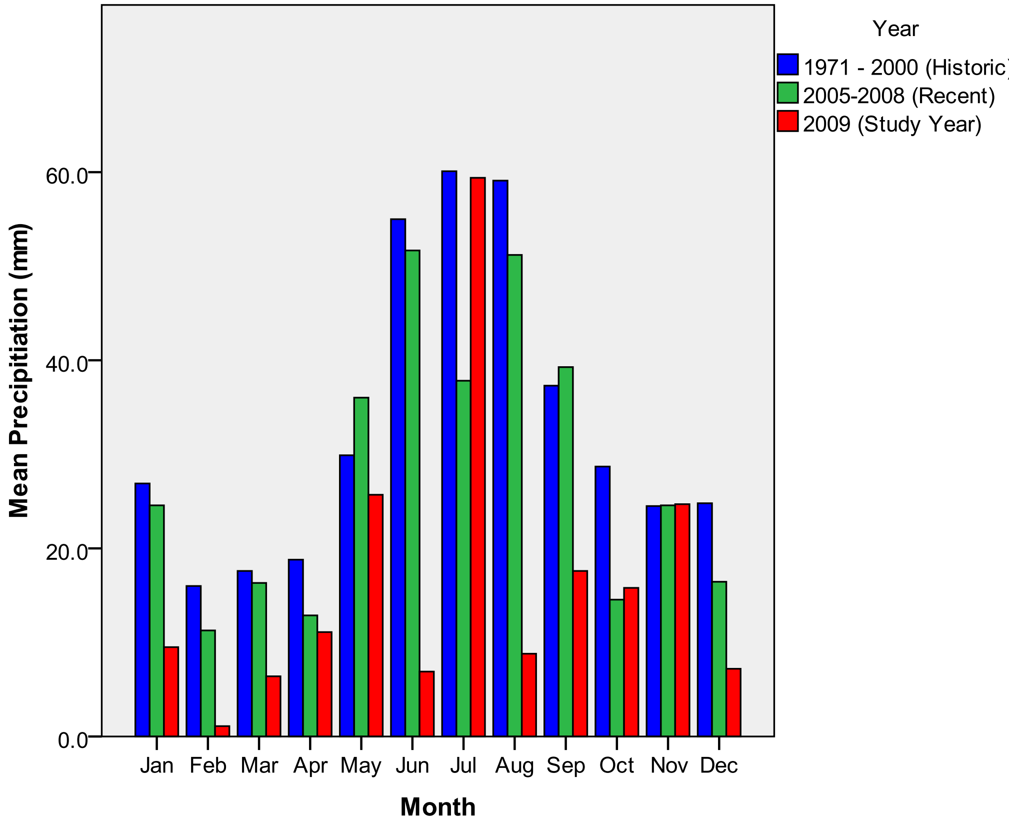

Figure 5. Historic, recent and study year comparison of Jasper National Park precipitation from the Jasper Warden Station.

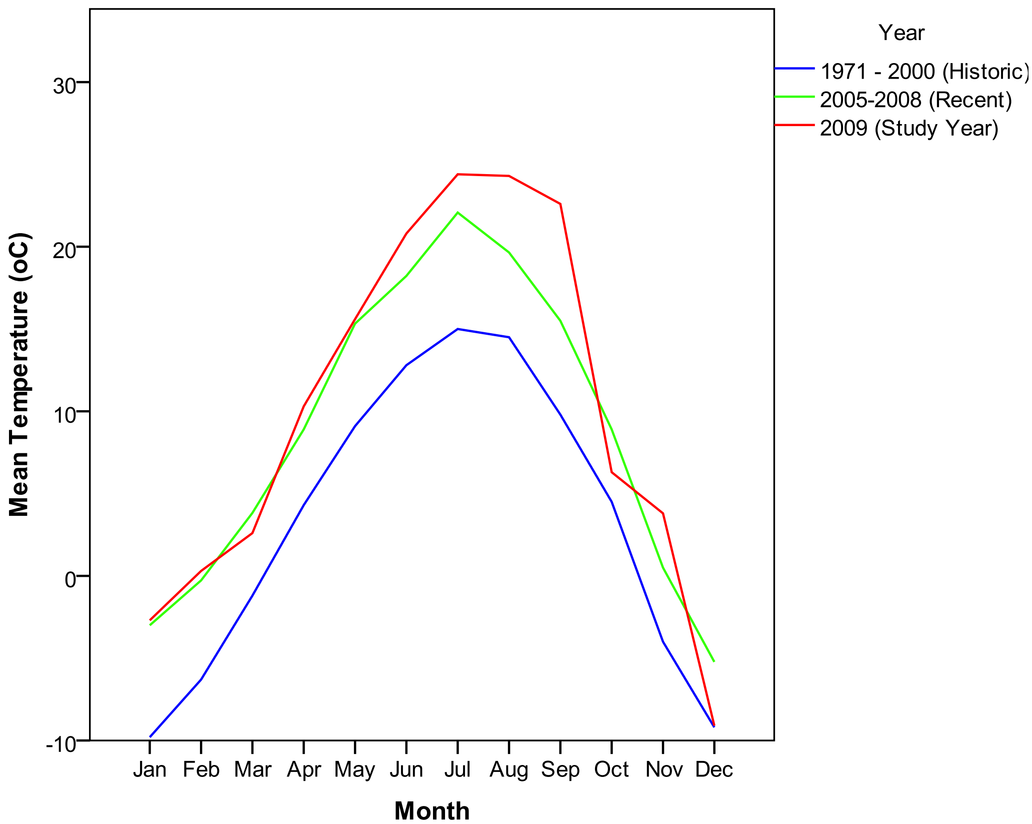

Figure 6. Historic, recent and study year comparison of Jasper National Park air temperature from the Jasper Warden Station.

Table 1. Canadian climate normals from 1971 to 2000 for Jasper (Environment Canada 2002).

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Air Temperature (^{o}C)	-9.8	-6.3	-1.2	4.3	9.1	12.8	15	14.5	9.8	4.5	-4	-9.2
Precipitation (mm)	26.9	16	17.6	18.8	29.9	55	60.1	59.1	37.3	28.7	24.5	24.8
Snowfall (cm)	30.5	18.3	16.9	8.6	1.4	0.3	0	0.2	1.9	8	21.6	30.3
Rainfall (mm)	4.5	2.8	5.1	12	28.7	54.7	60.1	59	35.9	22.1	8.3	3.4
Snow Depth (cm)	23	24	15	2	0	0	0	0	0	0	5	16
Wind Speed (km h^{-1}) SW	9.2	9.1	8.3	8.6	8.5	8.1	7.9	7.3	7.6	8.5	8.7	9.1
Relative Humidity (%) 0600 h	81.4	80.9	80.8	80.2	80	81	83	87	86.8	82.3	83.5	82.3
Relative Humidity (%) 1500 h	70.9	61.5	49.9	38.5	38.3	40.5	41.8	44.2	47.1	50.8	66.7	74.3

Table 2. Calcareous soil series descriptions (TERA Environmental Consultants and University of Alberta 2007).

Soil Series	Soil Classification	Parent Material	Texture	Topsoil (cm)	Calcareous Surface
Devona	Calcareous orthic, Calcareous cumulic regosol	Eolian	Silt loam to very fine sandy loam	13-22	Extremely
Vermilion Lakes	Calcareous rego gleysol	Fluvial	Silt loam	0-22	Strongly to very strongly
Talbot	Calcareous orthic, Calcareous cumulic regosol	Eolian / fluvial or till	Silt loam / gravelly sandy loam to gravelly loamy sand	9-35	Extremely
Hillsdale 1	Calcareous orthic, Calcareous cumulic regosol	Fluvial fan	Very fine sandy loam to gravelly loamy sand	0-25	Strongly to very strongly
Hinton	Calcareous melanic brunisol	Eolian / till	Loam to silt loam / stony loam	10-90	Strongly to extremely

Table 3. ALS Laboratory methods used for soil analyses.

Soil Parameter	Analytical Method Reference
Bulk density	CSSS 50.2 Wt./Vol Density
Inorganic and organic carbon	SSSA (1996) Pp. 455-456
Total carbon by combustion	SSSA (1996) Combustion Instrument
Carbon:nitrogen ratio	Calculation
Carbonate	APHA 2320 B Potentiometric Titration
Particle size	CSSS 47.3 Hydrometer
Total Kjeldahl nitrogen (organic N)	Forestry Canada (1991) Pp. 57-59
Available nitrate	CSSS (1993) 4.3
Available phosphate and potassium	Comm. Soil Sci. Plant Anal, 25 (5 and 6)
Available sulphate	NCR-13 (1998) Pp.35-39
Chloride	APHA 4500 Cl- E Autod Ferricyanide
Sodium adsorption ratio	CSSS 18.4 Calculation
Sulfate	APHA 3120 B-ICP-OES
Electrical conductivity and pH	CSSS, Chp. 18 Saturation extract

Table 4. Common plant species occurring on calcareous soil sites from predisturbance data collection on pipeline right-of-way.

Scientific Name	Common Name
Amelanchier alnifolia Nutt.	Saskatoon
Antennaria alpina(L.) Gaertn.	Alpine pussytoes
Arctostaphylos uva-ursi (L.) Spreng.	Common bearberry
Artemisia frigida Willd.	Pasture sage
Aster conspicuus Lindl.	Showy aster
Astragalus americanus (Hook.) M.E. Jones	American milk vetch
Carex phaeocephala Piper	Head like sedge
Castilleja miniata Douglas ex Hook.	Indian paintbrush
Chrysopsis villosa (Pursh) Nutt. ex DC.	Golden aster
Cornus canadensis L.	Bunchberry
Cornus sericea Michx.	Red osier dogwood
Equisetum arvense L.	Common horsetail
Fragaria virginiana Mill.	Wild strawberry
Gaillardia aristata Pursh.	Brown eyed susan
Galium boreale L.	Northern bedstraw
Hedysarum boreale Nutt.	Northern sweet vetch
Juniperus communis L.	Common juniper
Juniperus horizontalis Moench	Creeping juniper
Koeleria macrantha (L.) J.A. Schultes f.	June grass
Lilium philadelphicum L.	Wood lily
Maianthemum canadense Desf.	Lily of the valley
Maianthemum stellatum (L.) Link	Star flower soloman’s seal
Mertensia paniculata (Aiton) G. Don	Alpine bluebell
Pentaphylloides floribunda (Pursh) A. Love	Shrubby cinquefoil
Picea glauca (Moench) Voss	White spruce
Pinus contorta Loudon	Lodgepole pine
Poa alpina L.	Alpine bluegrass
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen
Rosa acicularis Lindl.	Wild rose
Shepherdia canadensis (L.) Nutt.	Canada buffaloberry
Smilacina racemosa (L.) Desf.	False soloman's seal
Solidago multiradiata Aiton	Northern goldenrod
Stipa viridula (Trin.) Barkworth	Green needle grass
Trisetum spicatum (L.) Richt.	Spike trisetum
Vaccinium membranaceum Douglas ex Torr.	Mountain huckleberry
Vicia americana Muhl.	American vetch
Zigadenus elegans (Pursh)	Mountain death camas
Zigadenus venenosus S. Watson	Death camas

Table 5. Calcareous soils seed mix developed for TMX-Anchor Loop pipeline project.

Common Name	Scientific Name	Mix %
Idaho fescue	*Festuca idahoensis* Elmer	25
Green needle grass	*Stipa viridula* (Trin.)	20
Spike trisetum	*Trisetum spicatum* (L.) Richt.	15
Bluebunch wheat grass	*Agropyron spicatum* (Pursh) Scribn. and Smith	15
June grass	*Koeleria macrantha* (L.) J.A. Schultes f.	15
Violet wheat grass	*Agropyron violaceum* (Hornem.) Lange	5
Slender / awned wheat grass	*Agropyron trachycaulum* (Link) Malte / *subsecundum* (Link) Hitchc.	5

Table 6. Compost characteristics (Enviro-Test Laboratories 2005, A&L Laboratories Inc. 2005).

Test Parameter	Result
Sample 1 Escherichia Coli (MPN $gram^{-1}$)	4
Sample 1 Fecal Coliform (MPN $gram^{-1}$)	>1100
Sample 2 Escherichia Coli (MPN $gram^{-1}$)	<3
Sample 2 Fecal Coliform (MPN $gram^{-1}$)	4
pH	6.8
C:N ratio	24:1
Water (%)	53.8
Particle size (inches)	3/8 to ¼
Soluble salts (ms cm^{-1})	1.4
Sodium (%)	1.6
Maturity index (Slovita)	7
Chromium (ug g^{-1})	15.15
Copper (ug g^{-1})	145.65
Lead (ug g^{-1})	4.35
Nickel (ug g^{-1})	10.15
Zinc (ug g^{-1})	129.80

* Arsenic, cadmium, cobalt, mercury, molybdenum and selenium tested below detectable limits

**Salmonella not isolated

Table 7. 2007 pre-disturbance soil properties for the calcareous soil series along the TMX-Anchor Loop pipeline.

Parameter	Devona	Hinton	Hillsdale	Talbot	Vermilion Lakes
Inorganic Carbon (%)	4.04	3.04	3.63	3.90	1.71
Organic Carbon (%)	6.08	5.53	5.53	4.32	6.23
Total Carbon (%)	10.03	8.57	9.18	8.18	7.89
$CaCO_3$ (%)	33.6	25.9	30.7	33.0	19.6
Total Nitrogen (%)	0.315	0.261	0.353	0.213	0.255
Available N (mg kg^{-1})	4.3	4.4	10.3	5.9	5.9
Available P (mg kg^{-1})	1.7	0.7	2.3	1.4	0.5
Available K (mg kg^{-1})	120.5	122.3	197.2	113.0	170.3
Available S (mg kg^{-1})	7.7	9.1	11.2	9.3	18.9
Calcium (mg L^{-1})	103.5	69.4	106.8	81.8	95.4
Magnesium (mg L^{-1})	17.5	21.1	18.3	26.3	22.3
Potassium (mg L^{-1})	15.3	7.4	12.4	9.2	5.7
Sodium (mg L^{-1})	7.8	6.7	6.8	6.8	6.3
Base Saturation (%)	102.2	97.0	88.4	87.6	103.3
Soil pH	7.42	7.56	7.38	7.67	7.26
Electrical Conductivity (dS m^{-1})	0.62	0.50	0.64	0.56	0.57
Sodium Adsorption Ratio	0.17	0.18	0.17	0.17	0.15

Table 8. 2009 post-disturbance calcareous soil series properties.

Parameter	Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
PR 5 (MPa)	1.1	2.1	1.7	1.5	1.4
PR 10 (MPa)	2.0	3.2	2.7	2.5	2.7
PR 15 (MPa)	2.3	3.1	3.2	2.9	3.2
Soil Water (%)	12.8	8.6	11.5	14.2	11.6
Base Saturation (%)	80.7	60.9	79.8	73.6	69.4
Available N mg kg^{-1})	15.6	41.4	26.3	15.4	6.0
Available P mg kg^{-1})	82.2	120.7	85.3	73.6	120.0
Available K mg kg^{-1})	177.6	205.3	290.7	164.0	249.7
Available S (mg kg^{-1})	13.2	20.4	25.3	22.9	15.4
$CaCO_3$ (%)	39.9	43.4	29.2	40.7	25.0
Ca (mg L^{-1})	123.1	162.6	124.3	128.8	138.0
Mg (mg L^{-1})	27.6	32.2	76.1	36.9	46.1
K (mg L^{-1})	41.8	42.3	47.9	36.9	21.1
Na (mg L^{-1})	11.9	8.2	13.8	9.0	13.8
Electric Conductivity (dS m^{-1})	0.834	1.109	1.071	0.846	0.857
Soil pH	7.17	7.09	7.39	7.29	7.20
Sodium Adsorption Ratio	0.26	0.15	0.23	0.18	0.26
Total Nitrogen (%)	0.359	0.343	0.321	0.316	0.271
Inorganic Carbon (%)	4.73	5.13	3.45	4.81	2.94
Total Carbon (%)	10.7	9.8	9.1	10.6	8.2
Organic Carbon (%)	5.99	4.65	5.65	5.82	5.30

*PR = Penetration Resistance

Table 9. 2009 post-disturbance pipeline area soil properties.

Parameter	Spoil	Trench	Work
PR 5 (MPa)	1.3	1.5	1.9
PR 10 (MPa)	2.2	2.7	2.9
PR 15 (MPa)	2.4	3.0	3.3
Soil Water (%)	12.0	11.7	11.5
Base Saturation (%)	75.5	71.4	71.8
Available N mg kg^{-1})	15.2	26.7	21.0
Available P mg kg^{-1})	94.8	98.9	95.6
Available K mg kg^{-1})	215.8	217.3	219.9
Available S (mg kg^{-1})	41.9	19.1	24.2
CaCO3 (%)	35.6	36.0	35.3
Ca (mg L^{-1})	125.5	140.4	140.3
Mg (mg L^{-1})	39.8	45.5	46.1
K (mg L^{-1})	35.6	40.9	37.5
Na (mg L^{-1})	10.3	11.5	12.2
Electric Conductivity (dS m^{-1})	0.863	0.993	0.975
Soil pH	7.24	7.21	7.23
Sodium Adsorption Ratio	0.20	0.21	0.23
Inorganic Carbon (%)	4.21	4.25	4.16
Organic Carbon (%)	5.69	5.41	5.36
Total Carbon (%)	9.9	9.7	9.5
Total Nitrogen (%)	0.335	0.316	0.315

* PR = Penetration Resistance

Table 10. 2009 post-disturbance amendment treatment soil properties.

Parameter	Cont	Fert	HC	HC Inc	LC	LC Inc	WC	WC + Fert	WC Inc	WC Inc + Fert
PR 5 (MPa)	2.1	2.0	1.6	1.1	2.0	1.4	1.6	1.7	1.2	1.2
PR 10 (MPa)	2.8	2.8	2.6	2.5	2.8	2.6	2.6	2.6	2.6	2.3
PR 15 (MPa)	2.9	3.0	2.8	2.9	3.0	2.9	2.9	2.9	2.9	2.7
Soil Water (%)	12.7	13.1	12.2	9.5	12.2	10.8	12.8	13.0	11.2	10.0
Base Saturation (%)	70.1	69.2	76.6	77.4	70.1	71.5	73.5	73.9	72.6	73.7
Available N mg kg^{-1})	17.1	21.7	42.9	51.7	24.9	29.6	5.5	5.6	3.9	6.9
Available P mg kg^{-1})	5.0	14.6	319.0	377.8	87.3	116.2	6.9	13.6	5.6	15.6
Available K mg kg^{-1})	157.2	162.5	303.9	333.7	211.4	220.2	199.2	192.0	193.1	200.9
Available S (mg kg^{-1})	26.9	21.8	24.4	28.1	20.9	26.2	9.7	11.3	12.2	13.2
$CaCO_3$ (%)	37.4	36.5	33.7	32.7	35.5	35.4	36.7	36.1	36.0	36.2
Ca (mg L^{-1})	143.2	136.0	142.4	150.0	139.7	149.8	120.6	120.2	122.7	129.7
Mg (mg L^{-1})	42.3	41.7	53.9	60.3	46.6	50.8	34.3	34.0	35.8	38.5
K (mg L^{-1})	23.6	25.5	60.7	68.3	35.8	39.4	31.7	31.2	30.1	33.2
Na (mg L^{-1})	11.3	12.0	13.7	14.5	12.2	13.0	8.6	8.8	9.4	10.2
Electric Conductivity (dS m^{-1})	0.945	0.966	1.106	1.183	0.984	1.048	0.769	0.805	0.772	0.863
Soil pH	7.42	7.42	6.90	6.81	7.22	7.19	7.32	7.33	7.35	7.35
Sodium Adsorption Ratio	0.21	0.23	0.25	0.25	0.23	0.24	0.17	0.18	0.19	0.20
Inorganic Carbon (%)	4.42	4.32	3.97	3.86	4.20	4.20	4.33	4.27	4.26	4.28
Organic Carbon (%)	4.85	4.73	6.27	6.62	5.17	5.42	5.44	5.47	5.47	5.34
Total Carbon (%)	9.3	9.1	10.2	10.5	9.4	9.6	9.8	9.7	9.7	9.6
Total Nitrogen (%)	0.298	0.286	0.391	0.420	0.318	0.333	0.291	0.294	0.295	0.294

*PR = Penetration resistance

Table 11. Volumetric soil water content, pH and electrical conductivity by amendment treatment.

Amendment Treatment	Soil Water (%)	Soil pH	Electrical Conductivity (dS m^{-1})
Control	12.7 (0.5)	7.42 (0.02)	0.945 (0.062)
Fertilizer	13.1 (0.6)	7.42 (0.02)	0.966 (0.057)
Heavy Compost	12.2 (0.6)	6.90 (0.04)	1.106 (0.067)
Heavy Compost Incorporated	9.5 (0.5)	6.81 (0.04)	1.183 (0.080)
Light Compost	12.2 (0.5)	7.22 (0.02)	0.984 (0.045)
Light Compost Incorporated	10.8 (0.6)	7.19 (0.02)	1.048 (0.053)
Wood Chips	12.8 (0.5)	7.32 (0.02)	0.769 (0.032)
Wood Chips Fertilizer	13.0 (0.6)	7.33 (0.02)	0.805 (0.035)
Wood Chips Incorporated	11.2 (1.3)	7.35 (0.02)	0.772 (0.027)
Wood Chips Incorporated Fertilizer	10.0 (0.5)	7.35 (0.02)	0.863 (0.033)

*Mean (standard error)

Table 12. Carbon and nitrogen by amendment treatment.

Amendment Treatment	Organic Carbon (%)	Inorganic Carbon (%)	Total Nitrogen (%)	C:N
Control	4.85 (0.24)	4.42 (0.14)	0.298 (0.012)	31:1
Fertilizer	4.73 (0.16)	4.32 (0.14)	0.286 (0.008)	32:1
Heavy Compost	6.27 (0.23)	3.97 (0.14)	0.391 (0.013)	26:1
Heavy Compost Incorporated	6.62 (0.22)	3.86 (0.13)	0.420 (0.014)	25:1
Light Compost	5.17 (0.14)	4.20 (0.13)	0.318 (0.008)	30:1
Light Compost Incorporated	5.42 (0.16)	4,19 (0.12)	0.333 (0.009)	29:1
Wood Chips	5.45 (0.19)	4.33 (0.12)	0.291 (0.009)	34:1
Wood Chips Fertilizer	5.47 (0.22)	4.27 (0.13)	0.294 (0.011)	33:1
Wood Chips Incorporated	5.47 (0.18)	4.26 (0.13)	0.295 (0.008)	33:1
Wood Chips Incorporated Fertilizer	5.35 (0.18)	4.28 (0.13)	0.294 (0.009)	33:1

*Mean (standard error)

Table 13. Available soil nutrients by amendment treatment.

Amendment Treatment	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available S (mg kg^{-1})
Control	17.1 (4.4)	5.0 (0.5)	157.2 (10.5)	26.9 (6.7)
Fertilizer	21.7 (4.7)	14.6 (1.7)	162.5 (10.3)	21.8 (3.1)
Heavy Compost	42.9 (7.1)	319.0 (27.1)	303.9 (15.0)	24.4 (2.4)
Heavy Compost Incorporated	51.7 (8.5)	377.8 (30.2)	333.7 (16.2)	28.1 (2.8)
Light Compost	24.9 (3.8)	87.3 (8.4)	211.4 (11.5)	20.9 (2.2)
Light Compost Incorporated	29.6 (4.4)	116.2 (9.3)	220.2 (10.1)	26.2 (3.9)
Wood Chips	5.5 (2.6)	6.9 (0.9)	199.2 (11.7)	9.7 (1.5)
Wood Chips Fertilizer	5.6 (1.6)	13.6 (1.1)	192.0 (9.9)	11.3 (2.5)
Wood Chips Incorporated	3.9 (1.3)	5.6 (0.5)	193.1 (10.0)	12.2 (2.1)
Wood Chips Incorporated Fertilizer	6.9 (2.7)	15.6 (1.6)	200.9 (8.5)	13.2 (1.7)

*Mean (standard error)

Table 14. Penetration resistance by pipeline area.

Depth	Spoil	Trench	Work
5 cm (MPa)	1.3 (0.1)	1.5 (0.1)	1.9 (0.1)
10 cm (MPa)	2.2 (0.1)	2.7 (0.1)	2.9 (0.1)
15 cm (MPa)	2.4 (0.1)	3.0 (0.1)	3.3 (0.1)

*Mean (standard error)

Table 15. Penetration resistance by amendment treatment.

Amendment Treatment	5 cm (MPa)	10 cm (MPa)	15 cm (MPa)
Control	2.1 (0.1)	2.8 (0.1)	2.9 (0.2)
Fertilizer	2.0 (0.1)	2.8 (0.1)	3.0 (0.2)
Heavy Compost	1.6 (0.1)	2.6 (0.1)	2.8 (0.1)
Heavy Compost Incorporated	1.1 (0.1)	2.5 (0.1)	2.9 (0.2)
Light Compost	2.0 (0.1)	2.8 (0.1)	3.0 (0.2)
Light Compost Incorporated	1.4 (0.1)	2.6 (0.1)	2.9 (0.1)
Wood Chips	1.6 (0.1)	2.6 (0.1)	2.9 (0.1)
Wood Chips Fertilizer	1.7 (0.1)	2.6 (0.1)	2.9 (0.2)
Wood Chips Incorporated	1.2 (0.1)	2.6 (0.2)	2.9 (0.1)
Wood Chips Incorporated Fertilizer	1.2 (0.1)	2.3 (0.1)	2.7 (0.1)

*Mean (standard error)

Table 16. Grass species found in 2009 vegetation assessments.

Scientific Name	Common Name	Designation
Agropyron dasystachyum (Hook.)	Northern wheat grass	Native
Agropyron repens L.	Quack grass	Nuisance
Agropyron spicatum (Pursh)	Broad glumed wheat grass	Native*
Agropyron subsecundum (Link) Hitchc.	Awned wheat grass	Native*
Agropyron trachycaulum (Link)Malte	Slender wheat grass	Native*
Agropyron violaceum (Hornem.) Lange	Violet wheat grass	Native
Agrostis scabra Willd.	Tickle grass	Native
Agrostis stolonifera L.	Redtop	Native
Danthonia californica Bol.	California oat grass	Native
Elymus canadensis L.	Canada wildrye	Native
Elymus glaucus Buckley	Smooth wildrye	Native
Elymus innovatus (Beal) Pilg.	Hairy wildrye	Native
Festuca idahoensis Elmer	Idaho fescue	Native*
Festuca rubra L.	Richardson's fescue	Native
Festuca saximontana Rydb.	Rocky Mountain fescue	Native
Hordeum jubatum L.	Foxtail barley	Introduced
Koeleria macrantha (L.) J.A. Schultes f.	June grass	Native*
Phleum alpinum L.	Mountain timothy	Native
Poa alpina L.	Alpine blue grass	Native
Poa ampla J. Presl	Big blue grass	Native
Poa compressa L.	Canada blue grass	Native
Poa glauca Vahl	Timberline blue grass	Native
Poa palustris L.	Fowl blue grass	Native
Poa pratensis L.	Kentucky blue grass	Introduced
Puccinellia nuttalliana (Schult.) Hitchc.	Nuttal's alkali grass	Native
Stipa viridula (Trin.) Barkworth	Green needle grass	Native*
Trisetum spicatum (L.) Richt.	Spike trisetum	Native*

* Denotes species included in the prescribed seed mix

Table 17. Forb species found in 2009 vegetation assessments.

Scientific Name	Common Name	Designation
Achillea millefolium L.	Yarrow	Native
Androsace septentrionalis L.	Northern fairy candelabra	Native
Arabis lemmonii S. Watson	Lemmon's rock cress	Native
Arabis spp	Rock cress spp	Native
Arctostaphylos uva-ursi (L.) Spreng.	Common bearberry	Native
Artemisia frigida Willd.	Prairie sagewort	Native
Aster ciliolatus (Lindl.)	Fringed aster	Native
Astragalus alpinus L.	Alpine milk vetch	Native
Astragalus americanus (Hook.)	American milk vetch	Native
Astragalus spp	Milk vetch spp	Native
Campanula rotundifolia L.	Common harebell	Native
Capsella bursa-pastoris L.	Shepherd's purse	Nuisance
Carex spp	Sedge spp	Native
Chenopodium album L.	Lambs quarters	Introduced
Chenopodium capitatum (l.) Asch.	Strawberry blight	Native
Chrysanthemum leucanthemum L.	Ox eye daisy	Noxious
Cirsium arvense L.	Canada thistle	Noxious
Comandra umbellata (L.) Nutt.	Pale comandra	Native
Corydalis aurea Willd.	Golden corydalis	Native
Crepis tectorum L.	Narrow leaved hawk's beard	Nuisance
Delphinium glaucum S. Watson	Tall larkspur	Native
Descurainia sophia L.	Flixweed	Nuisance
Epilobium angustifolium L.	Fireweed	Native
Epilobium glandulosum Lehm.	Fringed willow herb	Native
Equisetum arvense L.	Common horsetail	Native
Erucastrum gallicum (Willd.) O.E. Schulz	Dog mustard	Nuisance
Erysimum cheiranthoides L.	Worm seed mustard	Nuisance
Erysimum pallasii (Pursh) Fernald	Pallas wall flower	Native
Fragaria virginiana Mill.	Wild strawberry	Native
Galium boreale L.	Northern bedstraw	Native
Hedysarum alpinum L.	Alpine sweet-vetch	Native
Hedysarum boreale Nutt.	Northern sweet-vetch	Native
Lappula squarrosa (retz.) Dumort.	Blue bur	Nuisance
Lathyrus lanszwertii Kellogg	White flowered peavine	Native
Lathyrus venosus Muhl. Ex Willd	Veiny peavine	Native
Lepidium densiflorum Schrad.	Common peppergrass	Introduced
Lilium philadelphicum L.	Wood lily	Native
Linaria vulgaris Mill.	Toadflax	Noxious
Lithospermum ruderale Douglas ex Lehm.	Lemon weed	Native
Medicago lupulina L.	Black medick	Native
Medicago sativa L.	Alfalfa	Introduced
Melilotus alba (l.) Lam.	White sweet clover	Introduced
Melilotus spp	Sweet clover	Introduced
Mertensia paniculata (Aiton) G. Don	Tall bluebells	Native
Oxytropis splendens Douglas ex Hook.	Showy locoweed	Native
Oxytropis spp	Locoweed spp	Native
Petasites palmatus (Aiton)	Sweet coltsfoot	Native
Plantago major L.	Common plantain	Introduced
Polygonum aviculare L.	Common knot weed	Native
Potentilla gracilis Douglas ex Hook.	Graceful cinquefoil	Native

Table 17. Forb species found in 2009 vegetation assessments (continued).

Scientific Name	Common Name	Designation
Potentilla norvegica L.	Rough cinquefoil	Nuisance
Pyrola spp	Winter green spp	Native
Sempervivum spp	Hen and chicks	Native
Silene acaulis (L.) Jacq.	Moss campion	Native
Sisymbrium altissimum L.	Tall tumble mustard	Introduced
Sisymbrium loeselii L.	Tall hedge mustard	Introduced
Sisyrinchium montanum Greene	Mountain blue eyed grass	Native
Smilacina stellata (L.) Link	False solomon's seal	Native
Solidago canadensis L.	Canada goldenrod	Native
Solidago multiradiata Aiton.	Northern goldenrod	Native
Solidago simplex Kunth	Spike like goldenrod	Native
Sonchus arvensis L	Perennial sow thistle	Noxious
Taraxacum officinale F.H. Wigg.	Dandelion	Nuisance
Thalictrum venulosum Trel.	Veiny meadow rue	Native
Thlaspi arvense L.	Field pennycress	Nuisance
Trifolium hybridum L.	Alsike clover	Native
Trifolium pratense L.	Red clover	Native
Trifolium repens L.	White clover	Native
Vicia americana Muhl.	American vetch	Native
Viola adunca Sm.	Early blue violet	Native
Viola orbiculata Geyer ex Holz.	Round leaved yellow violet	Native
Viola spp	Violet spp	Native
Zigadenus elegans (Persh)	Mountain death camas	Native

Table 18. Tree and shrub species found in 2009 vegetation assessments.

Scientific Name	Common Name	Designation
Alnus viridis (Chaix) DC	Green alder	Native
Alnus spp	Alder spp	Native
Amelanchier alnifolia Nutt.	Saskatoon	Native
Betula papyrifera Marsh.	Paper birch	Native
Cornus stolonifera Michx.	Red osier dogwood	Native
Juniperus communis L.	Common juniper	Native
Picea glauca (Moench) Voss	White spruce	Native
Populus balsamifera L.	Balsam poplar	Native
Potentilla fruticosa (L.) Rydb.	Shrubby cinquefoil	Native
Pseudotsuga menziesii (Mirb.) Franco	Douglas fir	Native
Ribes hudsonianum Richardson	Northern black current	Native
Ribes lacustre (Pers.) Poir.	Black gooseberry	Native
Ribes oxyacanthoides L.	Northern gooseberry	Native
Ribes spp	Gooseberry spp	Native
Rosa acicularis Lindl.	Prickly rose	Native
Rosa woodsii Lindl.	Prairie rose	Native
Rubus idaeus L.	Wild red raspberry	Native
Rubus parviflorus Nutt.	Thimbleberry	Native
Salix spp	Willow spp	Native
Shepherdia canadensis (L.) Nutt.	Canada buffalo berry	Native
Symphoricarpos albus (L.) S.F. Blake	Common snowberry	Native

Table 19. Seeded species cover (%) by calcareous soil series.

Seeded species	Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
Agropyron spicatum,	< 0.1	0.3	< 0.1	< 0.1	< 0.1
Agropyron subsecundum / Agropyron trachycaulum	0.3	0.1	0.2	< 0.1	0.4
Agropyron violaceum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Festuca idahoensis	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Koeleria macrantha / Trisetum spicatum	2.2	0.8	0.4	1.0	0.3
Stipa viridula	0.3	< 0.1	< 0.1	0.2	< 0.1

Table 20. Seeded species density (plants/m^2) by calcareous soil series.

Seeded species	Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
Agropyron spicatum,	1.1	2.6	2.6	1.0	1.3
Agropyron subsecundum / Agropyron trachycaulum	0.7	0.5	0.7	0.6	0.9
Agropyron violaceum	0.2	0.2	0.1	0.2	0.3
Festuca idahoensis	0.4	1.7	1.1	0.2	0.7
Koeleria macrantha / Trisetum spicatum	48.4	21.2	31.4	24.6	16.9
Stipa viridula	1.8	1.4	1.5	2.3	0.3

Table 21. Seeded species success: percent density of an individual seeded species from the complete seed mix species density for calcareous soil series.

Soil	*Agro spi*	*Agro sub/ Agro tra*	*Agro vio*	*Fest ida*	*Koel mac/ Tris spi*	*Stip vir*
Devona	4.3	4.8	1.5	0.9	82.0	6.6
Hillsdale	11.6	4.9	0.8	4.9	69.3	8.5
Hinton	7.6	7.7	1.8	2.8	71.9	8.3
Talbot	7.2	3.5	0.9	0.5	77.7	10.1
Vermilion Lakes	15.1	11.0	1.3	4.0	67.0	1.6

* *Agro spi = Agropyron spicatum, Agro sub / Agro tra = Agropyron subsecundum / Agropyron trachycaulum, Agro vio = Agropyron violaceum, Fest ida = Festuca idahoensis, Koel mac / Tris spi = Koeleria macrantha / Trisetum spicatum, Stip vir = Stipa viridula*

Table 22. Seeded species success: percent density of an individual seeded species from the complete seed mix species density for amendment treatments.

Treatment	*Agro spi*	*Agro sub/ Agro tra*	*Agro vio*	*Fest ida*	*Koel mac/ Tris spi*	*Stip vir*
Fert	4.2	3.6	2.3	1.2	83.8	4.7
Cont	11.9	4.1	0.1	1.0	77.7	5.2
WC	9.2	3.8	1.0	3.4	74.8	7.7
WC Inc	20.2	10.9	0.9	3.1	56.9	8.0
WC + F	5.1	2.9	1.8	2.5	83.2	4.5
WC Inc + F	27.8	1.1	0.3	3.1	63.2	4.4
LC	3.4	2.9	0.6	2.9	82.0	8.2
LC Inc	5.4	7.2	2.0	3.1	70.2	12.1
HC	2.5	3.6	1.9	2.5	81.7	7.8
HC Inc	4.5	24.5	1.4	3.3	58.9	7.4

* *Agro spi = Agropyron spicatum, Agro sub / Agro tra = Agropyron subsecundum / Agropyron trachycaulum, Agro vio = Agropyron violaceum, Fest ida = Festuca idahoensis, Koel mac / Tris spi = Koeleria macrantha / Trisetum spicatum, Stip vir = Stipa viridula*

** Treatment Fert = fertilizer, Cont = control, WC = wood chips, WC Inc = wood chips incorporated, WC + F = wood chips and fertilizer, WC Inc + F = wood chips incorporated and fertilizer, LC = light application compost, LC Inc = light application compost incorporated, HC = heavy application compost, HC Inc = heavy application compost incorporated.

Table 23. Vegetation density (plants/m^2) for soils by pipeline areas.

	Devona			Hillsdale			Hinton			Talbot			Vermilion Lakes		
	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work
SN	53.2	60.5	46.4	28.4	41.1	22.2	15.9	8.7	11.2	29.3	36.0	21.9	22.6	16.7	21.8
	(12.0)	(12.6)	(9.8)	(7.3)	(10.8)	(4.1)	(5.3)	(2.0)	(2.8)	(4.3)	(7.9)	(2.8)	(3.3)	(2.8)	(5.6)
USN	31.7	22.7	20.7	22.5	22.7	19.8	8.1	6.2	7.3	14.6	10.2	8.3	25.3	13.2	11.5
	(4.2)	(3.4)	(2.5)	(3.2)	(3.5)	(1.9)	(1.6)	(0.7)	(1.6)	(2.9)	(1.4)	(1.4)	(5.5)	(1.9)	(1.9)
NN	2.3	1.8	1.1	1.6	1.4	0.8	0.8	1.3	1.4	2.8	0.9	0.6	1.8	1.1	0.7
	(0.3)	(0.3)	(0.3)	(0.4)	(0.3)	(0.2)	(0.2)	(0.3)	(0.5)	(0.6)	(0.2)	(0.2)	(0.6)	(0.3)	(0.2)
TD	87.1	85.0	68.2	52.5	65.2	43.9	24.8	16.2	20.0	46.7	47.1	30.8	49.7	31.0	34.0
	(14.7)	(15.1)	(11.1)	(9.9)	(13.9)	(5.5)	(5.6)	(2.2)	(3.5)	(5.2)	(8.2)	(3.3)	(6.7)	(3.8)	(7.0)

* SN = seeded native species, USN = unseeded native species, NN = non-native species, TD = total density

Table 24. Vegetation cover (%) for soils by pipeline areas.

	Devona			Hillsdale			Hinton			Talbot			Vermilion Lakes		
	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work	Spoil	Trench	Work
SN	4.1	2.7	2.0	1.5	1.6	1.3	0.4	0.5	0.5	1.9	1.2	1.0	0.7	1.0	0.9
	(0.9)	(0.5)	(0.3)	(0.6)	(0.5)	(0.4)	(0.1)	(0.2)	(0.2)	(0.5)	(0.3)	(0.2)	(0.2)	(0.3)	(0.2)
USN	8.7	1.9	1.6	1.6	1.8	1.8	0.7	0.4	0.3	1.9	0.7	0.6	0.9	1.0	1.7
	(1.8)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.1)	(0.0)	(0.4)	(0.1)	(0.1)	(0.1)	(0.2)	(0.6)
NN	4.4	4.6	2.6	1.6	1.8	0.9	0.9	0.4	0.4	1.7	0.4	0.3	3.1	1.6	2.2
	(1.3)	(1.7)	(1.0)	(0.8)	(1.0)	(0.6)	(0.3)	(0.2)	(0.1)	(0.7)	(0.2)	(0.1)	(1.6)	(1.0)	(0.9)
TC	17.3	9.1	6.2	4.7	5.3	3.9	2.0	1.3	1.1	5.5	2.4	1.8	4.7	3.7	4.8
	(2.8)	(2.0)	(1.3)	(1.2)	(1.3)	(0.9)	(0.5)	(0.3)	(0.2)	(1.1)	(0.4)	(0.3)	(1.7)	(1.3)	(1.3)

* SN = seeded native species, USN = unseeded native species, NN = non-native species, TC = total cover

Table 25. Post-disturbance vegetation density (plants/m^2) by amendment treatment.

Vegetation Class	Native Seeded	Native Non-Seeded	Non-Native	Total Density
Control	43.5	19.4	1.1	64.0
Fertilizer	65.1	20.3	1.2	86.5
Heavy Compost	4.6	14.3	2.4	21.3
Heavy Compost Incorporated	14.0	10.2	2.4	26.6
Light Compost	25.3	23.5	1.9	50.7
Light Compost Incorporated	38.0	16.5	2.3	56.8
Wood Chips	20.5	16.0	0.5	37.0
Wood Chips Fertilizer	31.7	20.7	1.3	53.6
Wood Chips Incorporated	26.0	12.2	0.3	38.6
Wood Chips Incorporated Fertilizer	28.5	13.2	0.5	42.3

Table 26. Post-disturbance vegetation cover (%) by amendment treatment.

Vegetation Class	Native Seeded	Native Non-seeded	Non-Native	Total Cover
Control	0.9	0.8	0.2	1.9
Fertilizer	1.7	1.1	1.5	4.3
Heavy Compost	1.2	3.4	5.5	10.2
Heavy Compost Incorporated	2.7	3.2	5.2	11.2
Light Compost	2.5	3.2	2.8	8.4
Light Compost Incorporated	3.8	2.3	3.4	10.0
Wood Chips	0.3	0.8	0.1	1.3
Wood Chips Fertilizer	0.9	1.5	0.3	2.7
Wood Chips Incorporated	0.4	0.6	0.1	1.0
Wood Chips Incorporated Fertilizer	0.6	1.1	0.1	1.8

CHAPTER 3: SUMMARY AND FUTURE DIRECTIONS

1. RESEARCH SUMMARY

Kinder Morgan Canada was granted approval for construction of the TMX Anchor-Loop Pipeline through Jasper National Park to meet the growing demand of Canada's western shipping routes for crude oil produced in Alberta. The pipeline right-of-way traverses five sensitive calcareous soil series in the park.

This research was initiated with two main objectives. The first was to evaluate compost, fertilizer, compost and combinations of these amendments to determine which provides the most suitable substrate conditions for native plant species and minimizes erosion potential on newly reclaimed calcareous soils. The second objective was to evaluate two compost application rates and two methods of application for compost and wood chip amendments to determine which provides the most initial benefit to soil physical and chemical properties and improves native vegetation establishment while minimizing labour and cost.

Four sites were chosen within each of the five soil series and divided into work, trench and spoil areas. Within each, ten amendment treatments were applied including control, fertilizer, wood chips, wood chips and fertilizer, incorporated wood chips, incorporated wood chips and fertilizer, heavy rate compost, incorporated heavy rate compost, light rate compost and incorporated light rate compost. Amendments were chosen based on availability and source within the park to comply with restrictions on bringing products into a national park.

Fertilizer treatments increased available nitrates and available phosphorous, when applied as the only amendment, but had little influence when applied with wood chip treatments. Most soil nutrients were immobilized in wood chips treatments even though pH was slightly decreased. Incorporation of amendments had little influence on soil chemical properties but decreased penetration resistance and slightly increased soil organic carbon. Soil parameters responded most favourably to compost treatments. Soil organic carbon and nutrients increased on compost treatments while soil chemical parameters were further increased by a decrease in soil pH and $CaCO_3$ equivalent.

Erosion control capabilities of amendment treatments could not be determined in this short study period. Although erosion was not extremely detrimental on the small plots used in this study, it would be an important factor to determine for large scale projects and applications.

Control and fertilizer treatments often had moderate vegetation density and cover, surpassing three of the four wood chips treatments; the exception was unincorporated wood chips treatments that had been fertilized. Plants were generally taller and more robust on fertilized than control treatments. Wood chip treatments provided an effective barrier for non native species emergence from the seed bank. Non native and native cover were reduced by wood chip treatments in comparison with the other six amendment options. Vegetation cover increased dramatically with compost. Plants were larger and many produced seed heads in the first growing season, providing an additional seed source for the upcoming season. Light compost treatments had similar cover, increased species diversity, decreased sizes of non-native species while still providing moderate plant densities compared to heavy compost counterparts. Incorporation of light compost treatments further improved soil and vegetation benefits but it is unclear if the incorporation had any influence on erosion control capability. Rooting of the more robust plants on compost treatments likely provided increased soil stability to aid in erosion reduction.

2. RECOMMENDATIONS

2.1 Reclamation and Monitoring Along the TMX

Reclamation and monitoring along the TMX-Anchor Loop project will continue for several years. Plots used in this study were constructed so that they may be used in the future to increase understanding of calcareous soil reclamation and the implications of disturbance in a protected park setting.

This study focused on early reclamation of calcareous soils along the TMX pipeline. As amendments decompose and the effects of fertilization have passed, it is necessary to monitor the changes and results of these treatments. Data collection and monitoring should continue through multiple growing seasons to determine the long term viability of the reclamation techniques and the influence of amendment treatments.

Plant density can be deceiving when not assessed in conjunction with cover, height and health data. Many plots had extremely high species densities. The small plants and seedlings that account for these densities may not survive winter because they had little root development and carbohydrate reserves throughout the first growing season. The high densities recorded in 2009 do not mean high survival for spring 2010. Vegetation assessments will be important in 2010 and beyond to determine survival rate and long term viability for success.

Many results from this study, especially when considering the low vegetation establishment on many plots, could have been negatively affected by lack of precipitation throughout early parts of the first growing season. Plant emergence was delayed on many plots until July and August resulting in low cover and small individual plants. A more in depth assessment of precipitation and soil water content determinations at more regular intervals throughout the growing season would be beneficial to determine if growing conditions were and will continue to be one of the most limiting factors to vegetation establishment.

Off site areas, treated with a hydroslurry of mulch, fertilizer and seed looked more successful than adjacent study sites. Many of these areas were seeded in the spring and summer of 2008, from half to a full growing season before the study areas which were seeded in late fall 2008. This head start in germination and establishment are likely the reason that off-site areas look much greener and healthier in comparison with study sites. Vegetation cover may be deceiving from a distance because large areas were treated with the hydroslurry and the m^2 research plots do not have the same visual extent of cover as the off-site areas. The hydroslurry also contained a green dye which early after its application gave the impression of a vegetation cover. Off-site plots should be used to compare the prescribed pipeline hydroslurry application with the research amendments. Based on visual observations during the time of vegetation assessments, the hydroslurry treated areas do not have high density or cover for vegetation if only a m^2 area is focused on. This visual deception would be interesting to quantify with complete data collection and compared on the same scale.

2.2 Future Research

Interesting information and observations came out of this research and like any research more questions arose. This study has provided a great starting point from which to expand scientific understanding of the effects of disturbance to calcareous soils but much more information is needed. A strong understanding of the effect of disturbance techniques, amendment types and application methods are crucial for the efficient and successful reclamation of these sensitive soils.

Erosion control suitability of amendment treatments was one of the original focuses for this study. Small plot size and the close proximity of plots to each other made it impossible to determine where eroded soil originated and what volume of soil moved off various amendment treatments. Visual evidence of erosion included soil deposition on plants and plot corner stakes but erosion rills and other quantifiable data were not collected. An erosion study using large plots with wider buffer zones would make erosion quantification easier. The use of silt fencing or other collection device could be used with a different plot set-up. Erosion of disturbed calcareous soils is a major concern and determining appropriate prevention techniques it critical for reclamation success.

Nutrient addition to disturbed calcareous soils is necessary for vegetation establishment. An amendment such as compost that provides an immediate nutrient source and a long term, slow release source seems to be the most efficient method for successful early vegetation establishment on reclaimed sites. Further monitoring will provide information on long term viability of compost treatments, but the large volumes of compost required for extensive calcareous soil reclamation is not readily available in most areas. Research into other amendments that provide similar benefits while also being more readily available would be beneficial. This is especially true if calcareous soils become more commonly disturbed through development and mineral exploitation.

Another approach to making compost use for reclamation more feasible would be to conduct a study to determine the minimal application rates and depths of incorporation. Finding an application rate that provides the greatest benefit for the least amount of the scarce amendment material would increase efficiency and decrease waste. More area could be successfully reclaimed with smaller volumes of compost amendment. A low application rate supplemented with another amendment could be beneficial. The current study only assessed three amendments due to restrictions on amendment use within the national park.Projects conducted outside of park boundaries could utilize a wider range of amendment options. Previous research utilized sulphur or sulfuric acid to reduce pH and compost options such as feedlot manure or whey products from cheese production for the addition of nutrients. If a large scale waste product or other underutilized material could produce successful reclamation results while reducing waste from other industries, the environmental benefits would be further increased.

3. LITERATURE CITED

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Appendix

Table A1. Sites and plots where weed removal was conducted pre-vegetation assessments.

Sites	Pipeline Area	Plots
Hillsdale #1	Work	8
	Spoil	9
Hillsdale #2	Work	4
	Spoil	10
Hillsdale #3	Work	7, 10
	Trench	3, 4, 7, 8, 9
	Spoil	1, 3, 7, 8, 9, 10
Hillsdale #4	Work	7, 10
	Trench	10
Talbot #3	Trench	4
	Spoil	9
Devona #4	Work	9
	Trench	9

Table A2. Sites and plots that required 0.1 m^2 quadrats for vegetation assessments

Site	Pipeline Area	Plots
Hillsdale #2	Trench	1, 5, 6
	Spoil	5
Hillsdale #4	Work	1
	Trench	7
Hinton #1	Work	7, 8, 9, 10
	Trench	1, 2, 7, 8, 9, 10
	Spoil	1, 7, 8, 9, 10
Devona #1	Work	1
	Trench	1, 4, 7
	Spoil	1, 6
Devona #2	Spoil	1
Devona #3	Work	2, 4, 6
Vermilion Lakes #1	Spoil	2
Vermilion Lakes #2	Work	1

Table A3. 2009 soil properties for soils by pipeline work areas.

Area	Devona			Hillsdale			Hinton			Talbot			Vermilion Lakes		
	S	T	W	S	T	W	S	T	W	S	T	W	S	T	W
PR5	0.8	1.1	1.5	1.8	1.8	2.8	1.5	1.6	1.9	1.3	1.7	1.6	1.4	1.3	1.6
(MPa)	(0.1)[c]	(0.1)[b]	(0.1)[a]	(0.2)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
PR10	1.5	1.9	2.6	2.8	3.2	3.8	2.4	3.1	2.8	2.0	2.8	2.8	2.3	2.7	3.0
(MPa)	(0.1)[c]	(0.1)[b]	(0.1)[a]	(0.2)	(0.2)	(0.2)	(0.1)	(0.2)	(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	(0.1)
PR15	1.8	2.1	3.0	2.6	2.9	4.2	2.8	3.8	3.0	2.1	3.3	3.3	2.9	3.3	3.7
(MPa)	(0.1)[c]	(0.1)[b]	(0.1)[a]	(0.2)	(0.2)	(0.3)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.3)	(0.1)
SW (%)	10.8	79.8	13.3	8.2	8.8	8.9	11.9	11.3	11.4	15.1	14.4	13.3	14.3	9.8	10.6
	(0.6)	(1.1)	(0.6)	(0.8)	(0.8)	(0.8)	(0.5)	(0.4)	(0.6)	(0.5)	(0.5)	(0.5)	(0.8)	(0.7)	(0.5)
Sat (%)	88.0	79.8	74.4	61.4	59.8	61.5	80.8	79.2	79.4	77.8	68.9	74.2	69.4	69.3	69.4
	(3.6)	(1.1)	(1.6)	(1.9)	(1.3)	(1.4)	(2.3)	(1.5)	(1.0)	(2.9)	(2.5)	(2.3)	(2.7)	(2.3)	(2.1)
$CaCO_3$	38.7	40.4	40.6	44.0	44.6	41.5	29.3	29.2	29.1	41.5	40.4	40.2	24.8	25.2	25.0
(%)	(1.0)	(0.8)	(0.7)	(0.7)	(0.9)	(0.5)	(0.5)	(0.6)	(0.5)	(1.0)	(0.5)	(0.5)	(0.8)	(0.7)	(0.6)
Avail N	11.1	19.3	16.4	31.4	52.6	40.2	13.0	39.6	26.2	17.2	15.2	13.9	3.6	6.4	8.2
(mg kg^{-1})	(2.4)	(6.7)	(3.9)	(6.3)	(9.0)	(7.2)	(3.3)	(12.5)	(5.6)	(3.7)	(5.3)	(4.1)	(1.1)	(3.1)	(2.6)
Avail P	75.3	89.4	82.0	117.2	122.3	122.7	77.0	86.7	92.2	89.0	67.8	64.1	115.3	127.9	116.8
(mg kg^{-1})	(19.8)	(25.3)	(21.2)	(30.1)	(29.4)	(33.6)	(18.9)	(22.8)	(26.6)	(33.3)	(18.5)	(17.5)	(27.8)	(36.2)	(29.9)
Avail K	187.2	179.0	166.8	198.5	205.5	22.0	273.8	302.8	295.6	170.1	158.3	163.7	248.1	239.7	261.3
(mg kg^{-1})	(12.0)	(11.0)	(10.1)	(12.9)	(14.8)	(14.6)	(16.0)	(26.5)	(22.8)	(13.3)	(10.3)	(9.3)	(11.7)	(12.9)	(13.8)
Avail S	11.4	14.7	13.5	11.4	15.2	34.6	19.9	30.2	25.7	18.2	22.3	28.2	13.7	13.4	19.0
(mg kg^{-1})	(1.2)	(2.2)	(1.4)	(1.1)	(2.0)	(59.3)	(2.0)	(3.7)	(2.8)	(1.0)	(5.5)	(6.9)	(1.8)	(1.9)	(2.2)
Soil pH	7.15	7.15	7.21	7.11	7.06	7.09	7.42	7.39	7.37	7.31	7.31	7.26	7.22	7.14	7.24
	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)
EC	0.77	0.89	0.85	0.96	1.17	1.204	0.96	1.20	1.06	0.83	0.83	0.88	0.80	0.88	0.89
(dS m^{-1})	(0.02)	(0.07)	(0.04)	(0.06)	(0.09)	(0.08)	(0.05)	(0.11)	(0.06)	(0.05)	(0.08)	(0.07)	(0.03)	(0.06)	(0.03)
SAR	0.25	0.25	0.27	0.14	0.15	0.16	0.21	0.24	0.25	0.18	0.18	0.19	0.25	0.24	0.28
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)

* Mean (standard error)[significance]

** S = spoil area, T = trench area, W = work area

*** PR5 = penetration resistance at 5 cm depth, PR10 = penetration resistance at 10 cm depth, PR15 = penetration resistance at 15 cm depth, SW = volumetric soil water, Sat = soil base saturation, Avail N = available nitrogen, Avail P = available phosphorous, Avail K = available potassium, Avail S = available sulphur, EC = electrical conductivity, SAR = sodium adsorption ratio.

Table A3. 2009 soil properties for soils by pipeline work areas (continued).

Area	Devona			Hillsdale			Hinton			Talbot			Vermillion Lakes		
	S	T	W	S	T	W	S	T	W	S	T	W	S	T	W
Ca	118.2	129.5	121.6	141.0	166.6	180.2	114.1	137.1	121.6	112.9	128.0	135.4	131.1	140.5	142.5
(mg L^{-1})	(3.1)	(6.9)	(4.5)	(7.5)	(11.0)	(14.2)	(4.7)	(9.5)	(4.6)	(5.7)	(9.4	(9.0)	(3.8)	(5.1)	(4.5)
Mg	24.9	29.1	28.9	27.6	32.1	36.7	67.9	82.6	77.8	36.5	36.3	38.0(	41.9(	47.2(	49.2(
(mg L^{-1})	(1.2)	(2.8)	(1.9)	(1.9)	(2.0)	(2.6)	(4.8)	(7.9)	(5.8)	(3.1)	(4.0)	3.4)	3.9)	5.3)	3.8)
K	42.0	42.8	40.6	38.5	45.4	43.1	41.7	57.5	44.4	36.4	37.3	37.1	19.4	21.4	22.4
(mg L^{-1})	(2.7)	(3.9)	(3.2)	(2.9)	(3.7)	(3.7)	(4.0)	(8.4)	(4.7)	(3.4)	(4.2)	(3.3)	(1.8)	(2.6)	(2.2)
Na	11.1	12.1	12.6	7.2	8.3	9.0	11.9	15.0	14.6	8.7	9.0	9.3	12.7	13.3	15.5
(mg L^{-1})	(0.5)	(0.6)	(0.7)	(0.4)	(0.5)	(0.5)	(0.8)	(1.3)	(1.1)	(0.5)	(0.6)	(0.5)	(0.9)	(0.9)	(1.1)
IOC (%)	4.59	4.79	4.81	5.21	5.28	4.90	3.46	3.45	3.43	4.91	4.78	4.75	2.91	2.97	2.93
	(0.12)	(0.11)	(0.08)	(0.09)	(0.10)	(0.06)	(0.06)	(0.07)	(0.06)	(0.12)	(0.06)	(0.06)	(0.09)	(0.08)	(0.07)
TOC	6.67	5.79	5.51	4.68	4.56	4.73	5.81	5.61	5.54	5.96	5.69	5.83	5.33	5.39	5.17
(%)	(0.39)	(0.19)	(0.23)	(0.21)	(0.19)	(0.23)	(0.18)	(0.24)	(0.15)	(0.32)	(0.25)	(0.28)	(0.22)	(0.23)	(0.20)
TC (%)	11.3	10.6	10.3	9.9	9.8	9.6	9.3	9.1	9.0	10.9	10.5	10.6	8.2	8.4	8.1
	(0.3)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	(0.2)	(0.3)	(0.2)	(0.2)	(0.2)
TN (%)	0.38	0.36	0.34	0.34	0.34	0.35	0.33	0.32	0.32	0.35	0.30	0.31	0.28	0.27	0.27
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

* Mean (standard error)^{significance}

** S = spoil area, T = trench area, W = work area

*** IOC = inorganic carbon, TOC = total organic carbon, TC = total carbon, TN = total nitrogen.

Table A4. Sodium adsorption ratio for soils by amendment treatments.

Amendment Treatment	Sodium Adorption Ratio				
	Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
Control	0.28 (0.03)^{ab}	0.10 (0.01)^{e}	0.23 (0.02)^{bcde}	0.16 (0.01)^{c}	0.30 (0.04)^{a}
Fertilizer	0.30 (0.04)^{a}	0.13 (0.01)^{cde}	0.25 (0.023)^{abcd}	0.15 (0.01)^{c}	0.30 (0.04)^{ab}
Heavy Compost	0.27 (0.01)^{ab}	0.22 (0.01)^{ab}	0.26 (0.02)^{abc}	0.23 (0.02)^{a}	0.25 (0.01)^{abc}
Heavy Compost Incorporated	0.25 (0.01)^{ab}	0.24 (0.01)^{a}	0.30 (0.02)^{a}	0.22 (0.01)^{ab}	0.25 (0.02)^{abc}
Light Compost	0.27 (0.02)^{ab}	0.16 (0.01)^{cd}	0.27 (0.02)^{ab}	0.18 (0.01)^{bc}	0.26 (0.02)^{abc}
Light Compost Incorporated	0.28 (0.03)^{ab}	0.17 (0.01)^{be}	0.26 (0.02)^{abc}	0.19 (0.01)^{abc}	0.27 (0.03)^{abc}
Wood Chips	0.21 (0.01)^{b}	0.10 (0.01)^{e}	0.18 (0.02)^{e}	0.16 (0.01)^{c}	0.22 (0.02)^{c}
Wood Chips Fertilizer	0.22 (0.02)^{b}	0.13 (0.01)^{cde}	0.17 (0.01)^{e}	0.16 (0.01)^{c}	0.23 (0.01)^{bc}
Wood Chips Incorporated	0.22 (0.01)^{b}	0.12 (0.01)^{de}	0.20 (0.02)^{de}	0.16 (0.01)^{c}	0.24 (0.02)^{abc}
Wood Chips Incorporated Fertilizer	0.25 (0.02)^{ab}	0.13 (0.01)^{cde}	0.21 (0.02)^{cde}	0.19 (0.01)^{abc}	0.23 (0.02)^{abc}

* Mean (standard error)^{significance}

Table A5. Electrical conductivity for soils by amendment treatments.

Amendment Treatment	Electrical Conductivity (dS m^{-1})				
	Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
Control	0.82 (0.05)^{ab}	1.23 (0.22)^{ab}	0.93 (0.09)^{c}	0.94 (0.18)^{ab}	0.80 (0.06)
Fertilizer	0.87 (0.04)^{ab}	1.21 (0.21)^{ab}	1.10 (0.10)^{bc}	0.79 (0.13)^{ab}	0.85 (0.07)
Heavy Compost	1.10 (0.18)^{a}	1.15 (0.08)^{ab}	1.41 (0.21)^{ab}	0.91 (0.10)^{ab}	0.10 (0.12)
Heavy Compost Incorporated	0.95 (0.12)^{ab}	1.31 (0.17)^{a}	1.56 (0.24)^{a}	1.13 (0.19)^{a}	0.97 (0.12)
Light Compost	0.87 (0.06)^{ab}	1.19 (0.11)^{ab}	1.22 (0.11)^{abc}	0.83 (0.11)^{ab}	0.82 (0.05)
Light Compost Incorporated	0.88 (0.06)^{ab}	1.29 (0.14)^{ab}	1.19 (0.10)^{abc}	0.10 (0.16)^{ab}	0.90 (0.07)
Wood Chips	0.70 (0.06)^{b}	0.89 (0.09)^{ab}	0.81 (0.09)^{c}	0.69 (0.05)^{b}	0.77 (0.05)
Wood Chips Fertilizer	0.69 (0.05)^{b}	1.02 (0.11)^{ab}	0.81 (0.08)^{c}	0.68 (0.05)^{b}	0.82 (0.05)
Wood Chips Incorporated	0.71 (0.04)^{b}	0.85 (0.06)^{b}	0.82 (0.08)^{c}	0.69 (0.06)^{b}	0.79 (0.05)
Wood Chips Incorporated Fertilizer	0.76 (0.05)^{ab}	0.98 (0.12)^{ab}	0.87 (0.07)^{c}	0.82 (0.06)^{ab}	0.90 (0.05)

* Mean (standard error)^{significance}

Table A6. Soil pH for soils by amendment treatments.

Amendment Treatment	Soil pH Devona	Hillsdale	Hinton	Talbot	Vermilion Lakes
Control	7.28 (0.05)^{a}	7.36 (0.03)^{a}	7.53 (0.05)^{ab}	7.44 (0.04)^{a}	7.46 (0.03)^{a}
Fertilizer	7.32 (0.04)^{a}	7.35 (0.02)^{ab}	7.57 (0.03)^{a}	7.43 (0.04)^{a}	7.40 (0.04)^{ab}
Heavy Compost	6.87 (0.07)^{b}	6.62 (0.08)^{e}	7.13 (0.08)^{d}	7.16 (0.90)^{bc}	6.74 (0.08)^{d}
Heavy Compost Incorporated	6.75 (0.08)^{b}	6.63 (0.06)^{e}	7.01 (0.08)^{d}	6.91 (0.11)^{c}	6.76 (0.08)^{d}
Light Compost	7.21 (0.04)^{a}	7.08 (0.04)^{cd}	7.38 (0.06)^{bc}	7.31 (0.06)^{ab}	7.15 (0.04)^{c}
Light Compost Incorporated	7.16 (0.06)^{a}	7.05 (0.03)^{d}	7.33 (0.04)^{c}	7.19 (0.05)^{ab}	7.20 (0.04)^{bc}
Wood Chips	7.25 (0.05)^{a}	7.18 (0.04)^{bcd}	7.48 (0.04)^{abc}	7.37 (0.05)^{ab}	7.30 (0.05)^{abc}
Wood Chips Fertilizer	7.30 (0.04)^{a}	7.15 (0.03)^{cd}	7.53 (0.02)^{ab}	7.36 (0.05)^{ab}	7.30 (0.04)^{abc}
Wood Chips Incorporated	7.29 (0.05)^{a}	7.21 (0.04)^{abcd}	7.47 (0.05)^{abc}	7.43 (0.04)^{a}	7.34 (0.05)^{abc}
Wood Chips Incorporated Fertilizer	7.29 (0.05)^{a}	7.24 (0.04)^{abc}	7.51 (0.05)^{abc}	7.37 (0.04)^{ab}	7.33 (0.04)^{abc}

* Mean (standard error)^{significance}

Table A7. Total nitrogen, $CaCO_3$ equivalent and potassium for soils by amendment treatments.

Amend Treat	Total Nitrogen (%) DVA	HDL	HTN	TAB	VLN	CaCO3 Equivalent (%) DVA	HDL	HTN	TAB	VLN	K (mg/L) DVA	HDL	HTN	TAB	VLN
Cont	0.36 (0.04)^{bc}	0.31 (0.02)^{b}	0.29 (0.01)^{b}	0.30 (0.02)^{ab}	0.23 (0.02)^{b}	40.8 (1.8)^{a}	45.0 (1.5)^{ab}	29.9 (1.1)^{a}	42.8 (1.9)	27.2 (1.1)^{a}	27.2 (2.5)^{c}	23.5 (2.1)^{c}	29.2 (9.4)^{b}	25.9 (4.9)^{cd}	10.9 (1.3)^{c}
Fert	0.32 (0.01)^{c}	0.29 (0.02)^{b}	0.29 (0.01)^{b}	0.29 (0.03)^{b}	0.23 (0.02)^{b}	41.0 (1.5)^{a}	46.8 (0.9)^{a}	29.3 (1.1)^{a}	39.9 (0.9)	26.2 (0.8)^{a}	29.8 (3.3)^{c}	28.6 (2.4)^{bc}	35.2 (9.1)^{b}	20.0 (5.3)^{d}	13.2 (1.7)^{bc}
HC	0.42 (0.03)^{ab}	0.45 (0.04)^{a}	0.40 (0.02)^{a}	0.33 (0.18)^{ab}	0.35 (0.03)^{a}	37.7 (2.1)^{b}	40.5 (1.3)^{cd}	27.5 (0.9)^{b}	40.3 (1.2)	22.3 (1.3)^{bc}	66.8 (8.4)^{a}	69.8 (6.2)^{a}	83.0 (15.1)^{a}	47.2 (4.5)^{b}	36.8 (6.2)^{a}
HC Inc	0.45 (0.02)^{a}	0.45 (0.02)^{a}	0.44 (0.03)^{a}	0.38 (0.04)^{a}	0.39 (0.03)^{a}	37.5 (1.8)^{b}	37.9 (1.0)^{d}	27.5 (1.0)^{b}	39.1 (1.2)	21.7 (1.3)^{c}	64.8 (5.4)^{ab}	78.3 (8.5)^{a}	90.6 (14.0)^{a}	70.7 (10.0)^{a}	36.9 (5.6)^{a}
LC	0.33 (0.01)^{c}	0.34 (0.02)^{b}	0.32 (0.01)^{b}	0.32 (0.02)^{ab}	0.28 (0.02)^{b}	40.3 (1.3)^{ab}	43.3 (1.2)^{abc}	29.4 (1.0)^{a}	40.6 (1.1)	24.1 (1.1)^{abc}	41.3 (3.5)^{c}	40.6 (2.4)^{b}	47.7 (7.4)^{b}	29.5 (4.9)^{bcd}	19.8 (3.0)^{bc}
LC Inc	0.36 (0.02)^{bc}	0.36 (0.02)^{b}	0.34 (0.02)^{b}	0.34 (0.02)^{ab}	0.27 (0.02)^{b}	40.5 (1.4)^{ab}	42.1 (1.0)^{bc}	28.9 (0.8)^{ab}	39.9 (0.9)	25.8 (1.4)^{ab}	44.8 (3.6)^{bc}	42.1 (4.2)^{b}	49.1 (7.0)^{b}	43.6 (7.0)^{bc}	17.4 (2.0)^{bc}
WC	0.33 (0.03)^{c}	0.32 (0.02)^{b}	0.28 (0.01)^{b}	0.29 (0.02)^{b}	0.24 (0.01)^{b}	40.3 (1.3)^{ab}	43.9 (1.2)^{abc}	29.9 (0.9)^{a}	41.7 (1.2)	27.4 (1.1)^{a}	38.8 (6.0)^{c}	32.6 (2.6)^{bc}	40.0 (10.1)^{b}	30.1 (3.6)^{bcd}	17.3 (1.5)^{bc}
WC + F	0.36 (0.04)^{bc}	0.30 (0.02)^{b}	0.29 (0.01)^{b}	0.29 (0.02)^{b}	0.24 (0.02)^{b}	39.8 (1.4)^{ab}	45.8 (1.4)^{ab}	29.5 (0.9)^{a}	40.4 (0.9)	25.2 (1.3)^{abc}	34.7 (5.2)^{c}	39.1 (2.0)^{b}	31.4 (5.0)^{b}	28.4 (3.5)^{bcd}	22.3 (3.2)^{b}
WC Inc	0.33 (0.01)^{c}	0.30 (0.02)^{b}	0.29 (0.01)^{b}	0.31 (0.02)^{ab}	0.25 (0.01)^{b}	40.9 (1.2)^{a}	44.4 (0.8)^{ab}	29.8 (0.9)^{a}	41.2 (1.8)	25.0 (1.0)^{abc}	35.2 (2.8)^{c}	33.7 (3.4)^{bc}	37.4 (9.6)^{b}	29.8 (3.9)^{bcd}	16.5 (2.3)^{bc}
WC Inc+ F	0.33 (0.02)^{c}	0.32 (0.01)^{b}	0.28 (0.01)^{b}	0.30 (0.03)^{ab}	0.24 (0.01)^{b}	40.4 (1.4)^{ab}	44.0 (1.3)^{abc}	30.2 (1.3)^{a}	41.1 (1.4)	25.3 (1.3)^{abc}	34.7 (3.0)^{c}	35.0 (2.5)^{bc}	35.2 (5.9)^{b}	41.4 (3.6)^{bc}	19.5 (2.2)^{bc}

* Mean (standard error)^{significance}

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC + Fert = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + Fert = wood chips incorporated and fertilizer.

Table A8. Inorganic and organic carbon for soils by amendment treatments.

Amend Treat	Inorganic Carbon (%)					Organic Carbon (%)				
	DVA	HDL	HTN	TAB	VLN	DVA	HDL	HTN	TAB	VLN
Cont	4.84 (0.22)^{a}	5.33 (0.18)^{ab}	3.54 (0.14)^{a}	5.06 (0.23)	3.20 (0.13)^{a}	5.85 (0.82)^{ab}	3.72 (0.21)^{bc}	4.98 (0.34)^{c}	5.31 (0.55)	4.26 (0.28)^{d}
Fert	4.87 (0.19)^{a}	5.55 (0.11)^{a}	3.46 (0.13)^{a}	4.72 (0.12)	3.07 (0.10)^{a}	5.34 (0.31)^{b}	3.52 (0.16)^{c}	5.07 (0.20)^{c}	5.40 (0.55)	4.45 (0.28)^{cd}
HC	4.46 (0.25)^{b}	4.79 (0.16)^{cd}	3.24 (0.11)^{b}	4.77 (0.14)	2.62 (0.15)^{bc}	6.84 (0.67)^{ab}	6.06 (0.65)^{a}	6.45 (0.34)^{ab}	6.03 (0.49)	5.98 (0.42)^{ab}
HCInc	4.44 (0.21)^{b}	4.47 (0.12)^{d}	3.33 (0.12)^{b}	4.62 (0.14)	2.54 (0.16)^{c}	7.22 (0.46)^{a}	6.02 (0.30)^{a}	6.89 (0.42)^{a}	6.43 (0.71)	6.56 (0.48)^{a}
LC	4.78 (0.16)^{ab}	5.13 (0.14)^{abc}	3.47 (0.12)^{a}	4.80 (0.12)	2.83 (0.13)^{abc}	5.39 (0.25)^{b}	4.33 (0.25)^{bc}	5.34 (0.16)^{bc}	5.67 (0.44)	5.10 (0.23)^{bcd}
LCInc	4.81 (0.17)^{ab}	4.98 (0.12)^{bc}	3.42 (0.10)^{ab}	4.17 (0.10)	3.03 (0.17)^{ab}	5.53 (0.38)^{ab}	4.71 (0.33)^{b}	5.72 (0.37)^{abc}	6.11 (0.25)	5.06 (0.32)^{bcd}
WC	4.78 (0.16)^{ab}	5.19 (0.14)^{abc}	3.54 (0.11)^{a}	4.93 (0.14)	3.23 (0.13)^{a}	6.03 (0.60)^{ab}	4.65 (0.30)^{bc}	5.79 (0.31)^{abc}	5.50 (0.53)	5.27 (0.27)^{bcd}
WC + F	4.71 (0.17)^{ab}	5.42 (0.17)^{ab}	3.48 (0.11)^{a}	4.77 (0.11)	2.96 (0.16)^{abc}	6.08 (0.73)^{ab}	4.34 (0.14)^{bc}	5.44 (0.25)^{bc}	5.96 (0.57)	5.53 (0.40)^{abc}
WCInc	4.84 (0.14)^{a}	5.26 (0.09)^{ab}	3.52 (0.11)^{a}	4.87 (0.21)	2.93 (0.12)^{abc}	5.77 (0.26)^{ab}	4.60 (0.25)^{bc}	5.73 (0.41)^{abc}	5.86 (0.49)	5.55 (0.47)^{abc}
WCInc + F	4.79 (0.16)^{ab}	5.21 (0.15)^{abc}	3.57 (0.16)^{a}	0.49 (0.16)	2.97 (0.15)^{abc}	5.86 (0.41)^{ab}	4.60 (0.27)^{bc}	5.14 (0.28)^{c}	5.92 (0.56)	5.23 (0.32)^{bcd}

* Mean (standard error)^{significance}

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC + F = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + F = wood chips incorporated and fertilizer.

Table A9. Available nitrogen and phosphorous for soils by amendment treatments.

Amend Treat	Available N (mg/kg) DVA	HDL	HTN	TAB	VLN	Available P (mg/kg) DVA	HDL	HTN	TAB	VLN
Cont	11.1 (4.6)^{b}	52.6 (17.8)^{ab}	7.9 (3.1)^{c}	10.7 (4.0)^{b}	1.8 (0.4)^{b}	3.6 (0.3)^{b}	5.2 (0.7)^{b}	6.1 (1.8)^{b}	6.6 (1.2)^{b}	3.2 (1.2)^{c}
Fert	14.7 (3.0)^{b}	59.7 (18.4)^{a}	14.8 (4.0)^{c}	14.1 (3.0)^{b}	4.0 (2.0)^{b}	14.8 (3.4)^{b}	16.4 (2.4)^{b}	11.4 (2.0)^{b}	22.8 (7.3)^{b}	9.0 (1.6)^{bc}
HC	45.6 (19.7)^{a}	54.1 (8.1)^{ab}	66.8 (24.2)^{ab}	23.7 (7.2)^{ab}	24.2 (10.7)^{a}	269.3 (45.3)^{a}	423.2 (72.8)^{a}	321.7 (50.9)^{a}	157.2 (41.2)^{a}	423.5 (59.3)^{a}
HCInc	28.1 (10.2)^{ab}	72.1 (18.1)^{a}	97.2 (28.7)^{a}	49.7 (16.2)^{a}	11.5 (3.4)^{ab}	338.7 (52.5)^{a}	455.1 (57.2)^{a}	308.6 (54.5)^{a}	318.0 (93.4)^{ab}	468.8 (67.9)^{a}
LC	19.2 (7.3)^{ab}	48.6 (10.5)^{abc}	32.9 (8.5)^{bc}	19.8 (7.0)^{b}	4.2 (2.3)^{b}	62.8 (11.0)^{b}	119.5 (18.3)^{b}	65.2 (9.9)^{b}	45.8 (9.1)^{b}	143.0 (25.0)^{b}
LCInc	21.5 (7.0)^{ab}	54.0 (13.7)^{ab}	34.8 (8.3)^{bc}	27.0 (9.4)^{ab}	10.6 (5.7)^{ab}	101.5 (20.5)^{b}	143.1 (15.2)^{b}	101.4 (16.8)^{b}	120.7 (34.3)^{b}	114.4 (10.2)^{bc}
WC	2.9 (1.2)^{b}	20.5 (12.3)^{bcd}	1.6 (0.4)^{c}	1.6 (0.4)^{b}	1.0 (0.0)^{b}	2.9 (1.2)^{b}	5.9 (1.0)^{b}	9.1 (4.1)^{b}	7.8 (0.9)^{b}	5.0 (0.5)^{c}
WC+F	5.2 (1.4)^{b}	15.9 (7.3)^{cd}	3.0 (0.8)^{c}	3.0 (0.4)^{b}	1.1 (0.1)^{b}	5.2 (1.4)^{b}	17.9 (1.8)^{b}	10.7 (2.4)^{b}	16.2 (3.2)^{b}	14.2 (2.4)^{bc}
WCInc	2.9 (1.1)^{b}	12.6 (6.0)^{d}	1.5 (0.2)^{c}	1.7 (0.4)^{b}	1.0 (0.0)^{b}	2.9 (1.2)^{b}	4.8 (0.7)^{b}	6.0 (1.2)^{b}	7.2 (0.8)^{b}	3.6 (0.3)^{c}
WCInc+F	4.7 (1.7)^{b}	23.8 (21.5)^{bcd}	2.3 (0.4)^{c}	2.9 (1.0)^{b}	1.0 (0.0)^{b}	4.7 (1.7)^{b}	16.0 (1.8)^{b}	12.6 (1.9)^{b}	24.8 (5.8)^{b}	15.3 (3.5)^{bc}

* Mean (standard error)^{significance}

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC + F = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + F = wood chips incorporated and fertilizer.

Table A10. Available potassium and sulphur for soils by amendment treatments.

Amend Treat	Available K (mg/kg) DVA	HDL	HTN	TAB	VLN	Available S (mg/kg) DVA	HDL	HTN	TAB	VLN
Cont	129.4 (11.6)[b]	141.7 (19.1)[b]	215.0 (38.9)[c]	117.5 (12.8)[cd]	181.1 (11.1)[c]	15.8 (2.9)[abcd]	33.7 (25.3)	23.8 (3.2)[bcd]	42.8 (20.7)[a]	17.0 (3.8)[abcd]
Fert	133.3 (13.4)[b]	146.4 (16.8)[b]	225.0 (34.5)[bc]	107.1 (12.4)[d]	191.4 (12.6)[c]	20.6 (3.9)[a]	15.7 (5.5)	33.9 (6.6)[ab]	19.2 (12.6)[ab]	19.3 (5.5)[abc]
HC	252.8 (17.2)[a]	313.9 (32.0)[a]	427.3 (36.6)[a]	207.8 (12.2)[ab]	317.7 (27.5)[a]	19.4 (4.8)[ab]	27.3 (5.6)	32.6 (6.7)[abc]	17.5 (4.0)[ab]	25.2 (5.0)[a]
HC Inc	258.3 (18.5)[a]	324.2 (20.0)[a]	456.2 (47.1)[a]	268.6 (31.7)[a]	351.4 (30.4)[a]	16.5 (2.7)[abc]	30.3 (4.5)	43.0 (7.3)[a]	30.6 (9.1)[ab]	20.1 (2.8)[abc]
LC	167.8 (10.3)[b]	191.9 (19.1)[b]	298.8 (32.3)[bc]	145.7 (12.5)[bcd]	252.8 (19.9)[b]	15.1 (2.3)[abcd]	16.8 (3.4)	34.9 (4.7)[ab]	21.2 (7.5)[ab]	16.3 (2.4)[abcd]
LC Inc	185.3 (13.8)[b]	202.6 (16.1)[b]	305.7 (28.5)[b]	177.7 (14.7)[bc]	229.8 (16.2)[bc]	14.3 (2.1)[abcd]	31.3 (14.1)	31.7 (4.0)[abc]	32.1 (11.8)[ab]	21.3 (4.2)[ab]
WC	167.8 (19.3)[b]	175.9 (17.2)[b]	265.5 (40.1)[bc]	146.8 (14.4)[bcd]	239.9 (15.3)[bc]	6.4 (0.9)[d]	8.2 (3.0)	11.8 (2.3)[d]	15.4 (6.1)[ab]	6.7 (1.0)[d]
WC+F	162.6 (27.2)[b]	182.2 (17.6)[b]	217.1 (16.9)[bc]	140.9 (12.7)[cd]	257.6 (18.4)[b]	7.0 (0.9)[cd]	18.8 (11.6)	10.3 (1.0)[d]	12.4 (4.0)[b]	7.9 (1.2)[d]
WC Inc	154.6 (9.2)[b]	179.9 (15.1)[b]	254.3 (33.7)[bc]	144.2 (12.5)[cd]	237.2 (15.7)[bc]	6.9 (1.1)[d]	12.258 (6.6)	14.1 (2.6)[d]	19.0 (7.3)[ab]	9.1 (2.0)[cd]
WC Inc+F	154.6 (12.6)[b]	194.7 (17.8)[b]	242.2 (22.5)[bc]	174.8 (11.6)[bc]	238.1 (17.4)[bc]	10.3 (2.8)[bcd]	10.0 (1.4)	16.5 (2.6)[cd]	18.6 (7.1)[ab]	10.9 (2.3)[bcd]

* Mean (standard error)[significance]

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HCInc = heavy application compost incorporated, LC = light application compost, LCInc = light application compost incorporated, WC = wood chips, WC+F = wood chips and fertilizer, WCInc = wood chips incorporated, WC Inc+F = wood chips incorporated and fertilizer.

Table A11. Calcium, magnesium and sodium for soil by amendment treatments.

Amend	Ca (mg/L)					Mg (mg/L)					Na (mg/L)				
Treat	DVA	HDL	HTN	TAB	VLN	DVA	HDL	HTN	TAB	VLN	DVA	HDL	HTN	TAB	VLN
Cont	129.7 (5.7)	198.9 (37.5)	114.9 (10.0)^{bc}	142.3 (24.5)	131.8 (5.8)	26.5 (2.6)^{abc}	31.3 (6.0)^{bc}	69.2 (8.4)^{bcd}	39.4 (8.6)^{ab}	43.5 (8.7)^{ab}	13.0 (1.4)^{ab}	6.7 (0.9)^{de}	12.6 (1.3)^{bcde}	8.2 (1.1)^{c}	16.2 (2.5)
Fert	131.3 (5.3)	169.0 (27.3)	120.7 (8.9)^{bc}	120.4 (13.6)	136.0 (9.1)	25.4 (2.2)^{bc}	26.1 (3.2)^{c}	79.5 (11.7)^{abcd}	31.5 (5.8)^{b}	44.3 (9.1)^{ab}	14.4 (1.7)^{a}	6.6 (0.3)^{de}	14.5 (2.0)^{bcd}	7.3 (0.7)^{c}	16.2 (2.8)
HC	141.7 (18.0)	147.2 (12.6)	150.0 (19.0)^{ab}	126.6 (8.4)	146.2 (14.1)	39.5 (7.7)^{a}	42.1 (1.9)^{ab}	92.3 (13.5)^{ab}	39.9 (5.7)^{ab}	55.5 (6.8)^{ab}	13.9 (0.9)^{a}	11.6 (0.7)^{ab}	16.9 (2.4)^{ab}	11.7 (1.4)^{ab}	14.2 (1.3)
HCInc	127.4 (12.1)	163.4 (21.5)	161.4 (18.4)^{a}	149.5 (21.9)	148.4 (12.3)	36.7 (3.8)^{ab}	48.9 (4.4)^{a}	106.9 (18.4)^{a}	51.2 (9.2)^{a}	57.7 (10.4)^{a}	12.4 (0.8)^{ab}	13.0 (0.8)^{a}	20.4 (2.7)^{a}	12.1 (1.2)^{a}	14.6 (1.6)
LC	127.3 (6.3)	172.8 (14.8)	138.2 (8.9)^{abc}	127.3 (11.7)	132.6 (7.6)	28.8 (3.1)^{abc}	34.2 (2.2)^{bc}	89.7 (10.8)^{abc}	36.1 (5.5)^{ab}	44.1 (6.5)^{ab}	12.6 (0.9)^{ab}	8.7 (0.5)^{cd}	17.2 (2.1)^{ab}	8.7 (0.8)^{bc}	13.7 (1.5)
LCInc	127.1 (6.8)	191.7 (23.4)	133.4 (5.9)^{abc}	150.8 (20.5)	145.9 (6.2)	29.3 (2.5)^{abc}	41.1 (4.6)^{ab}	87.3 (11.4)^{abc}	46.3 (8.2)^{ab}	50.8 (8.6)^{ab}	13.3 (1.1)^{ab}	9.8 (0.6)^{bc}	16.3 (2.1)^{abc}	10.3 (1.1)^{abc}	15.4 (2.0)
WC	111.5 (9.2)	142.5 (13.7)	107.5 (10.2)^{c}	111.0 (6.7)	130.8 (8.4)	22.0 (2.4)^{c}	23.0 (2.0)^{c}	59.4 (7.3)^{cd}	29.4 (3.1)^{b}	37.9 (6.3)^{b}	9.3 (0.6)^{b}	5.3 (0.4)^{e}	9.7 (1.0)^{de}	7.5 (0.4)^{c}	11.1 (1.2)
WC + Fert	106.1 (6.6)	152.0 (17.4)	102.7 (8.6)^{c}	111.2 (7.4)	128.7 (5.3)	21.1 (2.0)^{c}	26.1 (3.3)^{c}	54.1 (5.9)^{d}	27.7 (2.1)^{b}	41.2 (6.9)^{ab}	9.5 (0.6)^{b}	6.9 (0.7)^{de}	8.7 (0.7)^{e}	7.2 (0.3)^{c}	11.6 (0.8)
WCInc	112.2 (6.1)	140.6 (11.3)	106.6 (9.4)^{c}	114.7 (8.2)	136.1 (4.1)	22.9 (2.4)^{c}	23.8 (1.5)^{c}	59.6 (7.5)^{cd}	31.8 (3.8)^{b}	42.1 (7.6)^{ab}	9.7 (0.8)^{b}	6.2 (0.4)^{e}	10.6 (1.4)^{de}	7.5 (0.6)^{c}	12.8 (1.4)
WCInc + Fert	116.6 (7.5)	147.9 (14.4)	107.3 (7.9)^{c}	132.9 (12.1)	143.8 (4.2)	24.3 (3.0)^{bc}	25.2 (2.4)^{c}	63.0 (7.6)^{bcd}	36.0 (6.6)^{ab}	43.7 (7.3)^{ab}	11.2 (0.8)^{ab}	6.6 (0.4)^{de}	11.3 (1.3)^{cde}	9.1 (0.8)^{abc}	12.6 (1.5)

* Mean (standard error)^{significance}

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC + Fert = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + Fert = wood chips incorporated and fertilizer.

Table A12. Penetration resistance for soils by amendment treatments.

Amend. Treat	Devona PR5 (MPa)	Devona PR10 (MPa)	Devona PR15 (MPa)	Hillsdale PR5 (MPa)	Hillsdale PR10 (MPa)	Hillsdale PR15 (MPa)	Hinton PR5 (MPa)	Hinton PR10 (MPa)	Hinton PR15 (MPa)	Talbot PR5 (MPa)	Talbot PR10 (MPa)	Talbot PR15 (MPa)	Vermillion Lakes PR5 (MPa)	Vermillion Lakes PR10 (MPa)	Vermillion Lakes PR15 (MPa)
Cont	1.6 (0.2)[a]	2.2 (0.2)	2.4 (0.3)	2.8 (0.4)[a]	3.4 (0.3)	3.2 (0.8)[a]	2.2 (0.1)[ab]	2.7 (0.1)	3.2 (0.4)	1.8 (0.2)[a]	2.8 (0.3)	3.0 (0.4)	1.8 (0.2)[a]	2.9 (0.3)	3.4 (0.4)
Fert	1.4 (0.1)[a]	2.0 (0.2)	2.4 (0.3)	2.8 (0.4)[a]	3.6 (0.3)	2.9 (0.2)[ab]	2.0 (0.2)[ab]	2.9 (0.3)	3.3 (0.3)	1.9 (0.2)[a]	2.8 (0.3)	3.2 (0.4)	1.8 (0.1)[a]	3.0 (0.3)	3.3 (0.4)
HC	1.2 (0.1)[abc]	2.0 (0.1)	2.1 (0.1)	2.2 (0.3)[abcd]	2.9 (0.4)	2.2 (0.2)[b]	1.9 (0.2)[bc]	3.1 (0.3)	3.1 (0.3)	1.5 (0.1)[abcd]	2.6 (0.3)	3.1 (0.4)	1.3 (0.1)[abc]	2.5 (0.2)	3.1 (0.4)
HCInc	0.7 (0.1)[d]	1.8 (0.1)	2.4 (0.2)	1.3 (0.2)[e]	3.4 (0.3)	2.8 (0.5)[ab]	1.1 (0.1)[e]	2.3 (0.2)	3.4 (0.3)	1.3 (0.1)[bcd]	2.6 (0.3)	3.1 (0.4)	1.0 (0.2)[c]	2.4 (0.3)	3.0 (0.4)
LC	1.3 (0.2)[ab]	2.1 (0.2)	2.5 (0.4)	2.6 (0.4)[ab]	3.5 (0.4)	3.3 (0.5)[a]	2.5 (0.2)[a]	3.1 (0.2)	3.3 (0.3)	1.8 (0.1)[ab]	2.7 (0.3)	2.7 (0.3)	1.7 (0.2)[ab]	2.8 (0.3)	3.5 (0.4)
LCInc	0.9 (0.1)[bcd]	2.0 (0.2)	2.2 (0.2)	2.1 (0.4)[bcd]	3.4 (0.3)	3.0 (0.4)[ab]	1.2 (0.1)[cde]	2.5 (0.1)	3.2 (0.3)	1.6 (0.2)[abc]	2.4 (0.2)	2.9 (0.3)	1.4 (0.1)[abc]	2.6 (0.2)	3.4 (0.3)
WC	1.3 (0.1)[ab]	2.1 (0.2)	2.3 (0.3)	2.3 (0.3)[abc]	3.2 (0.3)	3.6 (0.4)[a]	1.7 (0.2)[bcde]	2.5 (0.2)	3.1 (0.2)	1.5 (0.1)[abc]	2.5 (0.3)	2.7 (0.3)	1.3 (0.1)[abc]	2.7 (0.2)	3.1 (0.3)
WC + Fert	1.3 (0.2)[ab]	2.0 (0.2)	2.3 (0.2)	2.3 (0.4)[abc]	3.2 (0.3)	3.6 (0.6)[a]	1.8 (0.1)[bcd]	2.8 (0.2)	2.9 (0.3)	1.5 (0.1)[abcd]	2.5 (0.3)	2.7 (0.3)	1.5 (0.1)[abc]	2.5 (0.3)	3.3 (0.3)
WCInc	0.8 (0.1)[d]	1.8 (0.1)	2.1 (0.2)	1.5 (0.3)[de]	3.1 (0.4)	3.3 (0.6)[a]	1.2 (0.2)[de]	3.1 (0.4)	3.4 (0.4)	1.2 (0.1)[cd]	2.3 (0.2)	2.9 (0.3)	1.3 (0.2)[abc]	2.7 (0.3)	3.1 (0.4)
WCInc + Fert	0.8 (0.2)[cd]	2.0 (0.2)	2.3 (0.2)	1.6 (0.3)[cde]	2.6 (0.2)	2.7 (0.4)[ab]	1.1 (0.1)[e]	2.4 (0.2)	2.9 (0.4)	1.1 (0.1)[d]	2.2 (0.2)	2.6 (0.3)	1.2 (0.1)[bc]	2.5 (0.3)	3.1 (0.2)

* Mean (standard error)[significance]

** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC + Fert = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + Fert = wood chips incorporated and fertilizer.

Table A13. Soil water and base saturation for soils by amendment treatments.

Amend Treat	Soil Water (%)					Base Saturation (%)				
	DVA	HDL	HTN	TAB	VLN	DVA	HDL	HTN	TAB	VLN
Cont	13.1 (1.1)	9.1 (1.3)[abcd]	13.7 (0.8)[a]	14.4 (0.8)[abcd]	13.0 (1.2)[abc]	80.4 (6.3)	56.7 (1.2)[bc]	77.6 (1.9)	72.7 (4.8)	62.1 (4.3)[c]
Fert	12.1 (0.9)	9.7 (1.2)[abc]	13.0 (0.9)[a]	16.2 (1.0)[a]	14.8 (1.6)[a]	79.5 (3.7)	54.0 (2.6)[c]	75.5 (1.7)	71.7 (5.3)	65.7 (4.3)[bc]
HC	13.9 (1.0)	9.0 (2.0)[abcd]	12.6 (0.8)[ab]	15.6 (0.9)[ab]	10.1 (1.0)[bcd]	84.3 (5.1)	69.1 (5.0)[a]	80.7 (1.1)	74.4 (5.0)	74.7 (5.8)[ab]
HCInc	10.6 (1.1)	6.1 (1.1)[d]	9.5 (0.6)[cd]	12.8 (0.8)[cd]	8.5 (0.8)[d]	82.1 (2.8)	65.7 (2.3)[ab]	87.4 (3.1)	75.4 (6.6)	76.5 (4.6)[a]
LC	12.6 (1.1)	8.7 (1.3)[abcd]	12.4 (0.7)[abc]	14.8 (0.9)[abc]	12.5 (1.2)[abc]	80.2 (2.9)	56.2 (1.5)[bc]	76.6 (1.2)	71.7 (5.0)	65.8 (2.4)[bc]
LCInc	11.6 (1.1)	6.7 (1.0)[cd]	10.0 (0.7)[bcd]	14.8 (1.4)[abcd]	11.0 (1.1)[abcd]	77.4 (3.5)	57.4 (1.7)[bc]	78.7 (2.9)	75.8 (3.1)	68.0 (3.6)[abc]
WC	12.6 (1.1)	11.5 (1.7)[a]	12.4 (0.8)[abc]	14.9 (0.6)[abc]	12.7 (1.5)[abc]	82.7 (6.8)	62.0 (2.7)[abc]	81.4 (2.3)	72.8 (4.6)	68.9 (3.8)[abc]
WC+F	13.4 (1.1)	10.8 (1.8)[ab]	13.2 (1.0)[a]	13.8 (0.9)[abcd]	13.9 (1.7)[ab]	82.2 (7.0)	63.8 (1.6)[abc]	78.2 (1.5)	73.7 (5.0)	71.7 (5.2)[abc]
WCInc	17.3 (6.2)	7.3 (1.2)[cd]	9.8 (0.6)[bcd]	12.2 (0.9)[d]	9.6 (1.2)[cd]	79.1 (2.5)	61.6 (1.5)[abc]	79.8 (3.8)	74.0 (4.5)	69.9 (4.4)[abc]
WCInc+F	11.1 (0.9)	7.4 (1.1)[bcd]	8.8 (0.7)[d]	13.1 (0.6)[bcd]	9.6 (1.3)[cd]	79.5 (3.7)	62.8 (2.4)[abc]	82.3 (6.7)	73.8 (4.9)	70.4 (3.5)[abc]

* Mean (standard error)[significance]

** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

*** Cont = control, Fert = fertilizer, HC = heavy application compost, HCInc = heavy application compost incorporated, LC = light application compost, LCInc = light application compost incorporated, WC = wood chips, WC+F = wood chips and fertilizer, WCInc = wood chips incorporated, WCInc + F = wood chips incorporated and fertilizer.

Table A14. Seed mix cover (%) for soils by amendment treatments.

Soil	Treat	*Agro spi*	*Agro sub / Agro tra*	*Agro vio*	*Fest ida*	*Koel mac / Tris spi*	*Sti vir*
DVA	1	0.03 (0.01)	0.25 (0.17)	0.10 (0.08)	0.06 (0.04)	1.83 (0.60)	0.03 (0.01)
	2	0.08 (0.02)	0.08 (0.06)	0.01 (0.01)	0.05 (0.04)	1.88 (0.91)	0.10 (0.04)
	3	0.04 (0.02)	0.03 (0.01)	0.06 (0.04)	0.05 (0.02)	0.28 (0.08)	0.07 (0.02)
	4	0.04 (0.02)	0.05 (0.04)	0.04 (0.02)	0.03 (0.01)	0.51 (0.17)	0.11 (0.04)
	5	0.06 (0.02)	0.18 (0.13)	0.03 (0.02)	0.03 (0.01)	1.61 (0.34)	0.10 (0.05)
	6	0.05 (0.02)	0.04 (0.02)	0.04 (0.04)	0.04 (0.02)	1.05 (0.25)	0.08 (0.01)
	7	0.03 (0.02)	0.23 (0.17)	0.04 (0.04)	0.05 (0.03)	3.70 (1.18)	0.11 (0.06)
	8	0.32 (0.17)	0.53 (0.42)	0.04 (0.04)	0.02 (0.01)	7.20 (1.95)	1.05 (0.41)
	9	0.09 (0.08)	0.59 (0.43)	0.13 (0.09)	0.00 (0.00)	0.60 (0.28)	0.10 (0.08)
	10	0.03 (0.02)	1.09 (0.71)	0.00 (0.00)	0.02 (0.04)	2.90 (0.75)	0.92 (0.58)
HDL	1	0.07 (0.01)	0.03 (0.01)	0.02 (0.02)	0.03 (0.01)	0.50 (0.24)	0.03 (0.01)
	2	0.05 (0.02)	0.03 (0.01)	0.00 (0.00)	0.02 (0.01)	0.28 (0.08)	0.03 (0.01)
	3	0.10 (0.03)	0.04 (0.02)	0.01 (0.01)	0.05 (0.02)	0.29 (0.09)	0.05 (0.02)
	4	0.11 (0.02)	0.02 (0.01)	0.03 (0.02)	0.05 (0.02)	0.25 (0.07)	0.08 (0.04)
	5	0.07 (0.01)	0.02 (0.01)	0.05 (0.02)	0.04 (0.01)	0.38 (0.08)	0.04 (0.01)
	6	0.10 (0.02)	0.04 (0.02)	0.02 (0.01)	0.05 (0.02)	0.23 (0.04)	0.08 (0.02)
	7	0.52 (0.25)	0.11 (0.08)	0.01 (0.01)	0.43 (0.17)	2.93 (1.19)	0.04 (0.02)
	8	0.77 (0.32)	0.13 (0.09)	0.06 (0.04)	0.38 (0.18)	1.70 (0.79)	0.21 (0.05)
	9	0.56 (0.41)	0.14 (0.12)	0.01 (0.01)	0.07 (0.04)	0.29 (0.11)	0.17 (0.09)
	10	0.27 (0.18)	0.76 (0.39)	0.01 (0.01)	0.15 (0.09)	0.78 (0.32)	0.14 (0.06)
HTN	1	0.05 (0.02)	0.20 (0.16)	0.01 (0.01)	0.03 (0.01)	0.42 (0.25)	0.06 (0.02)
	2	0.04 (0.02)	0.03 (0.01)	0.00 (0.00)	0.03 (0.01)	0.18 (0.09)	0.03 (0.01)
	3	0.05 (0.02)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.09 (0.04)	0.00 (0.00)
	4	0.03 (0.01)	0.03 (0.01)	0.00 (0.00)	0.02 (0.01)	0.03 (0.01)	0.02 (0.01)
	5	0.06 (0.04)	0.09 (0.06)	0.00 (0.00)	0.01 (0.01)	0.33 (0.12)	0.02 (0.01)
	6	0.05 (0.02)	0.04 (0.02)	0.00 (0.00)	0.02 (0.01)	0.13 (0.04)	0.02 (0.01)
	7	0.03 (0.01)	0.26 (0.17)	0.02 (0.02)	0.26 (0.17(	0.80 (0.29)	0.11 (0.08)
	8	0.12 (0.08)	0.85 (0.50)	0.27 (0.25)	0.05 (0.02)	0.66 (0.13)	0.21 (0.06)
	9	0.35 (0.26)	0.27 (0.18)	0.00 (0.00)	0.02 (0.01)	0.54 (0.20)	0.05 (0.02)
	10	0.05 (0.02)	0.04 (0.02)	0.01 (0.01)	0.07 (0.04)	0.77 (0.23)	0.29 (0.09)
TAB	1	0.11 (0.05)	0.10 (0.05)	0.06 (0.05)	0.02 (0.01)	4.12 (1.53)	0.21 (0.09)
	2	0.05 (0.02)	0.00 (0.00)	0.02 (0.01)	0.03 (0.01)	0.78 (0.25)	0.15 (0.04)
	3	0.05 (0.02)	0.02 (0.01)	0.03 (0.02)	0.01 (0.01)	0.21 (0.08)	0.07 (0.02)
	4	0.05 (0.02)	0.05 (0.02)	0.03 (0.02)	0.01 (0.01)	0.22 (0.08)	0.08 (0.01)
	5	0.09 (0.02)	0.02 (0.02)	0.09 (0.08)	0.02 (0.01)	0.70 (0.16)	0.11 (0.02)
	6	0.07 (0.01)	0.04 (0.02)	0.01 (0.01)	0.03 (0.01)	0.48 (0.17)	0.12 (0.20)
	7	0.11 (0.08)	0.05 (0.02)	0.02 (0.02)	0.00 (0.00)	1.25 (0.31)	0.10 (0.03)
	8	0.15 (0.09)	0.13 (0.09)	0.00 (0.00)	0.02 (0.01)	1.65 (0.52)	0.62 (0.21)
	9	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.15 (0.07)	0.01 (0.01)
	10	0.10 (0.07)	0.50 (0.34)	0.01 (0.01)	0.00 (0.00)	0.58 (0.12)	0.38 (0.18)
VLN	1	0.04 (0.02)	0.02 (0.01)	0.03 (0.02)	0.04 (0.01)	0.34 (0.07)	0.04 (0.01)
	2	0.07 (0.01)	0.02 (0.01)	0.00 (0.00)	0.01 (0.01)	0.17 (0.08)	0.03 (0.01)
	3	0.07 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.07 (0.04)	0.00 (0.00)
	4	0.05 (0.02)	0.03 (0.01)	0.00 (0.00)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)
	5	0.03 (0.01)	0.05 (0.03)	0.05 (0.03)	0.04 (0.01)	0.16 (0.02)	0.02 (0.02)
	6	0.07 (0.01)	0.03 (0.01)	0.00 (0.00)	0.04 (0.01)	0.11 (0.01)	0.01 (0.01)
	7	0.03 (0.01)	0.04 (0.02)	0.07 (0.04)	0.06 (0.01)	0.61 (0.23)	0.02 (0.01)
	8	0.05 (0.02)	0.17 (0.05)	0.04 (0.04)	0.14 (0.05)	0.84 (0.18)	0.07 (0.03)
	9	0.03 (0.02)	2.19 (0.73)	0.00 (0.00)	0.07 (0.04)	0.16 (0.05)	0.00 (0.00)
	10	0.11 (0.05)	1.79 (0.59)	0.00 (0.00)	0.15 (0.08)	0.48 (0.14)	0.02 (0.02)

* Mean (standard error)

***DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

** Treatment 1 = fertilizer, 2 = control, 3 = wood chips, 4 = wood chips incorporated, 5 = wood chips and fertilizer, 6 = wood chips incorporated and fertilizer, 7 = light compost, 8 = light compost incorporated, 9 = heavy compost, 10 = heavy compost incorporated.

Table A15. Seed mix density (plants/m^2) for soils by amendment treatment.

Soil	Treat	*Agro spi*	*Agro sub / Agro tra*	*Agro vio*	*Fest ida*	*Koel mac / Tris spi*	*Stip vir*
DVA	1	2.7 (1.4)	1.4 (0.6)	0.3 (0.1)	0.3 (0.1)	109.9(36.5)	4.3 (2.4)
	2	1.5 (.05)	0.8 (0.5)	0.1 (0.1)	0.3 (0.3)	83.0 (25.1)	1.5 (0.7)
	3	0.8 (0.3)	0.7 (0.4)	0.7 (0.5)	1.0 (0.7)	54.7 (12.1)	2.1 (0.5)
	4	1.8 (0.7)	0.2 (0.1)	0.3 (0.1)	0.7 (0.4)	73.2 (29.5)	1.5 (0.5)
	5	0.6 (0.2)	1.3 (0.7)	0.2 (0.1)	0.2 (0.1)	33.5 (7.1)	1.1 (0.5)
	6	1.8 (0.9)	0.4 (0.2)	0.2 (0.2)	0.6 (0.3)	39.3 (13.5)	1.8 (0.8)
	7	1.1 (0.4)	0.5 (0.3)	0.2 (0.2)	0.3 (0.2)	56.0 (12.5)	3.0 (0.5)
	8	0.4 (0.3)	0.6 (0.3)	0.1 (0.1)	0.2 (0.1)	10.7 (2.3)	1.4 (0.4)
	9	0.3 (0.2)	0.2 (0.1)	0.4 (0.3)	0.4 (0.3)	22.2 (6.0)	0.8 (0.5)
	10	0.2 (0.1)	0.8 (0.5)	0.0 (0.0)	0.0 (0.0)	1.9 (0.5)	0.3 (0.2)
HDL	1	3.9 (2.4)	0.7 (0.4)	0.1 (0.1)	2.4 (1.7)	49.1 (19.6)	0.8 (0.5)
	2	1.6 (0.7)	0.3 (0.2)	0.0 (0.0)	0.9 (0.7)	21.0 (6.4)	0.3 (0.1)
	3	2.7 (1.0)	0.6 (0.2)	0.2 (0.2)	1.2 (0.6)	16.8 (4.2)	1.3 (0.4)
	4	4.2 (1.5)	0.3 (0.3)	0.3 (0.3)	0.8 (0.3)	10.1 (2.2)	1.2 (0.5)
	5	5.0 (2.0)	0.3 (0.2)	0.5 (0.2)	4.2(2.2)	41.8 (17.9)	0.8 (0.4)
	6	1.8 (0.6)	0.3 (0.2)	0.5 (0.4)	1.5 (0.9)	20.9 (10.8)	5.5 (5.0)
	7	3.4 (1.1)	0.7 (0.4)	0.1 (0.1)	2.8 (1.3)	23.9 (6.7)	1.8 (0.9)
	8	0.8 (0.5)	0.8 (0.3)	0.3 (0.2)	0.8 (0.4)	8.8 (2.5)	0.8 (0.3)
	9	1.8 (0.8)	0.7 (0.4)	0.0 (0.0)	2.2 (0.9)	16.4 (4.6)	0.3 (0.1)
	10	1.1 (0.6)	0.7 (0.4)	0.1 (0.1)	0.4 (0.3)	2.8 (0.6)	0.8 (0.3)
HTN	1	4.4 (2.5)	0.5 (0.2)	0.2 (0.2)	0.7 (0.4)	71.5 (35.7)	1.3 (0.5)
	2	4.5 (3.2)	0.6 (0.3)	0.0 (0.0)	6.6 (6.3)	84.8 (58.5)	0.4 (0.2)
	3	2.2 (0.8)	0.5 (0.3)	0.0 (0.0)	0.3 (0.2)	10.1 (3.5)	0.8 (0.5)
	4	2.3 (1.2)	0.4 (0.2)	0.0 (0.0)	0.3 (0.2)	3.1 (1.8)	0.2 (0.1)
	5	2.6 (1.4)	1.1 (0.5)	0.0 (0.0)	0.1 (0.1)	25.2 (9.7)	0.3 (0.3)
	6	3.1 (1.7)	0.0 (0.0)	0.0 (0.0)	0.5 (0.4)	7.8 (3.4)	0.0 (0.0)
	7	2.3 (1.3)	1.3 (0.6)	0.1 (0.1)	2.2 (1.1)	40.5 (14.5)	5.2 (2.0)
	8	2.2 (1.3)	0.7 (0.4)	0.7 (0.4)	0.3 (0.1)	19.0 (5.9)	2.8 (0.8)
	9	1.3 (1.2)	1.5 (0.6)	0.0 (0.0)	0.4 (0.2)	43.7 (17.0)	1.3 (0.6)
	10	1.3 (0.7)	0.3 (0.1)	0.2 (0.2)	0.5 (0.4)	12.4 (4.7)	2.6 (1.4)
TAB	1	0.8 (0.3)	0.4 (0.2)	0.4 (0.3)	0.4 (0.3)	49.6 (10.0)	3.2 (0.8)
	2	2.2 (1.0)	0.0 (0.0)	0.2 (0.1)	0.3 (0.1)	57.4 (19.1)	5.8 (2.3)
	3	1.2 (0.3)	0.7 (0.3)	0.3 (0.2)	0.3 (0.1)	23.8 (4.6)	2.8 (0.6)
	4	1.7 (0.6)	1.8 (0.8)	0.3 (0.2)	0.2 (0.2)	17.3 (3.2)	2.0 (0.6)
	5	1.6 (0.4)	0.3 (0.3)	0.4 (0.3)	0.4 (0.2)	34.8 (6.1)	2.4 (0.6)
	6	0.9 (0.3)	0.3 (0.2)	0.1 (0.1)	0.3 (0.3)	13.0 (3.8)	1.8 (0.6)
	7	0.9 (0.5)	0.8 (0.6)	0.1 (0.1)	0.2 (0.1)	29.1 (7.9)	2.1 (0.4)
	8	0.2 (0.1)	1.0 (0.9)	0.0 (0.0)	0.0 (0.0)	10.6 (2.4)	1.3 (0.5)
	9	0.5 (0.3)	0.5 (0.2)	0.0 (0.0)	0.0 (0.0)	12.0 (2.7)	1.5 (0.5)
	10	0.2 (0.2)	0.1 (0.1)	0.2 (0.2)	0.0 (0.0)	2.0 (0.9)	0.2 (0.2)
VLN	1	1.4 (0.6)	0.2 (0.1)	0.8 (0.6)	0.7 (0.3)	55.9 (15.2)	0.9 (0.4)
	2	3.2 (2.4)	0.3 (0.2)	0.0 (0.0)	0.1 (0.1)	8.0 (2.4)	0.6 (0.3)
	3	1.8 (0.5)	0.8 (0.4)	0.3 (0.3)	1.0 (0.4)	10.7 (1.7)	0.3 (0.3)
	4	1.3 (0.5)	0.6 (0.3)	0.0 (0.0)	0.0 (0.0)	1.3 (0.9)	0.0 (0.0)
	5	1.4 (1.0)	0.8 (0.5)	0.8 (0.5)	0.5 (0.2)	11.4 (1.5)	0.3 (0.3)
	6	1.9 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (0.9)	0.0 (0.0)
	7	0.8 (0.4)	1.0 (0.3)	0.4 (0.3)	2.3 (0.7)	30.9 (4.6)	0.8 (0.3)
	8	0.6 (0.3)	2.1 (0.6)	0.3 (0.3)	1.0 (0.3)	10.2 (3.0)	0.2 (0.2)
	9	0.7 (0.4)	1.0 (0.5)	0.0 (0.0)	1.1 (0.3)	35.8 (5.8)	0.2 (0.1)
	10	0.2 (0.1)	1.9 (0.4)	0.0 (0.0)	0.5 (0.3)	3.3 (1.3)	0.0 (0.0)

* Mean (standard error)

***DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

** Treatment 1 = fertilizer, 2 = control, 3 = wood chips, 4 = wood chips incorporated, 5 = wood chips and fertilizer, 6 = wood chips incorporated and fertilizer, 7 = light compost, 8 = light compost incorporated, 9 = heavy compost, 10 = heavy compost incorporated.

Table A16. Vegetation density (plants/m^2) for soils by amendment treatments.

Veg. Class	Soil	Cont	Fert	WC	WC+Fert	WC Inc	WC Inc+Fert	LC	LC Inc	HC	HC Inc
NS	DVA	87.2 (25.3)[a]	118.8 (38.8)[a]	44.0 (14.0)[a]	36.8 (7.3)[a]	77.5 (29.3)[a]	59.9 (11.9)[a]	27.9 (6.6)[ab]	61.0 (12.4)[a]	3.3 (0.6)[c]	13.3 (2.5)[b]
	HDL	24.1 (6.9)[abc]	61.6 (24.5)[ab]	30.5 (16.6)[bc]	52.5 (21.9)[ab]	16.5 (4.2)[bc]	25.3 (5.6)[ab]	27.0 (7.0)[ab]	33.6 (7.8)[a]	5.7 (1.6)[bc]	14.2 (3.4)[bc]
	HTN	23.1 (17.2)[bcd]	16.2 (6.5)[abc]	3.9 (1.4)[cd]	8.2 (2.2)[bc]	2.4 (1.4)[d]	8.0 (2.6)[bc]	15.4 (5.4)[abc]	19.9 (2.8)[a]	6.6 (2.4)[bc]	15.8 (6.0)[ab]
	TAB	65.8 (20.5)[a]	54.8 (11.0)[a]	16.3 (4.2)[bcd]	39.9 (6.4)[a]	22.8 (3.6)[bc]	28.9 (1.5)[ab]	14.8 (3.7)[cd]	33.2 (8.4)[abc]	2.6 (1.1)[e]	13.1 (3.0)[d]
	VLN	12.1(3.2)[bc]	59.8(15.1)[a]	3.5(1.1)[de]	15.3(1.8)[b]	3.2 (1.1)[e]	14.8(1.7)[b]	38.8(5.8)[a]	36.3 (5.3)[a]	5.8 (1.3)[cd]	14.3(3.2)[b]
NSN	DVA	28.1 (5.7)[abc]	37.4 (9.2)[abc]	21.3 (4.7)[bc]	27.7 (4.7)[ab]	22.8 (8.3)[bc]	18.3 (3.3)[bc]	36.8 (8.2)[a]	16.8 (2.6)[bc]	28.8 (8.4)[abc]	15.2 (3.7)[c]
	HDL	17.3 (3.8)[cd]	23.9 (10.1)[bcd]	25.3 (3.9)[abc]	34.3 (7.0)[bc]	16.9 (2.4)[bcd]	18.8 (1.6)[bc]	25.1 (2.8)[ab]	24.5 (3.3)[ab]	11.9 (2.0)[d]	13.1 (2.0)[d]
	HTN	8.0(3.7)[abc]	6.9(1.3)[ab]	7.7(1.7)[a]	5.7(0.8)[a]	3.6(1.4)[bc]	14.6 (3.9)[a]	10.4(4.4)[a]	5.8(0.6)[a]	7.2(0.8)[a]	2.6(0.6)[c]
	TAB	15.3(8.3)[ab]	12.6(2.8)[a]	17.0 (3.6)[a]	12.2 (1.5)[a]	12.6 (4.5)[ab]	7.3 (1.5)[b]	12.6 (3.0)[ab]	9.8 (1.9)[ab]	7.8 (1.5)[ab]	3.2 (1.0)[c]
	VLN	25.7 (16.5)[cde]	16.3 (3.3)[bc]	6.7 (2.5)[ef]	19.7 (8.3)[cd]	3.9 (1.2)[f]	8.4 (1.9)[de]	31.0 (4.4)[a]	25.8 (4.5)[ab]	13.0 (2.2)[c]	15.9 (1.8)[bc]
NN	DVA	1.3(0.5)[bc]	2.2(0.8)[abc]	0.9 (0.3)[bc]	2.1 (0.5)[bc]	0.5 (0.2)[c]	1.1 (0.3)[bc]	2.8 (0.7)[a]	3.4 (0.7)[ab]	1.6 (0.5)[abc]	1.4 (0.6)[c]
	HDL	1.3(0.4)[ab]	1.2(0.4)[ab]	0.7 (0.2)[b]	1.5 (0.5)[ab]	0.7 (0.3)[b]	0.6 (0.3)[b]	2.0 (1.1)[ab]	2.1 (0.7)[ab]	0.7 (0.6)[b]	2.1 (0.6)[a]
	HTN	0.4(0.2)[bc]	0.4(0.2)[bc]	0.3 (0.2)[bc]	0.2 (0.1)[c]	0.1 (0.1)[c]	0.2 (0.2)[c]	1.8 (0.6)[ab]	2.3 (0.8)[a]	2.2 (0.4)[a]	3.6 (1.3)[a]
	TAB	2.3 (1.2)[abc]	2.0 (1.1)[ab]	0.8 (0.5)[cd]	1.7 (1.1)[abcd]	0.3 (0.2)[d]	0.6 (0.3)[bcd]	1.9 (1.0)[abcd]	1.9 (0.5)[a]	2.0 (0.7)[abc]	1.1 (0.4)[abcd]
	VLN	0.1(0.1)[d]	0.0(0.0)[d]	0.0 (0.0)[d]	0.6 (0.4)[d]	0.0 (0.0)[d]	0.1 (0.1)[d]	1,2 (0.3)[c]	1.6 (0.4)[c]	4.7 (1.2)[ab]	3.9 (1.2)[b]
TD	DVA	116.6 (27.3)[a]	158.3 (47.6)[a]	66.2 (17.7)[a]	66.5 (9.0)[a]	100.8 (36.6)[a]	79.3 (14.2)[a]	67.5 (13.2)[ab]	81.2 (14.7)[a]	33.6 (8.5)[d]	29.8 (4.7)[bc]
	HDL	42.7 (9.8)[abcd]	86.7 (33.1)[abcd]	56.4 (19.7)[abc]	88.3 (28.5)[a]	34.1 (5.5)[bcd]	44.7 (6.4)[abc]	54.1 (8.7)[ab]	60.3 (8.8)[a]	18.3 (3.0)[d]	29.4 (3.3)[cd]
	HTN	31.6 (18.4)[bcd]	23.6 (6.6)[abc]	11.9 (1.9)[c]	14.1 (2.9)[bc]	6.0 (2.7)[d]	22.8 (5.0)[abc]	27.7 (6.4)[abc]	28.0 (2.6)[a]	16.0 (2.7)[bc]	21.9 (7.1)[b]
	TAB	83.4 (21.6)[abc]	69.4 (13.2)[a]	34.0 (5.6)[cde]	53.8 (6.7)[ab]	35.6 (5.5)[bcd]	36.8 (6.0)[abcd]	29.3 (4.4)[de]	44.9 (7.4)[abcd]	12.3 (2.4)[f]	17.3 (2.7)[ef]
	VLN	37.8 (18.6)[bcd]	76.1 (18.2)[a]	10.2 (2.8)[de]	35.5 (9.6)[bc]	7.1 (1.3)[e]	23.3 (2.4)[c]	70.9 (4.6)[a]	63.7 (6.5)[a]	23.5 (2.7)[c]	34.1 (2.6)[b]

* Mean (standard error)[significance]

** NS = native seeded, NSN = Non seeded natives, NN = non natives, TD = total density

*** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

**** Cont = control, Fert = fertilizer, HC = heavy compost, HCInc = heavy compost incorporated, LC = light compost, LCInc = light compost incorporated, WC = wood chips, WC+F = wood chips and fertilizer, WCInc = wood chips incorporated, WCInc + F = wood chips incorporated and fertilizer.

A17. Vegetation cover (%) for soils by amendment treatments.

Veg Class	Soil	Cont	Fert	WC	WC+Fert	WC Inc	WC Inc+Fert	LC	LC Inc	HC	HC Inc
NS	DVA	2.2 (1.0) ^{cd}	2.3 (0.7) ^{bcd}	0.5 (0.1) ^{d}	2.0 (0.4) ^{bc}	0.8 (0.2) ^{d}	1.3 (0.3) ^{c}	5.0 (1.3) ^{a}	9.2 (2.2) ^{a}	1.4 (0.4) ^{cd}	5.1 (1.2) ^{ab}
	HDL	0.4 (0.1) ^{c}	0.7 (0.3) ^{c}	0.6 (0.1) ^{c}	0.6 (0.1) ^{c}	0.4 (0.1) ^{c}	0.5 (0.1) ^{c}	4.9 (1.9) ^{a}	4.2 (1.6) ^{ab}	1.4 (0.9) ^{bc}	2.7 (0.7) ^{ab}
	HTN	0.2 (0.0) ^{cd}	0.3 (0.1) ^{c}	0.1 (0.0) ^{d}	0.1 (0.0) ^{cd}	0.1 (0.0) ^{d}	0.1 (0.0) ^{cd}	0.7 (0.3) ^{bc}	1.2 (0.5) ^{ab}	0.3 (0.1) ^{c}	1.5 (0.5) ^{ab}
	TAB	1.0 (0.3) ^{bcd}	4.6 (1.6) ^{a}	0.4 (0.1) ^{ef}	1.0 (0.2) ^{abcd}	0.5 (0.1) ^{de}	0.8 (0.2) ^{c}	1.5 (0.3) ^{abc}	2.6 (0.6) ^{ab}	0.2 (0.1) ^{f}	1.6 (0.4) ^{abc}
	VLN	0.3 (0.1) ^{ef}	0.5 (0.1) ^{bc}	0.1 (0.0) ^{g}	0.4 (0.0) ^{cd}	0.1 (0.0) ^{g}	0.3 (0.0) ^{de}	0.8 (0.2) ^{b}	1.3 (0.2) ^{a}	2.5 (0.7) ^{a}	2.6 (0.6) ^{a}
NNS	DVA	1.0 (0.8)^{de}	2.6 (1.3)^{de}	1.9 (1.2)^{e}	4.5 (2.6)^{cd}	1.6 (0.7)^{e}	3.3 (2.1)^{de}	7.9 (2.7)^{a}	4.6 (1.8)^{abc}	7.0 (2.8)^{ab}	6.4 (3.9)^{bcd}
	HDL	1.0 (0.3)^{bcd}	0.9 (0.2)^{bcd}	1.1 (0.2)^{bc}	1.5 (0.4)^{b}	0.5 (0.1)^{d}	0.8 (0.2)^{cd}	4.4 (0.8)^{a}	2.6 (0.4)^{a}	2.2 (0.8)^{abc}	3.7 (0.5)^{a}
	HTN	0.2 (0.0)^{de}	0.3 (0.0)^{cde}	0.4 (0.1)^{bcd}	0.3 (0.4)^{cd}	0.2 (0.0)^{e}	0.2 (0.0)^{e}	0.8 (0.2)^{ab}	0.6 (0.1)^{abc}	1.3 (0.5)^{a}	0.6 (0.2)^{abc}
	TAB	0.5 (0.2)^{ef}	1.2 (0.3)^{ab}	0.5 (0.1)^{def}	0.6 (0.1)^{cde}	0.3 (0.1)^{f}	0.5 (0.2)^{def}	1.8 (0.6)^{abc}	1.4 (0.4)^{a}	2.5(0.7)^{abcd}	1.3 (0.7)^{bcdef}
	VLN	0.3 (0.10)^{cd}	0.5 (0.1)^{c}	0.3 (0.1)^{de}	0.4 (0.1)^{bcd}	0.2 (0.0)^{e}	0.3 (0.0)^{cd}	1.3 (0.2)^{a}	2.2 (0.5)^{a}	3.3 (1.6)^{a}	3.5 (1.1)^{a}
NN	DVA	0.4(0.3)^{bcde}	5.8 (3.1)^{abcde}	0.2 (0.1)^{cde}	0.9 (0.4)^{bcd}	0.2 (0.1)^{e}	0.3 (0.1)^{cde}	9.2 (3.7)^{ab}	8.6 (3.3)^{a}	8.3(3.8)^{abcd}	5.8 (3.1)^{abcde}
	HDL	0.3 (0.1)^{bc}	0.6 (0.3)^{abc}	0.1 (0.0)^{c}	0.2 (0.1)^{bc}	0.0 (0.0)^{c}	0.0 (0.0)^{c}	3.0 (2.3)^{abc}	4.7 (3.2)^{ab}	2.3 (2.1)^{abc}	5.3 (3.0)^{a}
	HTN	0.0 (0.0)^{d}	0.1 (0.1)^{cd}	0.1 (0.0)^{d}	0.0 (0.0)^{d}	0.0 (0.0)^{d}	0.0 (0.0)^{d}	1.1 (0.5)^{abc}	0.5 (0.2)^{b}	1.9 (0.8)^{a}	1.8 (0.6)^{ab}
	TAB	0.3 (0.2)^{abc}	0.6 (0.4)^{ab}	0.1 (0.1)^{c}	0.2 (0.2)^{bc}	0.1 (0.1)^{c}	0.1 (0.0)^{bc}	0.7 (0.4)^{abc}	1.7 (0.7)^{a}	1.9 (0.8)^{a}	2.1 (1.8)^{abc}
	VLN	0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.0)c	0.6 (0.2)^{c}	1.3 (0.6)^{bc}	11.1 (3.8)^{a}	10.2 (4.7)^{ab}
TC	DVA	4.6 (1.6)^{ef}	10.6 (3.6)^{bcdef}	2.6 (1.1)^{f}	7.4 (2.9)^{cde}	2.5 (0.9)^{f}	4.9 (2.3)^{ef}	22.1(5.8)^{ab}	22.3 (4.4)^{a}	16.7 (4.7)^{abcd}	17.2 (5.8)^{abc}
	HDL	1.6 (0.4)^{c}	2.1 (0.7)^{bc}	1.7 (0.3)^{bc}	2.3 (0.4)^{b}	1.0 (0.2)^{c}	1.4 (0.3)^{bc}	12.2 (2.8)^{a}	11.5 (3.1)^{a}	5.9 (2.8)^{abc}	11.8 (3.1)^{a}
	HTN	0.4 (0.1)^{cde}	0.7 (0.1)^{bc}	0.5 (0.1)^{cd}	0.5 (0.0)^{c}	0.3 (0.0)^{e}	0.3 (0.0)^{de}	2.7 (0.8)^{ab}	2.4 (0.6)^{a}	3.5 (0.9)^{a}	3.9 (0.8)^{a}
	TAB	1.8 (0.5)^{bc}	6.4 (1.9)^{a}	1.0 (0.3)^{c}	1.9 (0.4)^{b}	0.8 (0.2)^{c}	1.3 (0.3)^{bc}	4.0 (1.1)^{ab}	5.7 (1.4)^{a}	4.6 (1.3)^{ab}	5.0 (2.5)^{ab}
	VLN	0.6 (0.2)^{e}	1.1 (0.1)^{f}	0.4 (0.1)^{d}	0.8 (0.1)^{f}	0.3 (0.0)^{d}	0.6 (0.0)^{e}	2.6 (0.4)^{c}	4.9 (1.0)^{c}	16.8 (4.2)^{a}	16.2 (4.4)^{b}

* Mean (standard error)^{significance}

** NS = native seeded, NSN = Non seeded natives, NN = non natives, TD = total density

*** DVA = Devona, HDL = Hillsdale, HTN = Hinton, TAB = Talbot, VLN = Vermilion Lakes

**** Cont = control, Fert = fertilizer, HC = heavy application compost, HC Inc = heavy application compost incorporated, LC = light application compost, LC Inc = light application compost incorporated, WC = wood chips, WC+F = wood chips and fertilizer, WC Inc = wood chips incorporated, WC Inc + F = wood chips incorporated and fertilizer.

Calculations

Converting Penetration Resistance (PR) from psi to MPa

Dial reading in psi x (6.895 kPa psi^{-1}) x (0.001 MPa kPa^{-1}) x (3.0627) = PR (MPa)

Where 3.0627 is the ratio of the large to small cone base areas

Converting mg L^{-1} to mg kg^{-1} for Mg, Ca, K and Na

Cation value in mg L^{-1} x base saturation (%) = cation value in mg kg^{-1}

Example: Vermilion Lakes site 1, right-of-way spoil area, control treatment

Base saturation is 51.3 % = 0.513

Cation value is 116.0 mg L^{-1}

116.0 mg L^{-1} x 0.513 = 59.5 mg kg^{-1}