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RESEARCH & INNOVATION CENTRE

Greening Canada's Highways

Final Report

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Executive Summary

Ecological and Economic Benefits

- The soil remediation method developed in this research project (the Vineland method) is significantly less expensive, costing approximately $95,000 to plant 1000 trees as compared to $200,000 using the standard cost estimate for roadside tree planting in Ontario. In addition, the Vineland method improves tree survival and longevity, resulting in less tree replacement and lower replacement costs.
- Our research demonstrates that the failure of trees in un-remediated unmaintained sites increases after the two-year warranty period is up. As a result, the burden of the tree replacement costs falls on the land owner (e.g. a municipality) or in some cases, trees are just not replaced.
- Trees along roadsides provide many practical benefits to society. For instance, trees used as living snow fences have resulted in significant cost savings in winter road maintenance while also increasing road safety. Roadside trees also provide significant, less obvious benefits to society, like the sequestration of greenhouse gases, management of run-off and pollutants, and the provision of habitats for birds and insects.
- In order for roadside trees to provide the maximum ecological benefits, they must reach full mature canopy size. Our research demonstrates that this rarely happens.

Executive Summary

Tree Growth, Health and Survival

- Tree mortality in un-remediated, unmaintained highway roadside plantings increased in year two and trees continued to decline thereafter as a result of accumulated stress.
- The growth and tree health parameters we measured in this study are better indicators of the long-term success of tree planting than survival alone.
- Tree growth and health are improved in soils that are deep-ripped and amended with compost. In Ontario, we found that 25% compost v/v provided the greatest advantage for tree growth and health. There was no additional advantage was gained in the 50% compost v/v treatment, and in fact, there is a risk of increasing soil temperature when using high rates of compost. We observed high rates of mortality, as well as increased branch dieback, in trees in the 50% compost v/v treatment.
- Bed-style site preparation for tree planting improves the growth and health of trees as compared to planting-hole treatments, including a compost-amended planting hole treatment.
- The 60-70 mm caliper field-grown nursery stock planted in the Alberta trials are experiencing slow top-growth as the trees try to regain the roots lost from digging. We are beginning to observe an improved performance from the trees in the composted pulp and paper residuals treatment. However, two-years of monitoring does not capture the period of establishment of caliper trees and continued monitoring will allow the treatment effects to emerge.

Executive Summary

Soil Properties

- Organic matter is a critical component of a well-structured and functioning soil but is largely absent from highway roadside soils as a result of construction activities and inadequate topsoil specifications.
- The bulk density, soil texture and organic matter content of highway soils have a close relationship. When soil organic matter is increased, then bulk density is decreased, making the soils more amenable to tree establishment and growth.
- Mechanical remediation alone (deep ripping with no organic amendments) did not significantly reduce bulk density or improve tree performance. Using a calculated rate of organic amendment that is based on site soil conditions is the way to ensure that the bulk density and soil organic matter of remediated soils will be within the range that supports tree growth.
- Due to the compaction of highway roadside soils, some standard rear-mounted agricultural implements may not incorporate organic amendment to the desired depth (i.e. 30 cm).

Executive Summary

Soil Properties cont'd

- The highway roadside soils sampled at our Ontario and Alberta research sites were slightly alkaline (7.7) to alkaline (8.8). High soil pH limits nutrient availability.
- In Ontario, four years after transplanting and remediation, we found that the addition of 25% compost v/v significantly improved soil properties. No additional advantage was gained by adding 50% compost v/v, indicating that there is a critical threshold for the rate of amendment to improve chemical, biological and physical soil properties. In the 25% compost v/v treatment we found:
  - Nutrients (e.g. N, P and K) were increased to optimal levels
  - Microbial activity significantly greater than the control as measured by microbial respiration.
  - Water holding capacity was doubled as compared to the control.
- Findings from this work have been incorporated into the Ontario Provincial Standards and Specifications 802- topsoil specification.
- The feedstock of composted products will influence nutrient levels. It is critical to request compost analytics from producers and suppliers to ensure compost quality.

Executive Summary

Selecting species and stock size

- When choosing trees and shrubs for highway sites where no mowing occurs, stock should be over 100 cm in height to avoid being outcompeted by ground vegetation and to reduce the impact of herbivory.
- Whips over 100 cm performed the best at unmaintained highway roadside sites. Certain tree species, even those purported to be robust urban selections, have high mortality in unmaintained (un-mowed) plantings due to lack of irrigation.
- Large field-dug nursery stock will take longer to establish and may require on-going maintenance (e.g. irrigation).
- Planted material may be vulnerable if it is connected to sites with high populations of herbivores (e.g. rodents, rabbits and deer).
- Based on our findings and an extensive literature review, species should be selected based on known tolerance of specific environmental site conditions, soil quality and site preparation efforts, planned maintenance and maintenance period (e.g. scheduled irrigation).
- The information from our study and the literature review has been incorporated into a Tree Species Selector tool on our website: www.greeningcanadianlandscape.ca.

Roadside Tree Establishment Challenges

Introduction

- Typical lifespan of a tree along a major roadside is <u>5–10 years</u> (Nowak et al. 2004). Common challenges roadside trees face along highways include:
  - Soil compaction
  - High pH soils
  - **Low soil organic matter**
  - Unavailable nutrients/poor nutrient cycling
  - Inadequate soil pore space for gas exchange
  - Poorly drained soils
  - Salt and pollution

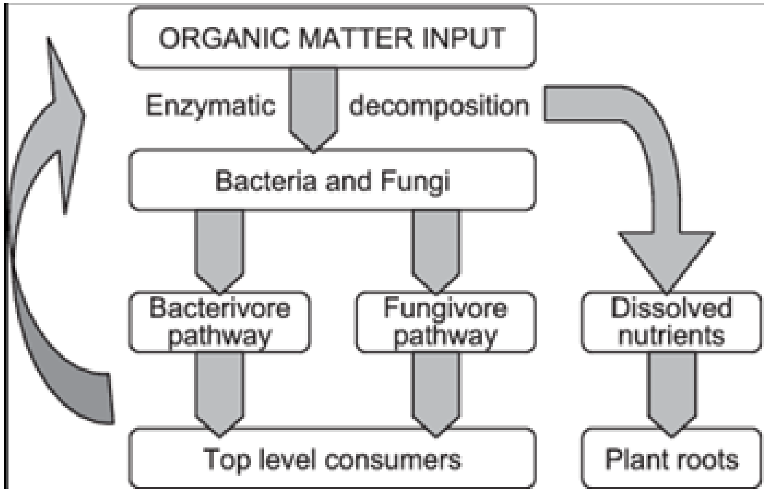
- Soil organic matter is a critical component of a functioning and well-structured soil

Nowak, D.J., Kuroda, M., Crane, D.E., 2004. Tree mortality rates and tree population projections in Baltimore Maryland, USA. Urban Forestry and Urban Greening 2, 139-147.

The importance of soil organic matter

Introduction

- Organic matter is made up of microbial and plant biomass, detritus and more stable humus (labelled as the organic matter input in the figure below).
- Plants can't feed directly on organic matter, however the activity of the micro-organisms make nutrients available to plants (e.g. bacteria and fungi).
- Micro-organisms help create soil aggregates, which improves soil structure and porosity. This is important for water infiltration, water holding capacity, drainage, gas exchange and root extension and expansion of fine root mass.
- Improved soil structure facilitates the growth of vegetation, contributes to biomass cycling and sustains soil and plant communities.



www.researchgate.net/figure/The-structure-of-a-ped-provides-a-diversity-of-habitats-that-sustain-the-diversity-of_fig2_51113773

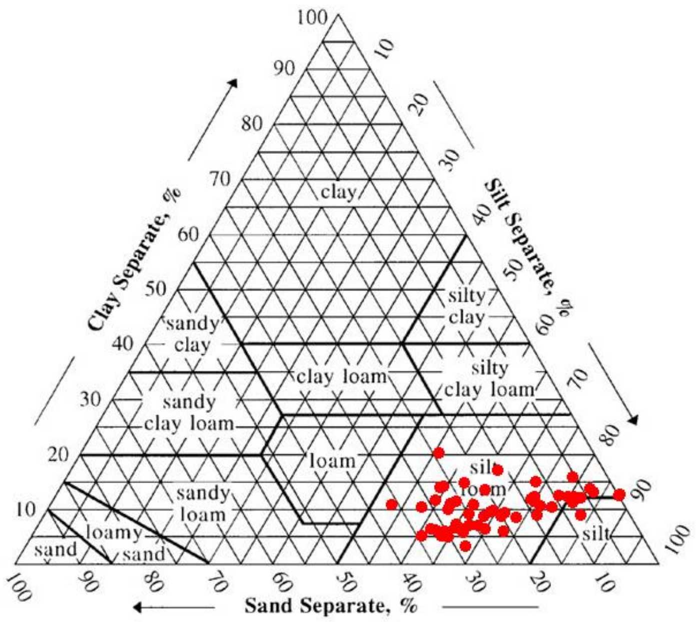
Soil Compaction and Bulk Density

Introduction

- Soil bulk density is the measure of dry mass of soil contained in a fixed volume. It is used as an indicator of soil compaction.
  - Reflects the soil's ability to function in terms of structure, water, air and nutrient movement
- Soil bulk density is influenced largely by soil texture (bottom left table) and organic matter content. The red dots depicted in the soil triangle (bottom right) represent the texture profile of several of our highway roadside sites, which are silt loam soils.

General relationship of bulk density to root growth based on soil texture (NRCS Soil Quality Institute, 1999)

Soil Texture	Ideal bulk densities (g/cm^{-3})	Bulk densities that limit root growth (g/cm^{-3})	Bulk densities that restrict root growth (g/cm^{-3})
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45%)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

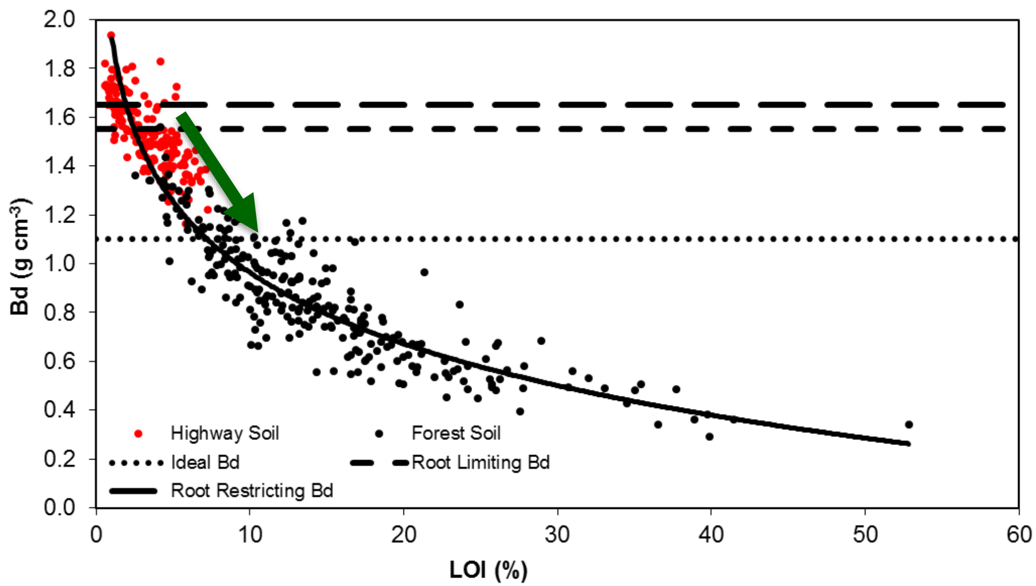


https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167

Bulk Density of Ontario Highway Roadside vs. Forest Soil

Introduction

- Forest soils provide a reference relationship between bulk density (Bd) (below the root limiting level on the graph below) and organic matter that is known to support tree growth.
- Highway roadside soils are typically highly compacted with low organic matter due to removal of topsoil and compaction of subsoil during the construction process.
- The soil curve depicts the relationship between Bd and soil organic matter (SOM) between un-remediated highway soils (red) vs. forest soils (black). SOM is measured using the loss-on-ignition (LOI) method. Increasing SOM will decrease the Bd.



Forest data provided by Trent University

- Ideal soil bulk density is < 1.1 g cm^{-3}
- Root limiting soil bulk density is > 1.55 g cm^{-3}
- Root restricting soil bulk density is > 1.65 g cm^{-3}

Critical aspects of topsoil specifications

Introduction

ONTARIO
PROVINCIAL
STANDARD
SPECIFICATION

METRIC
OPSS 802
NOVEMBER 2010
(Formerly OPSS 570, November 2007)

CONSTRUCTION SPECIFICATION FOR
TOPSOIL

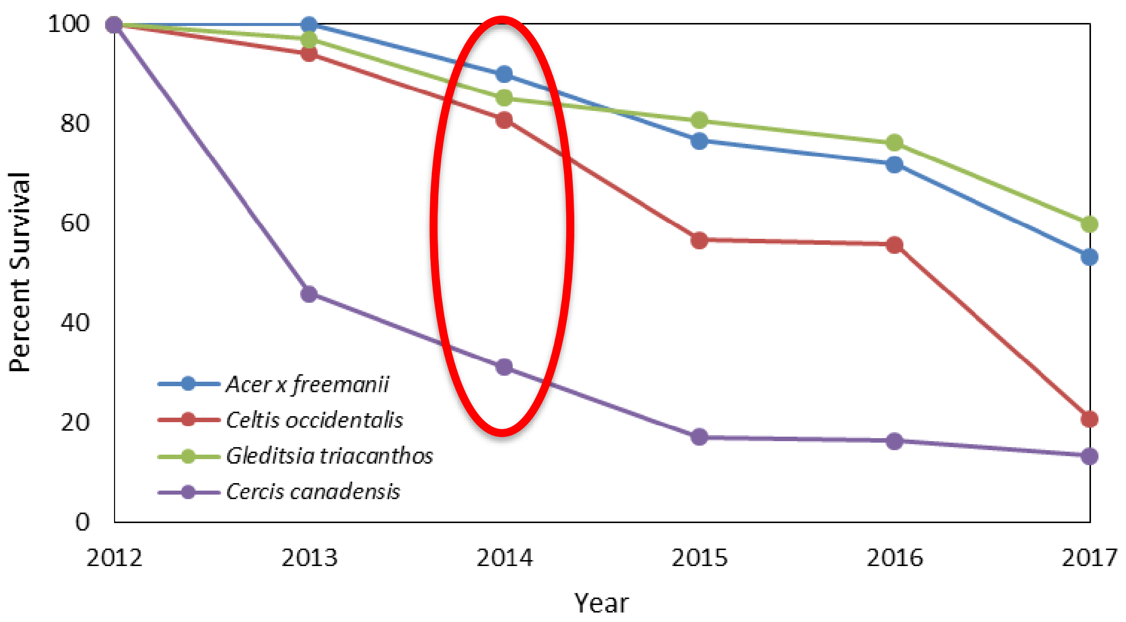
- Many specifications are lacking in important criteria for soil quality that ensure vegetation establishment (e.g. vigorous tree growth). In Ontario, we critiqued the current (Feb. 2018) OPSS 802 topsoil specification for these reasons:
  - No minimum organic matter content for topsoil
  - Subsoil is compacted before topsoil is applied
  - Compacted subsoil is only loosened to a depth of 2.5 cm
  - Topsoil is only applied to a depth of 5 cm

- 7.5 cm of un-compacted soil is inadequate for tree establishment. Findings from our research are helping to re-write critical components of topsoil specifications.

Testing Roadside Tree Survival

Sites 1 and 2 – Tree survival over 5 years

- In the fall of 2012, 555 trees were planted on two 400 series highway sites to monitor the survival of commonly planted urban trees in an unmaintained setting.
- Monitoring has indicated that tree survival is high for the first two years post-transplant, but mortality increases thereafter. Typical tree warranty periods end at the two year mark indicated in the graph below by the red oval.
- Survival is not a good measure of the success of tree planting on highway roadsides because warranties do not reflect the continued decline of the trees after two years. Tree stress and growth (parameters we studied in this project) are better indications of the establishment roadside trees.



Objectives for Greening Canada's Highways

Introduction

1. Determine the primary drivers for tree mortality in unmaintained plantings on highway roadside settings

2. Determine the main limiting factors impacting tree performance (ie. stress and growth)

3. Develop an economically feasible method for improving tree success in unmaintained plantings

4. Create awareness and facilitate uptake of new methods and tools

5. Connect stakeholders to strengthen the adoption of better tree planting practices along highway roadsides

Study Sites

Experimental Design

Ontario - Soil remediation and species selection trial with the Ministry of Transportation

- Sites 1 & 2: tree species survival trial with no soil remediation
- Sites 3 & 4: soil remediation trial
- Sites 6 & 7: species and stock size selection trial with soil remediation
- All sites with the exception of Site 6 were on 400 series highways

*Site 5: *was part of the soil remediation trial but we are not reporting on it here - high mortality in the first season as the result of unfinished compost introduced a confounding variable into the study.*

Alberta – Soil remediation trial with three city partners in partnership with Alberta Transport

- Airdrie, Calgary and Edmonton
  - Tested remediation techniques and organic amendments
- Airdrie and Calgary sites were located on cloverleaf interchanges along major highways
- Edmonton site was located beside a major highway

Remediation Process

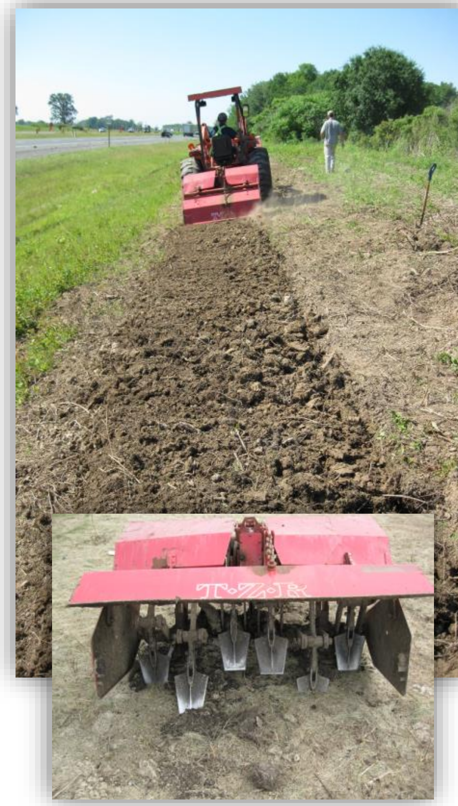
3 Step Process

Deep-ripping

Addition of Organic Amendment*

*Municipal compost used in Ontario trials
*Municipal compost and composted pulp and paper residuals used in Alberta trials

Incorporation of Organic Amendment

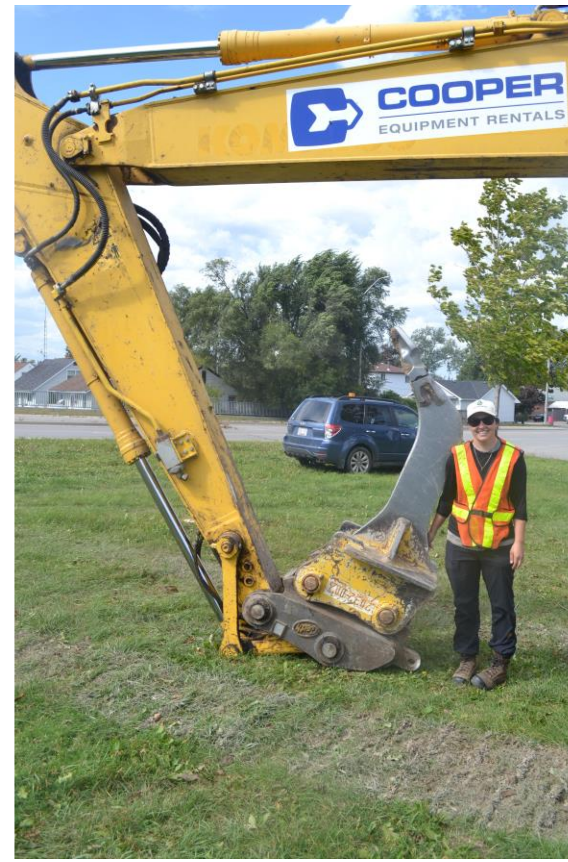


Step 1 – Deep-Ripping

Remediation Process

Mechanical creation of vertical fissures

- Used in forest reclamation (different than agricultural subsoiling)
- Breaks up compacted soil layers and improves drainage
- Ideal depth for trees is <u>90 cm</u> using a single tine



Step 2 – Addition of Organic Amendment

Remediation Process

- There are different forms of organic amendments. We have tested municipal compost (made from household and yard waste) and composted pulp and paper residuals (made from the solids recovered during papermaking).

- Composting is the conversion of organic matter through biological processes to a stable humus-like product.

- The benefits of composted products are:

  - **Accessibility and cost-effectiveness**
  - Improvement in soil structure
  - Increases water holding capacity
  - Increases soil organic matter and microbial communities, which provide sustained release of nutrients

- Other forms of organic amendments that we did not test include:
  - Peat Moss
  - Bark Mulches
  - Composted Animal Manure
  - Worm Castings (vermicompost)
  - Biochar

Recommendations for Selecting Compost

Remediation Process

To obtain the following information, request compost analytics from the supplier:

- Grade AA or A (Ontario), Grade A (Alberta), Regulations for composted pulp and paper residuals will vary by province
- pH of 5.5 – 8.5; however it is recommended to use compost with a similar pH to what is on-site
- C:N ratio: < 25:1
- Organic Matter Content (based on Loss-on-Ignition method): > 35%
- Moisture content: 35 - 50%

Step 3 – Mixing Organic Amendment

Remediation Process

- The objective of this step is to evenly incorporate organic amendment to a depth of at least 20 cm, but ideally to 30 cm, to create an appropriate depth for tree rooting.
  - Examples of equipment include a rotary spader (photos below), agricultural tiller or disk ripper (the suitability of equipment is based on the level of soil compaction at the site).

Ontario Research Trial Methods

Experimental Design for Sites 3 and 4

- Treatment 1 is the standard planting practice (planting hole 2x the diameter of the root ball)
- Treatment 2 is an amended planting hole treatment
- Treatments 3 – 6 are planting bed-style (trees are planted at least 1.25 m away from bed-edge). Trees are planted 2.5 m apart
- After planting, trees were not maintained
- 6 (site 3) and 7 (site 4) trees ea. of bare root 2-year branched whips of Autumn Blaze Maple (*Acer x Freemanii* 'Jeffersred') were planted into each of the treatment beds

*Treatment 6 on Site 3 is not represented on tree growth graphs because of high temperatures present in the first growing season, likely due to unfinished compost, which resulted in high tree mortality

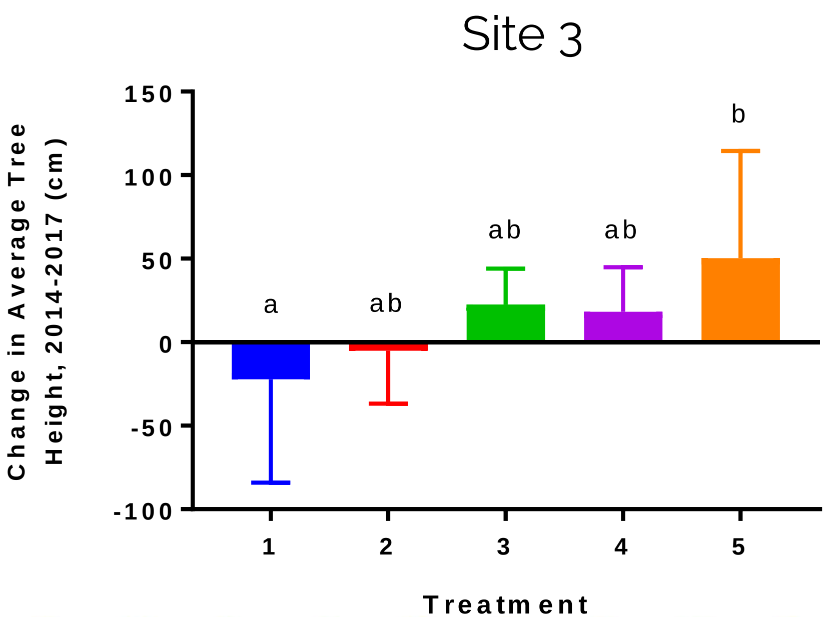
Treatment	Methods
1	Control
2	OA (50% mixed) in PH
3	Deep-Rip
4	Deep-Ripping + OA (10% v/v)
5	Deep-Ripping + OA (25% v/v)
6	Deep-Ripping + OA (50% v/v)

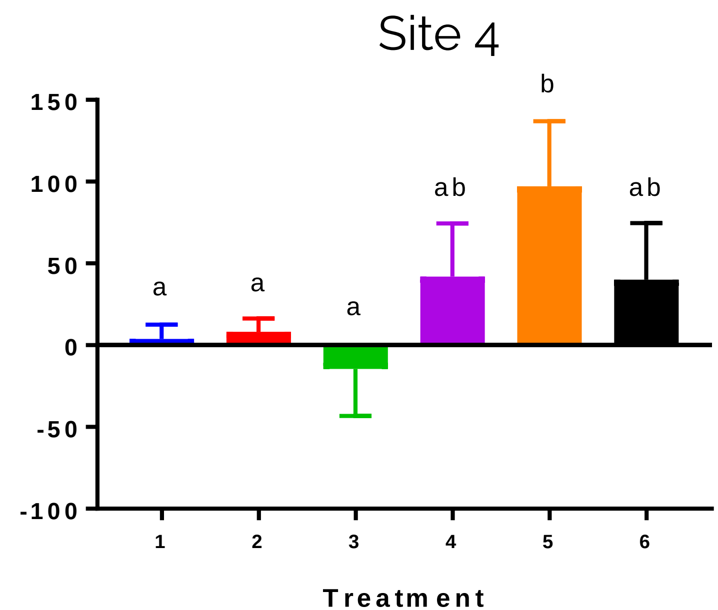
- OA – organic amendment
- PH – planting hole
- v/v – volume of OA/volume of native soil

Tree Height Change

Ontario Results

- **Change in average tree height over four growing seasons (2014 to 2017)**
  - Negative values indicate tree dieback
  - Trees in treatment 5 (25% compost) had better average cumulative growth in height over the 4 growing seasons

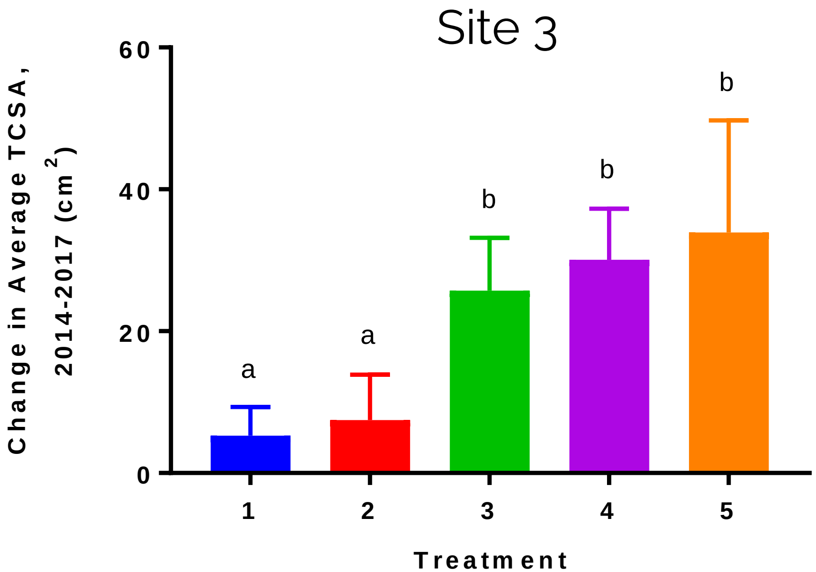


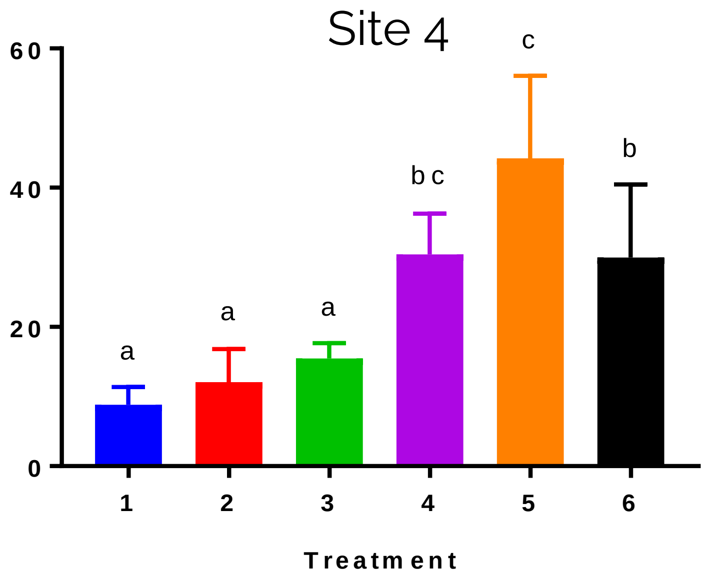


Trunk Cross-Sectional Area

Ontario Results

- **Change in average trunk cross-sectional area (TCSA) over four growing seasons (2014 to 2017)**
  - TCSA was measured as the area of the tree trunk at 30 cm above the ground
  - TCSA is used to estimate cumulative growth over long periods. It provides integrated information about tree growth.
  - Trees in treatment 5 (25% compost) had better average cumulative TCSA growth over the 4 growing seasons

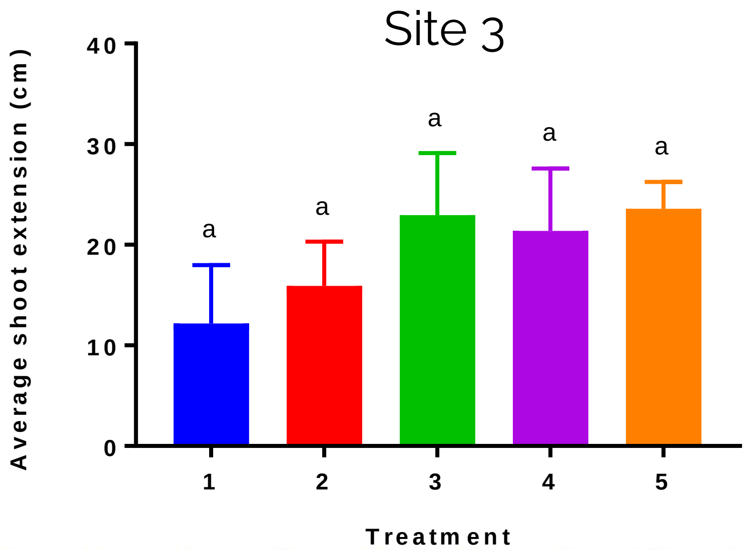


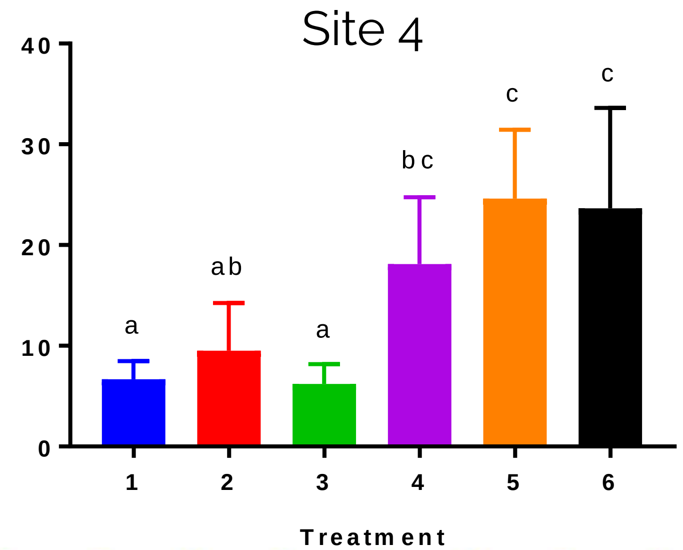


Shoot Extension 2015

Ontario Results

- Trees growing in compost bed treatments (4-6) at site 4 had greater average shoot extension in the first full growing season
- 2015 was an average year for precipitation from May to August in the Niagara region (**309 mm** – compared to the 30-year average of **318 mm**)
- The average shoot extension in treatment 1 (control) for site 4 was **6.7 cm** compared to the **24.6 cm** average for treatment 5

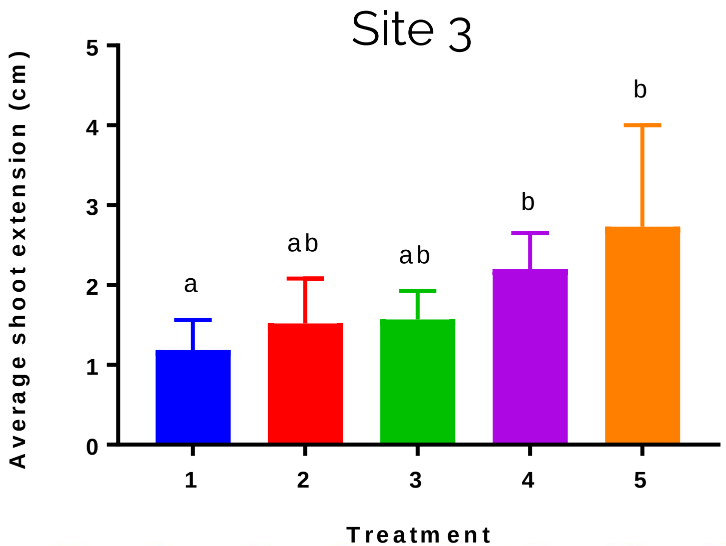


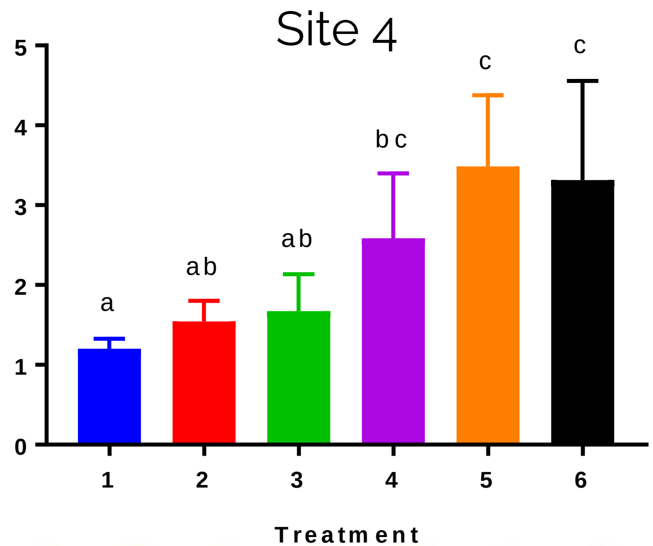


Shoot Extension 2016

Ontario Results

- Trees growing in compost bed treatments (4 & 5) at site 3 had greater average shoot extension than the control (treatment 1) trees. Treatments 4-6 at site 4 had greater average shoot extension in the second full growing season.
- 2016 was a below average year for precipitation from May to August in the Niagara region (**183 mm** – compared to the 30-year average of **318 mm**)
- The average shoot extension in treatment 1 (control) for site 4 was only **1.2 cm** compared to the **3.5 cm** average for treatment 5

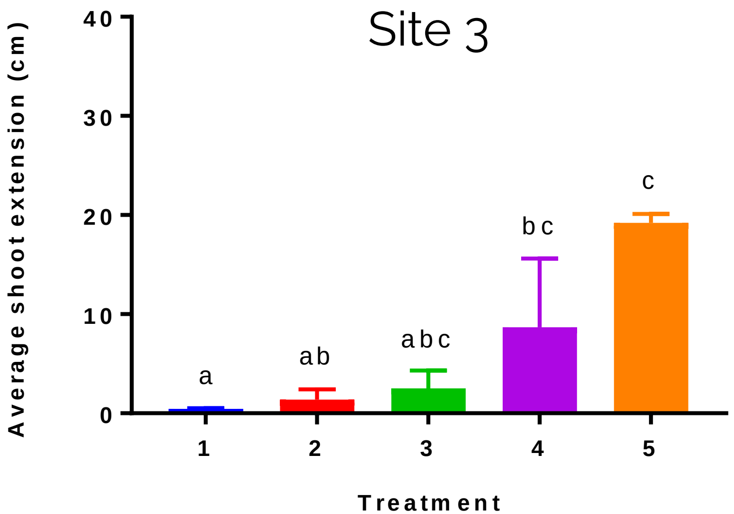


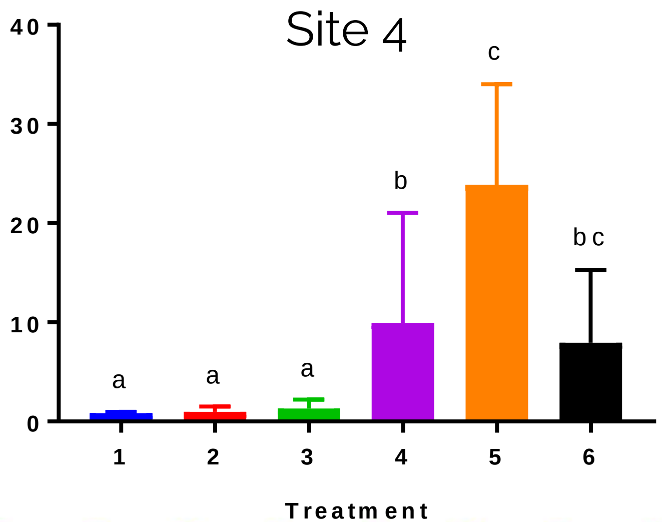


Shoot Extension 2017

Ontario Results

- By the end of the fourth season, trees in treatment 5 (25% compost) demonstrated a trend towards consistently greater growth than other treatments for both sites 3 and 4 (deep-ripping +0% compost and 10% compost respectively).
- 2017 was an above average year for precipitation from May to August in the Niagara region (**466 mm** – compared to the 30-year average of **318 mm**)
- The average shoot extension for trees in the control treatment (1) for site 4 was less than **1 cm** compared to the **24 cm** average for treatment 5. The average shoot extension for trees in in the control treatment for site 3 was less than **0.5 cm** compared to the **19 cm** average for treatment 5.

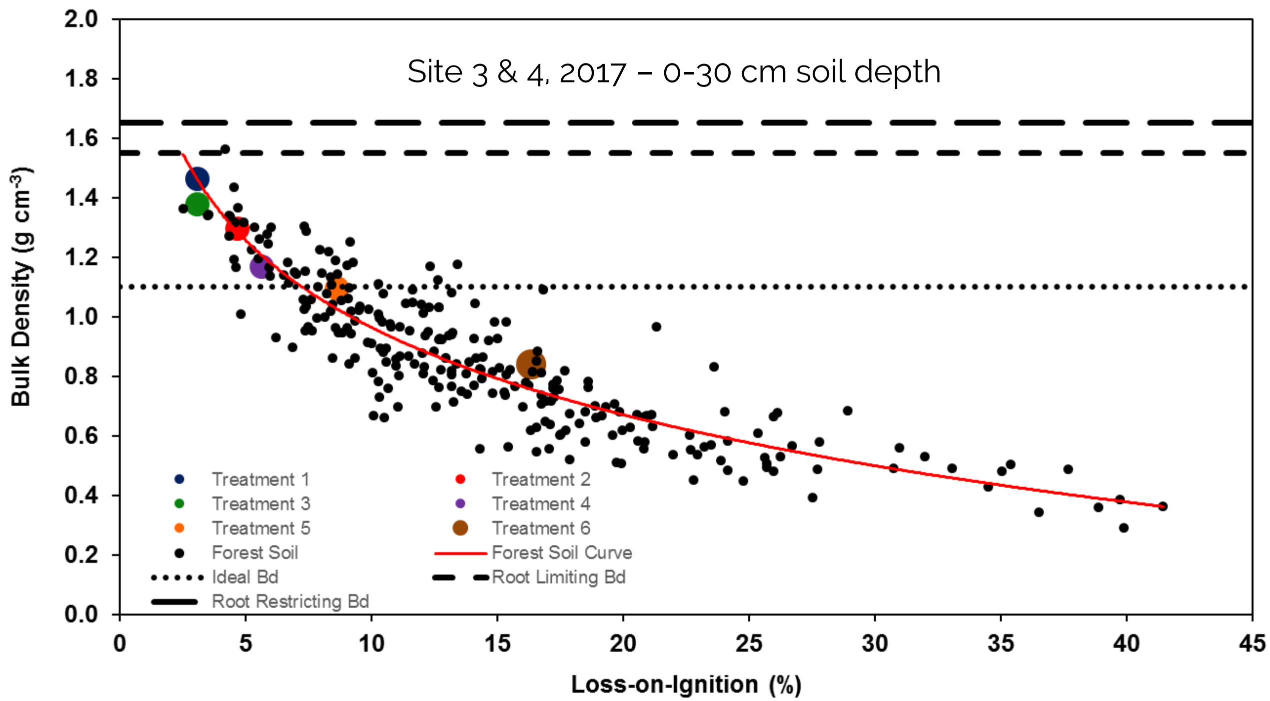




Bulk Density and Soil Organic Matter - 2017

Ontario Results

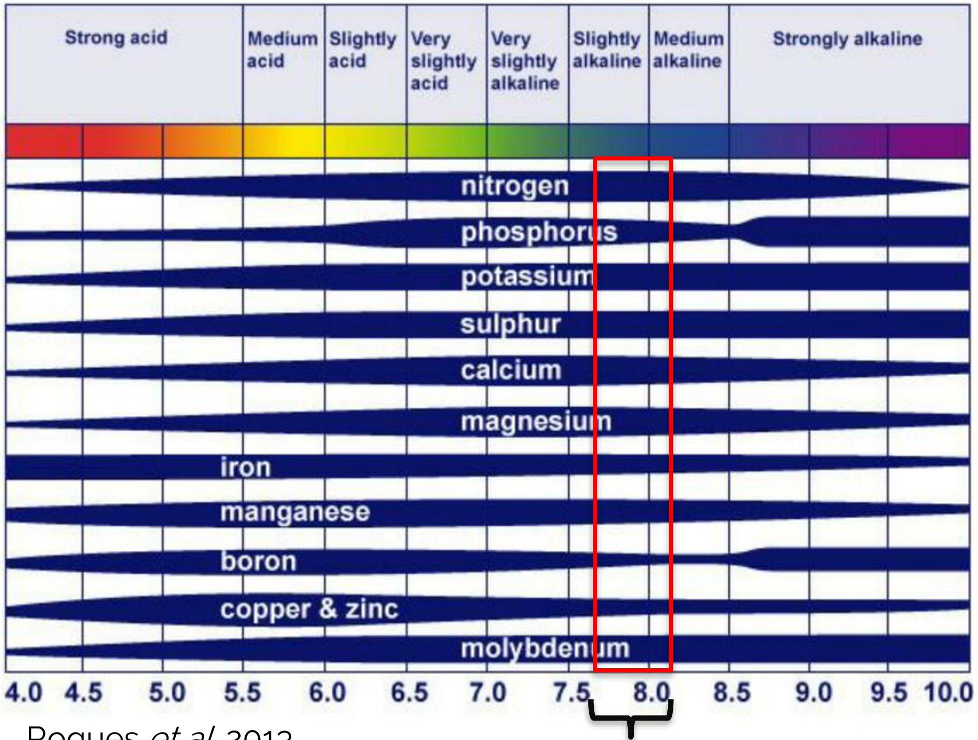
- Treatment 1 (control) soils had high Bd and low soil organic matter (Loss-on-Ignition). The data point representing averaged values is located above the 1.55 g cm^{-3} root limiting threshold.
- Treatment 2 (compost in planting hole) results were wide-ranging due uneven incorporation of the organic amendment in the planting hole.
- Treatment 3 (deep-ripping) soils has Bd values above or approaching root limiting ranges because no organic amendment was added.
- Treatments 4, 5 and 6 demonstrated that increased amounts of compost added (10, 25 and 50% v/v, respectively) increased SOM and decreased Bd.



Soil pH

Ontario Results

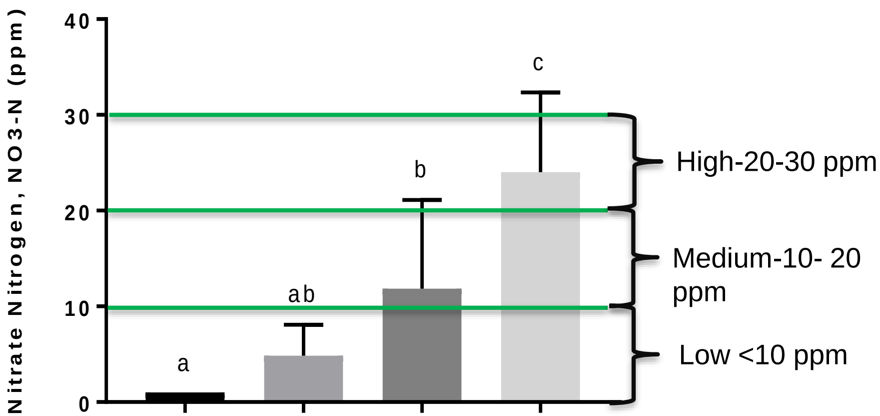
- Un-amended highway sites in Ontario had pH levels at the 0-30 cm soil depth ranging from 7.4 - 8.1, averaging **7.7**. The 40-50 cm soil depth ranged between 7.4 – 8.8, averaging **8.1**.
- These soils are slightly alkaline to alkaline. The figure (right) outlines how soil pH affects nutrient availability, e.g. phosphorous, iron, boron, copper and zinc are less available at our highway sites. Organic amendment can influence pH, but we did not usually find significant changes in pH in remediated planting beds.



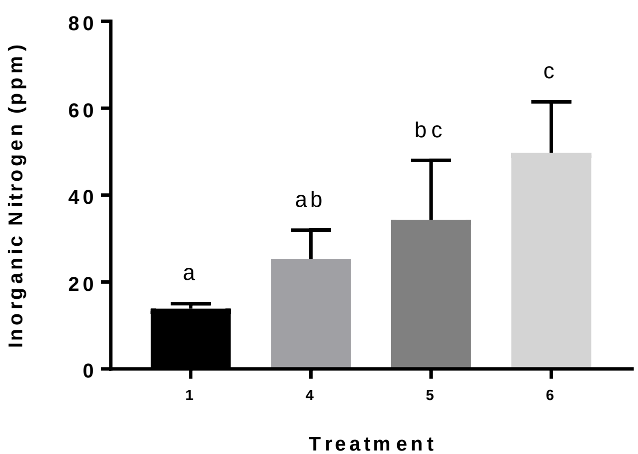
Roques *et al.* 2013

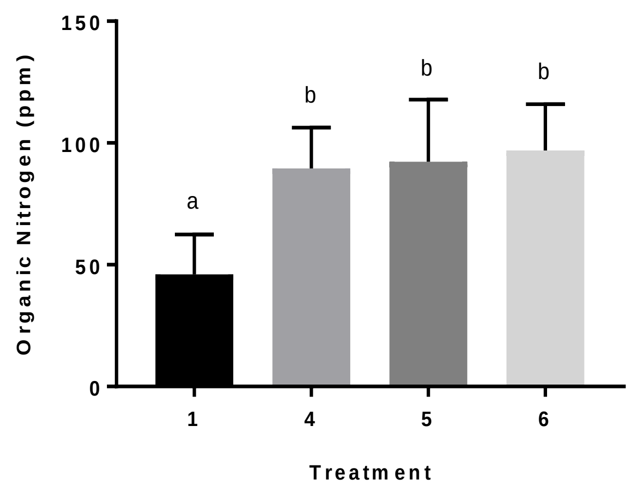
Nitrogen (N) – Site 4, 0-20 cm soil depth

Ontario Results 2017



- Nitrogen (N) promotes photosynthesis and tree growth. Different forms of N have different degrees of availability for plants. Inorganic N is in a plant available from, whereas organic N will be made plant-available in the future through microbial activity.
- In the compost-amended treatments, more N is readily available (i.e. inorganic) and more N will become available (i.e. organic)



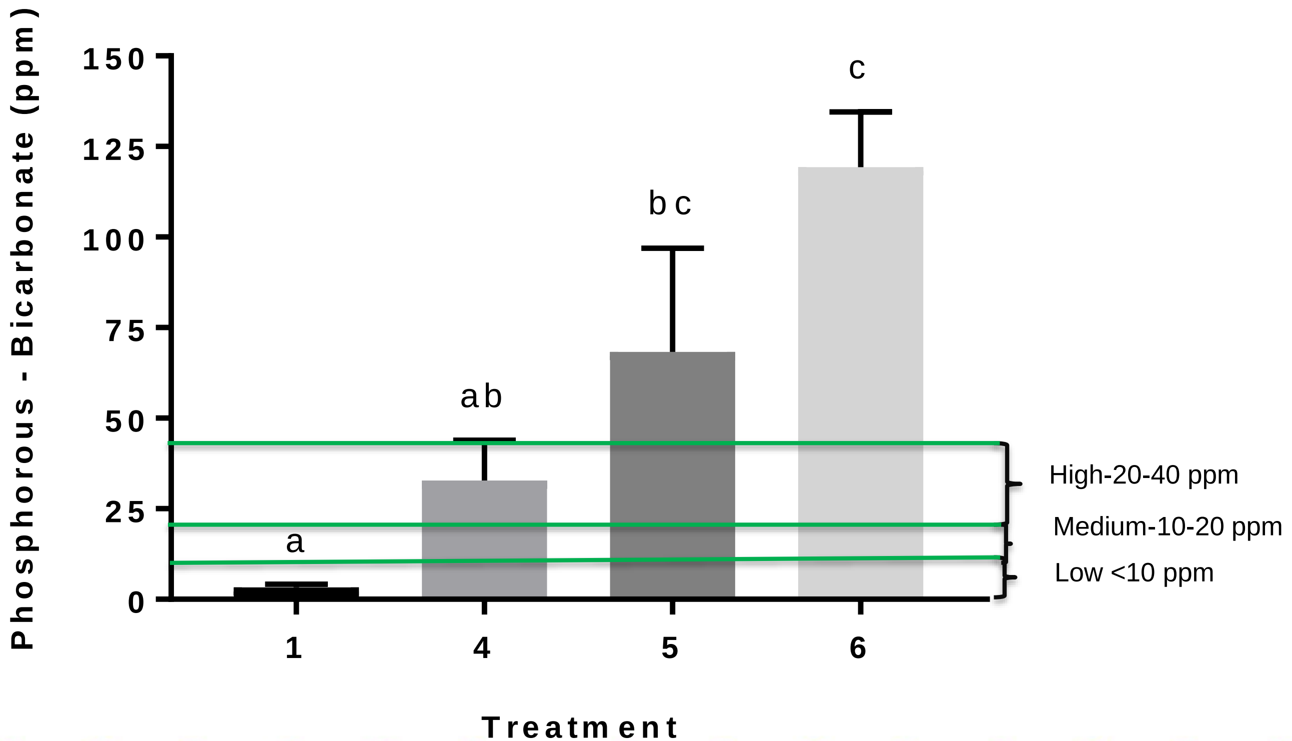


*Note: Treatments 2 and 3 are not represented in the graphs because they had been eliminated as effective remediation treatments due to poor tree performance and insufficient improvements in soil conditions.

Phosphorus (P) – Site 4, 0-20 cm soil depth

Ontario Results 2017

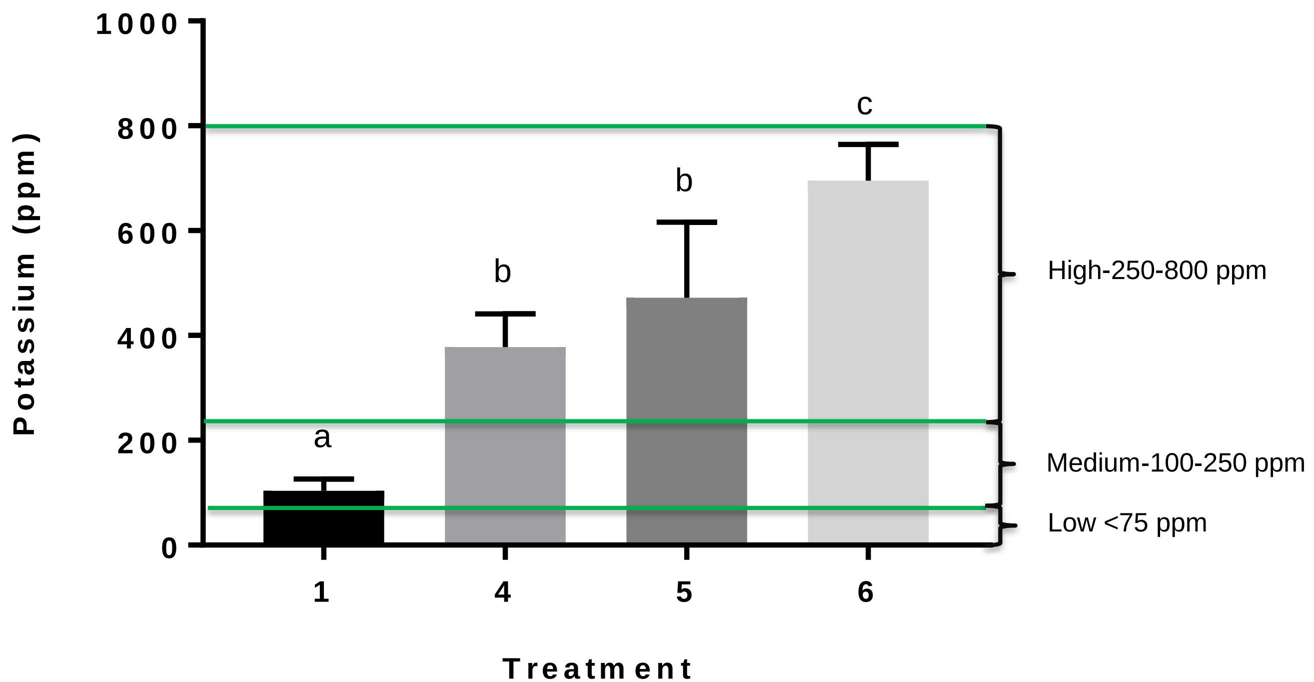
- P plays an important role in root branching and increasing root surface area
- Although the P rates are above the high range in treatments 5 and 6 (25 % and 50% compost v/v) , research shows that approximately 90% of phosphorous present in compost is in a slow-release form



Potassium (K) – Site 4, 0-20 cm soil depth

Ontario Results 2017

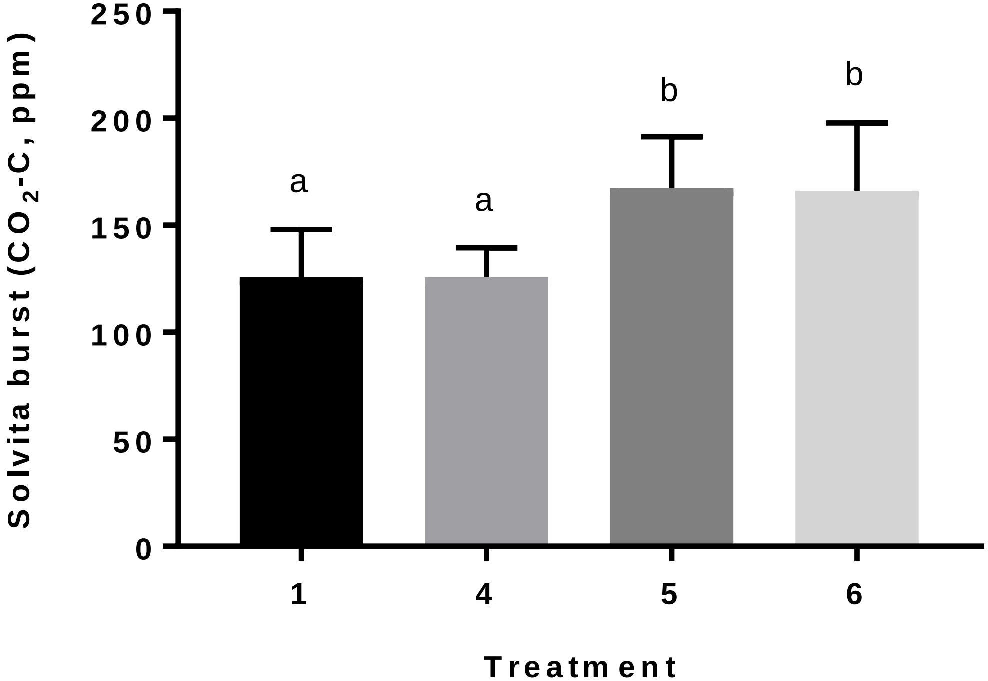
- K improves drought tolerance and winter hardiness
- Insufficient K levels can result in smaller leaves and reduced tree growth



Solvita Burst – Site 4, 0-20 cm depth

Ontario Results 2017

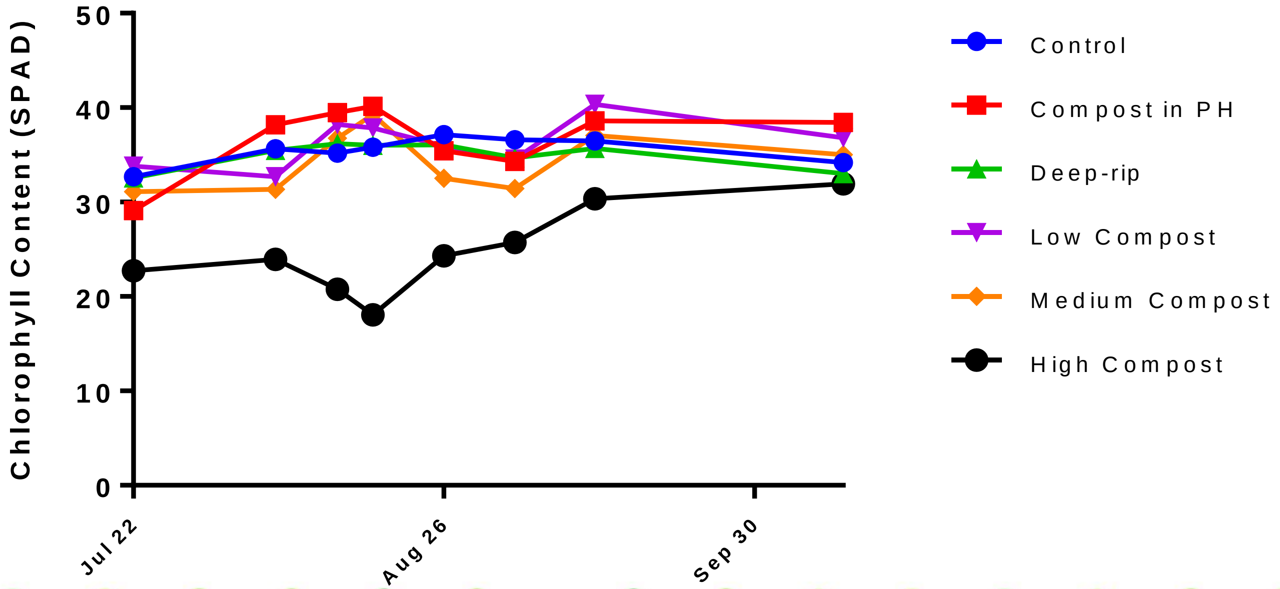
- Measures the amount of CO_2-C released in a 24 hour period due to the activity of microbes present in the soil. Higher release levels indicate greater microbial activity.
- Results suggest that an application of organic amendment at sufficient levels can improve microbial activity, as is seen in treatment 5 (25% compost) and 6 (50% compost).



Leaf Chlorophyll Content - Site 3, 2014

Ontario Results

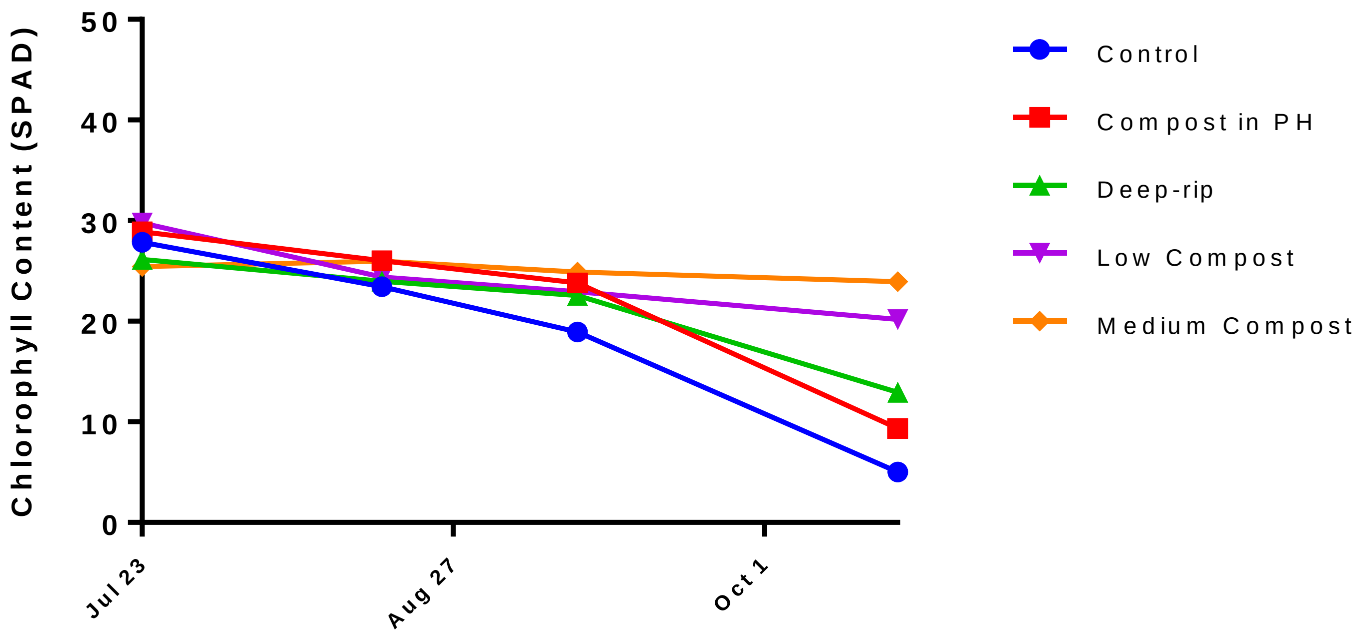
- The following graphs depict measured chlorophyll content in the field throughout 4 years, which is a good indicator of plant health/stress.
- In the first growing season after planting on site 3 chlorophyll measurements were similar for trees among all treatments except high compost (treatment 6).
- We hypothesize that this was due to immature compost applied that completed the curing process on the planting bed during the growing season.



Leaf Chlorophyll Content - Site 3, 2015

Ontario Results

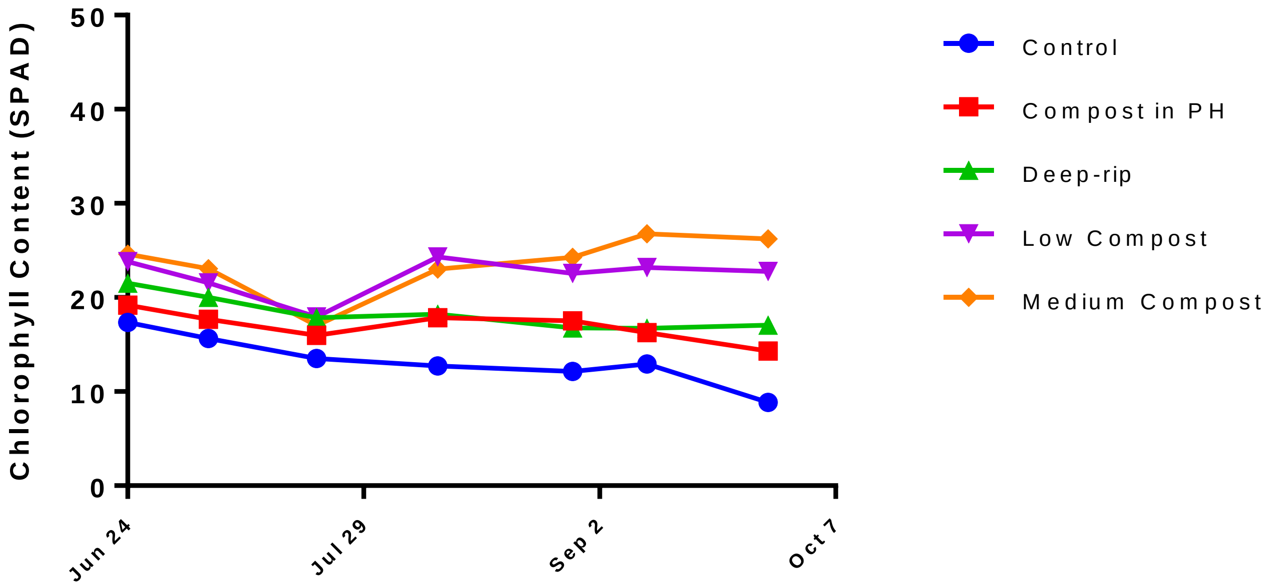
- In the second growing season on site 3 chlorophyll measurements were similar for all treatments up until mid-October, when trees in low and medium compost (treatments 4 and 5) maintained greater chlorophyll content later into the growing season.



Leaf Chlorophyll Content - Site 3, 2016

Ontario Results

- In the third growing season on site 3 chlorophyll measurements were greater for low and medium compost (treatments 4 and 5) compared to the control (treatment 1) with the exception of the July 22, 2016 measurement.
- Regional precipitation was very low in June (30.8 mm) and July (36.0 mm), but improved in August (74.7 mm). This explains why chlorophyll values were low earlier in the season, but then recovered for low and medium compost (treatments 4 and 5) by August onwards. Trees in control, compost in PH and deep-rip (treatments 1, 2 and 3) were not able to recover.



Leaf Chlorophyll Content - Site 3, 2017

Ontario Results

- In the fourth growing season on site 3 chlorophyll measurements were greater for low and medium compost (treatments 4 and 5) compared to the control (treatment 1), as well as between compost in PH (treatment 2) and medium compost (treatment 5) throughout the entire growing season.

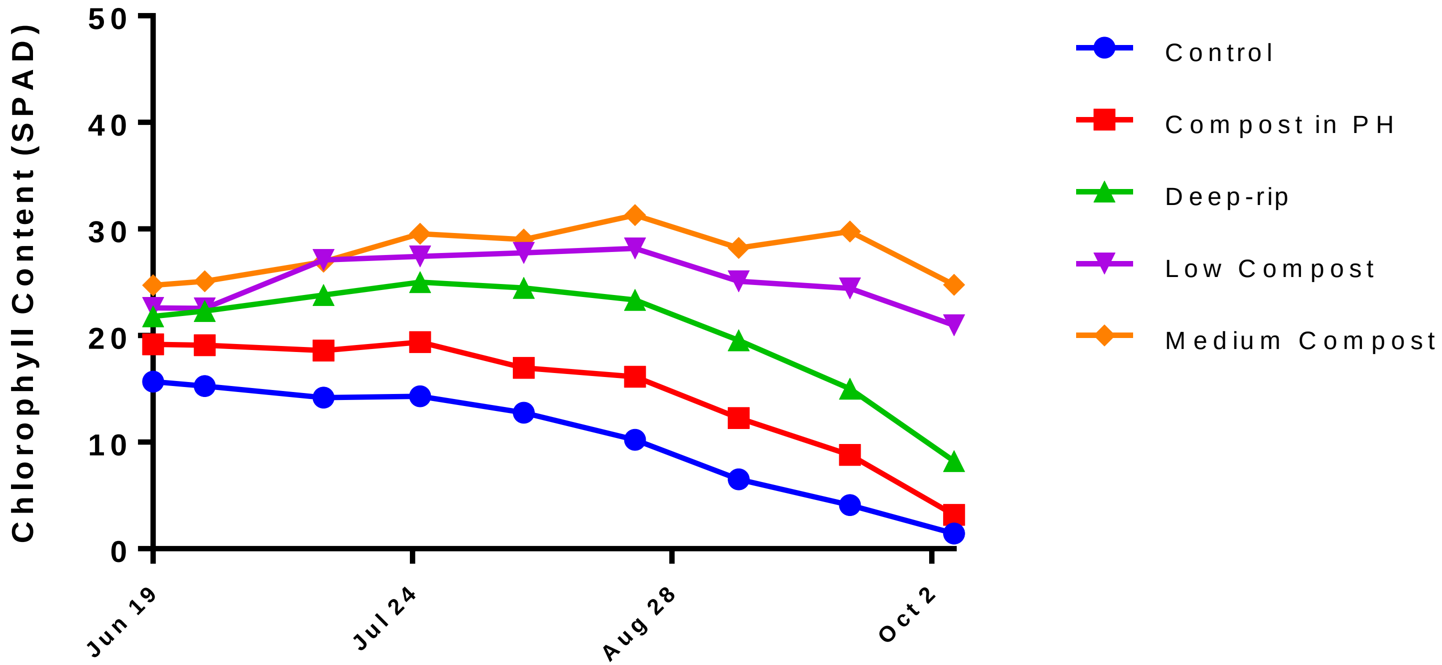


Photo Monitoring - Site 3

September 21st 2017

- Photo monitoring occurred bi-weekly throughout the study, including treatment bed photos and individual photos of representative trees for each treatment.
- Note the dieback and early senescence on representative trees in treatments 1 and 2, early senescence in treatment 3, and greater growth on treatments 4 and 5.

Treatment 1
0% compost
(control)

Treatment 2
50% compost in
planting hole

Treatment 3
Deep-rip + 0%
compost

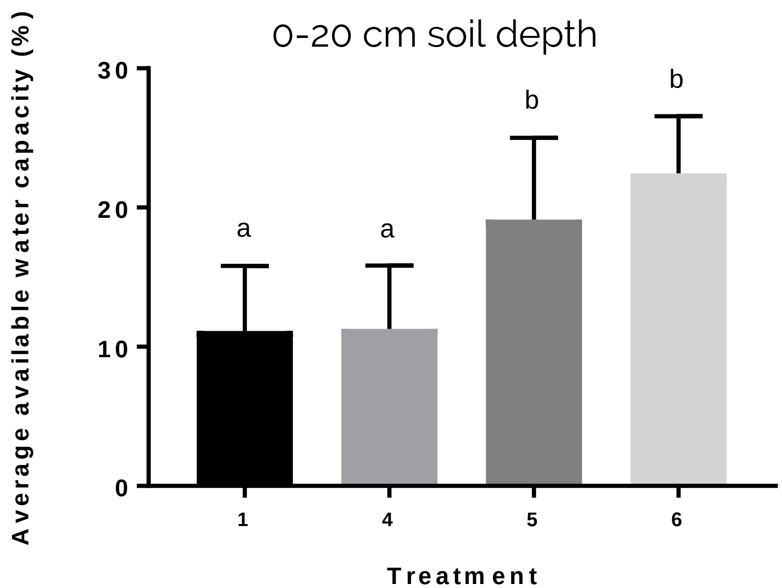
Treatment 4
10% compost

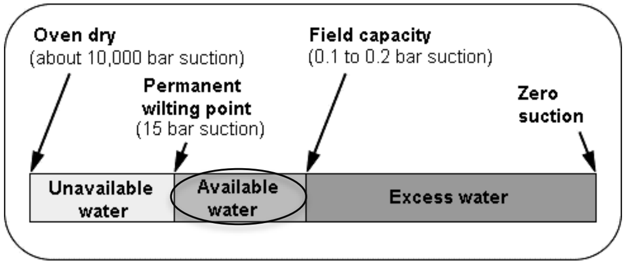
Treatment 5
25% compost

Available Water Capacity- Site 4

Ontario Results 2017

- Available water capacity is the percentage of water stored in the soil between **field capacity** and **permanent wilting point** (see bottom right). Soils with a high available water capacity will be able to store more water, and therefore water will be available to plants over a longer period of time (e.g. between rainfall events).
- Organic matter contributes to an increased available water capacity, which is why average available water capacity in treatments 5 (25% compost) and 6 (50% compost) were significantly greater (19.1% and 22.5%, respectively) than treatments 1 (control) and 4 (10% compost) (11.1% and 11.3%, respectively).



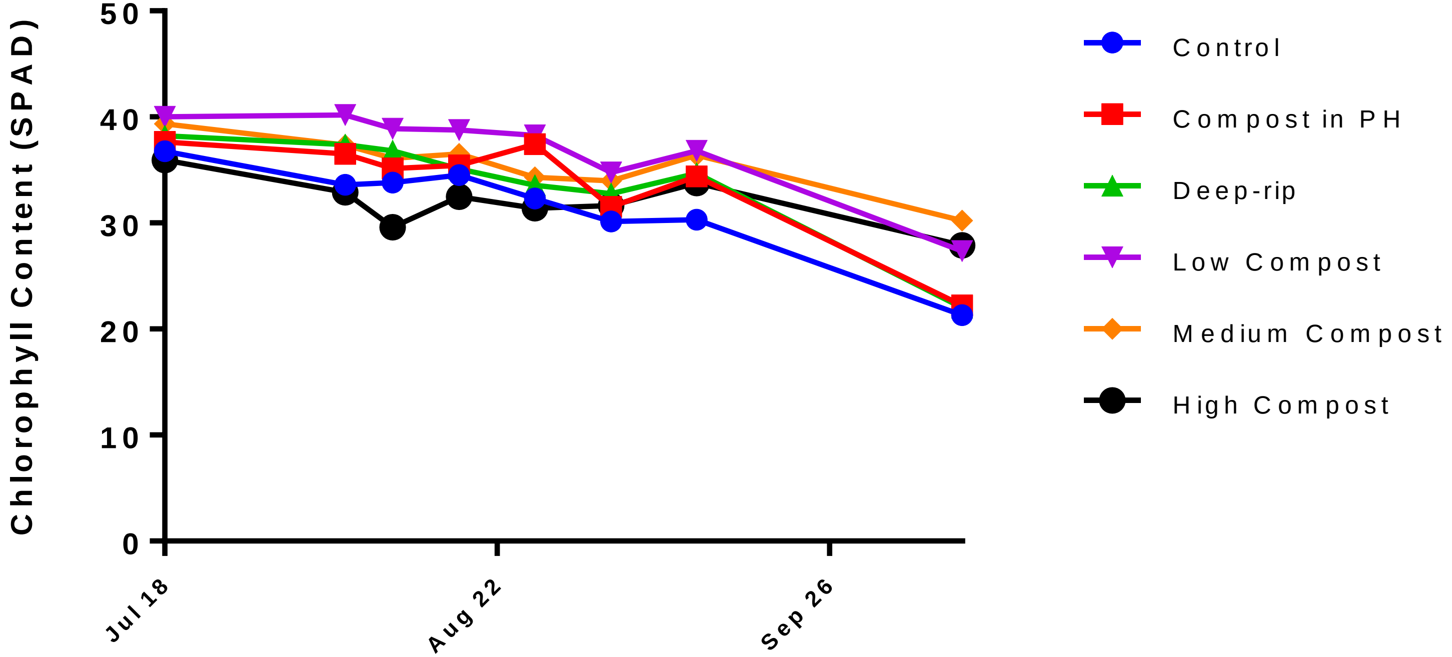


www.omafra.gov.on.ca/english/engineer/facts/11-037.htm

Leaf Chlorophyll Content - Site 4 2014

Ontario Results

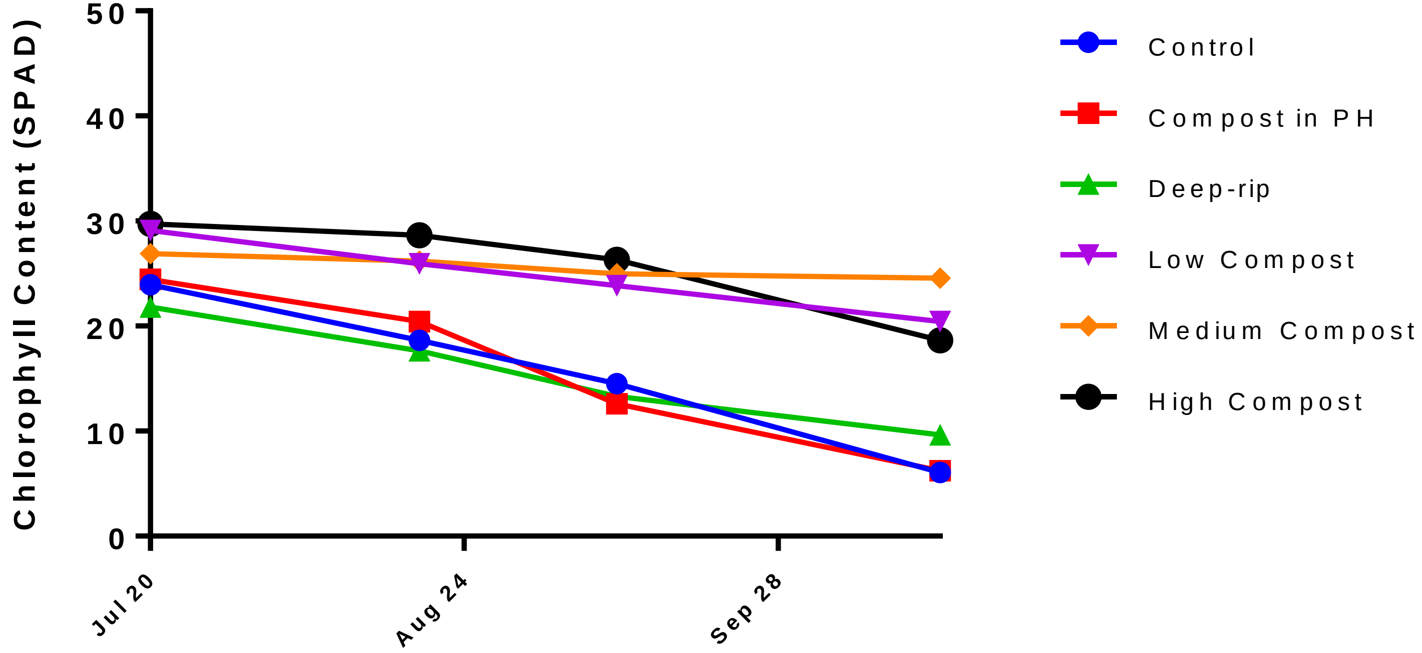
- In the first growing season on site 4 chlorophyll measurements were initially lower for high compost (treatment 6) until late August, when trees in the control (treatment 1) and then compost in PH (treatment 2) began to pre-maturely senesce.



Leaf Chlorophyll Content - Site 4 2015

Ontario Results

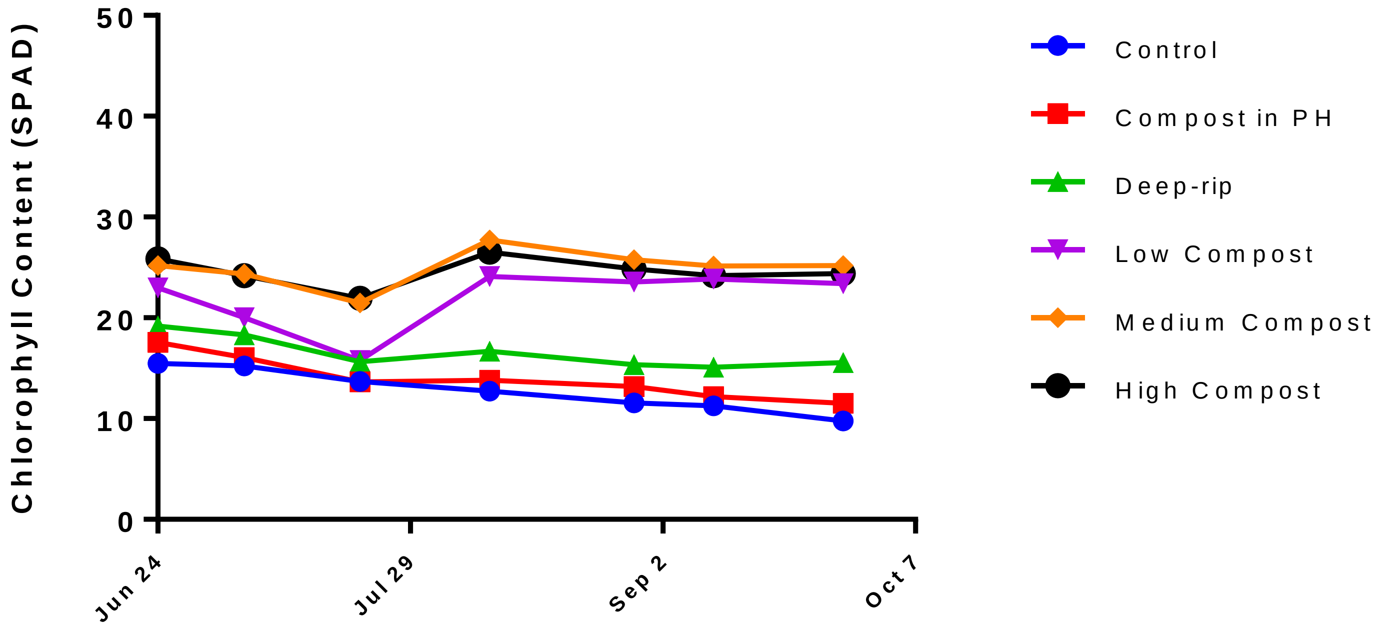
- In the second growing season on site 4 chlorophyll content diverged into two groups with compost bed treatments (low, medium and high compost) showing greater values compared to the control, compost in PH and deep-rip treatments.



Leaf Chlorophyll Content - Site 4 2016

Ontario Results

- In the third growing season on site 4 chlorophyll measurements were greater for compost bed treatments (low, medium and high compost) compared to control, compost in PH and deep-rip treatments.
- Regional precipitation was very low in June (30.8 mm) and July (36.0 mm), but improved in August (74.7 mm). This explains why chlorophyll values were low earlier in the season, but then recovered for low, medium and high compost beds (treatments 4, 5 and 6) by August onwards. Trees in control, compost in PH and deep-rip treatments were not able to recover.



Leaf Chlorophyll Content - Site 4 2017

Ontario Results

- In the fourth growing season on site 4, chlorophyll measurements were greater for compost bed treatments (low, medium and high compost) compared to control, compost in PH and deep-rip treatments.
- Tree performance was influenced by the accumulation of stress over time and results in the fourth growing season reflect this as the trees in compost bed treatments maintain greater chlorophyll levels later into the season.

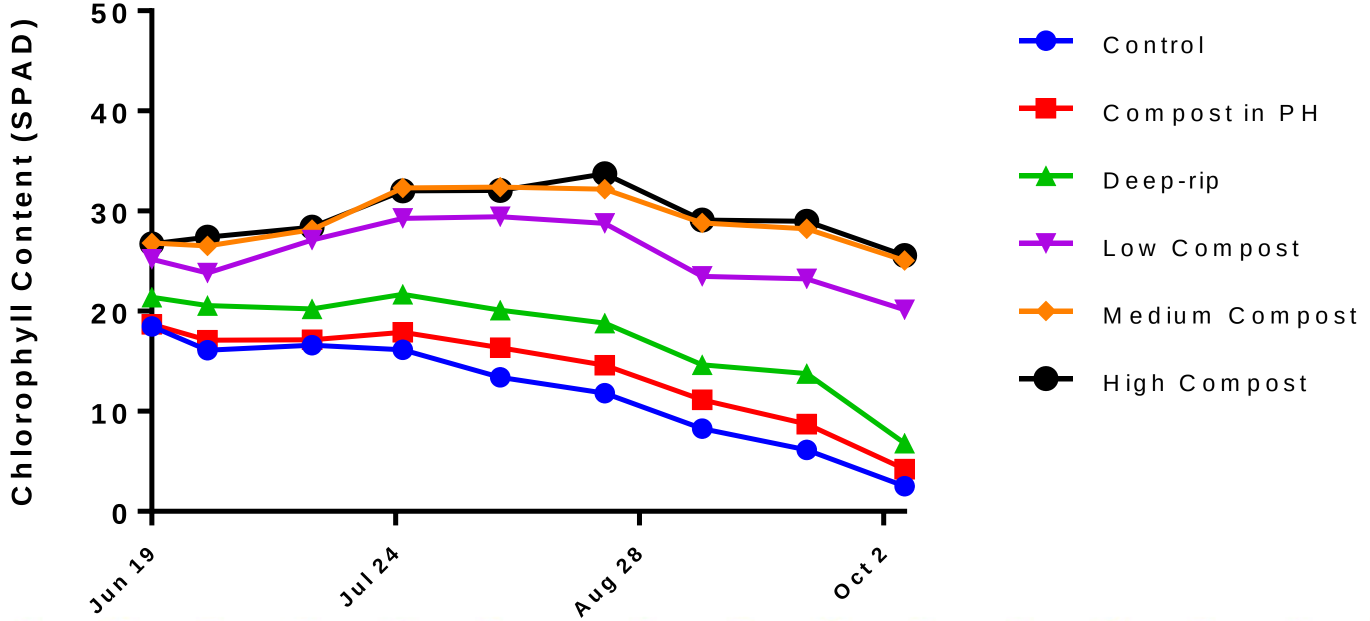


Photo Monitoring - Site 4

August 23rd 2017

- Photo monitoring occurred bi-weekly throughout the study, including treatment bed photos and individual photos of average trees for each treatment.
- Note the dieback and early senescence on representative trees in treatments 1 and 2, early senescence in treatment 3, and greater growth and chlorophyll content on treatments 4, 5 and 6.

Treatment 1
0% compost (control)

Treatment 2
50% compost in planting hole

Treatment 3
Deep-rip + 0% compost

Treatment 4
10% compost

Treatment 5
25% compost

Treatment 6
50% compost

Species Selection and Stock Size Trial

Site 7 - June 12th 2015

- The information from this trial, in conjunction with an extensive literature review on species and cultivar environmental tolerances, has been incorporated into our website (www.greeningcanadianlandscape.ca) in the Tree Species Selector tool.

Ontario Research Trial Methods

Experimental Design for Sites 6 and 7

- This experiment sought to investigate the establishment of different species of trees in two size classes (whips and seedlings), as well as shrubs. Tree species that were purported to be robust, drought tolerant and/or urban tolerant species were chosen for testing. The sites were prepared in the fall of 2014 and planted in the spring of 2015. Each treatment bed was deep-ripped to 90 cm and 10% compost v/v was incorporated using a rotary spader. After planting, trees were not maintained.
- 10% compost v/v was chosen as an application rate in order to test the efficacy of a minimum application rate with robust tree species.
- This trial has helped to refine the soil remediation calculator and validate the importance of site-specific application rates.

Treatment	Description
1	Seedlings only
2	Seedlings & whips
3	Whips only
4	Seedlings & shrubs
5	Whips & shrubs
6	Seedlings, whips & shrubs
7	Shrubs only

Animal damage and ground vegetation competition

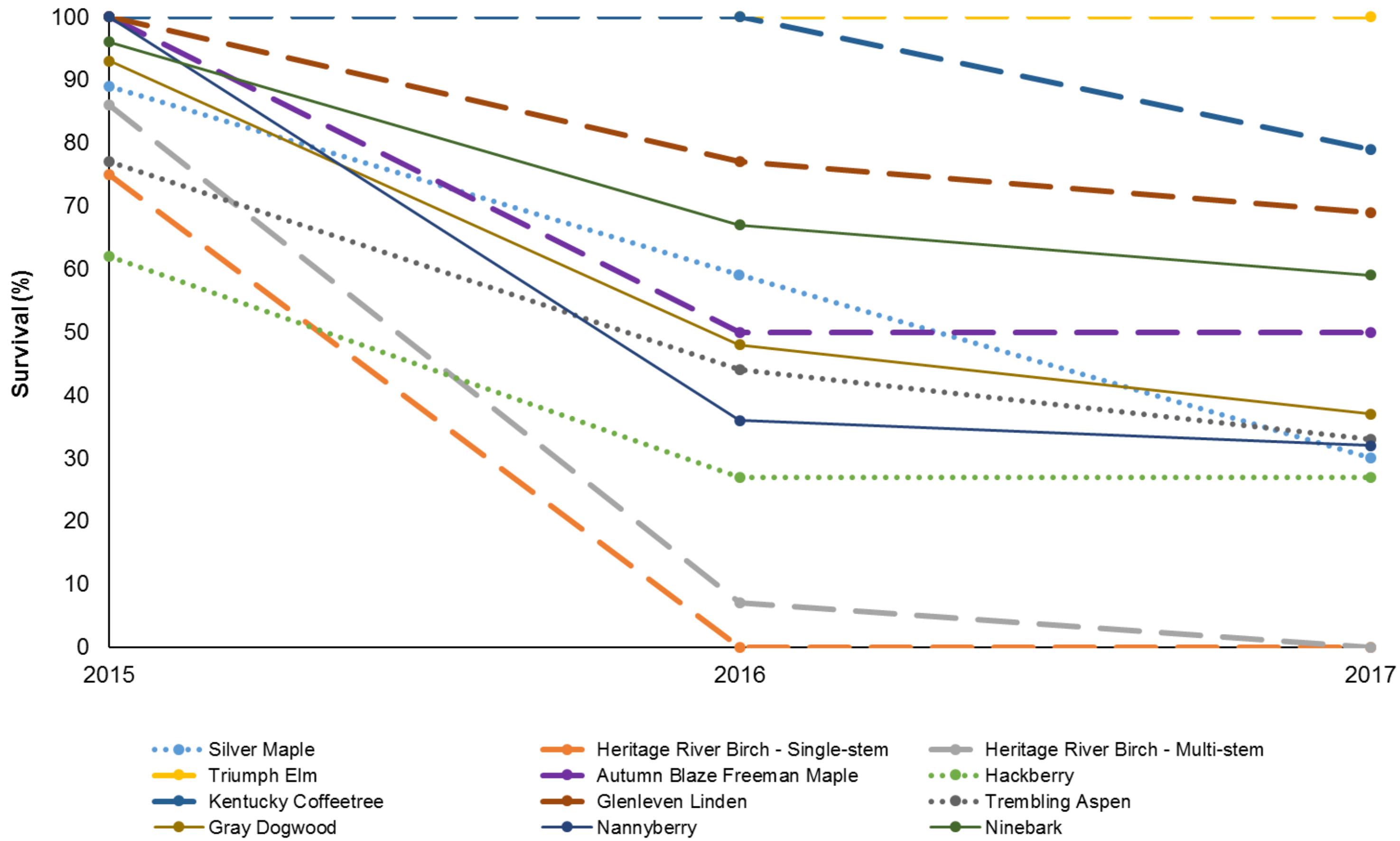
Ontario Results

- Animal damage is prevalent on un-maintained (un-mowed) sites because the grasses and herbaceous vegetation that colonize the sites provide suitable habitat and forage for rodents and deer. The types of animal damage observed on the highway sites include girdling, root chewing, burrowing within the root ball and browsing.
- Due to the pressure of herbivores and the competition between herbaceous vegetation and small seedlings, trees less than 100 cm in height are susceptible to poor establishment and/or mortality at these sites.

Survival – Site 6

Ontario Results

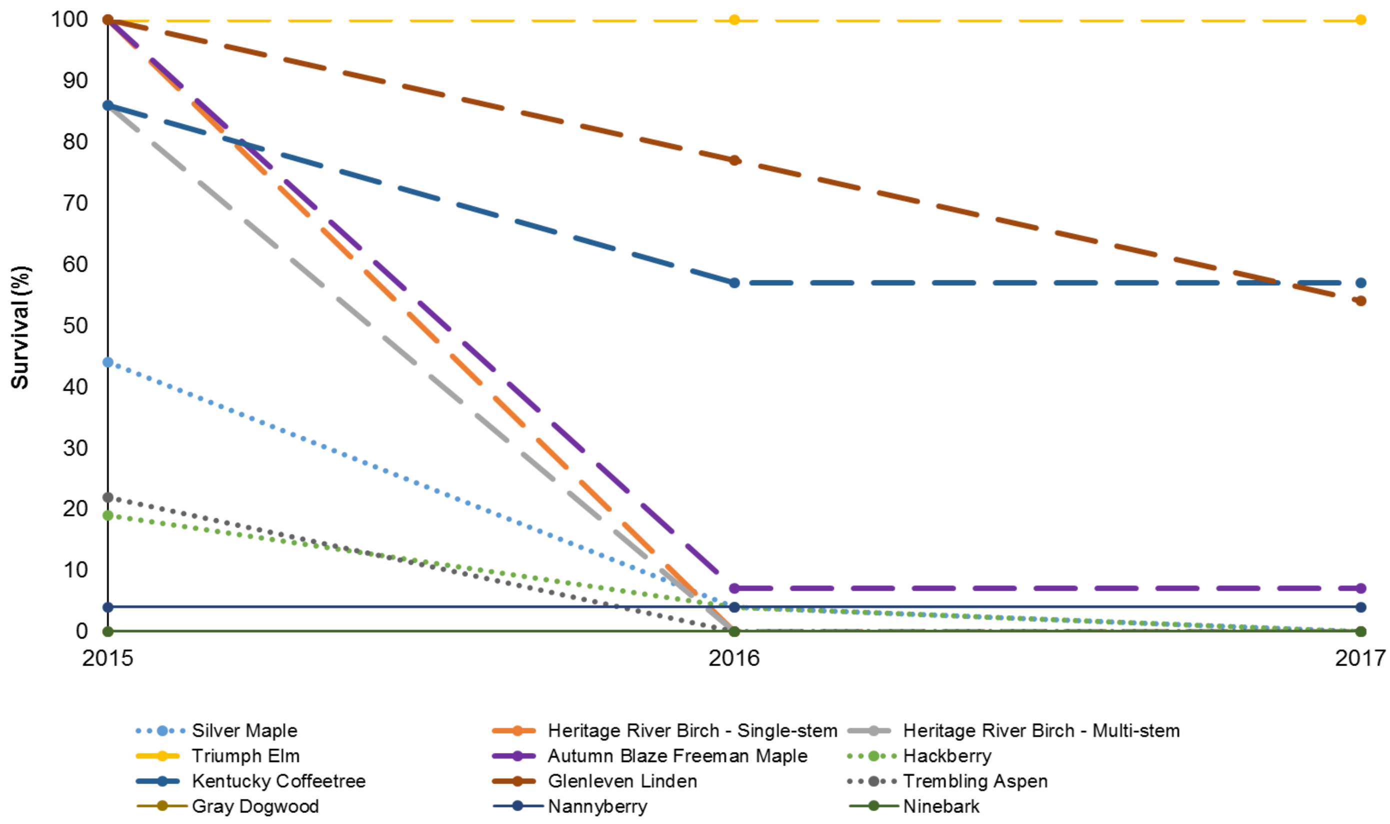
- In the graph below, seedlings are represented by small-dotted lines, whips are represented by large dashed lines and shrubs are represented by solid lines.
- Seedlings and shrubs experienced a continual decline in 2016 due to drought-like conditions in combination with herbivory and competition from ground cover vegetation. Only the most drought-tolerant whips were alive by 2017 (e.g. Triumph™ Elm had 100% survival by 2017).



Survival – Site 7

Ontario Results

- In the graph below, seedlings are represented by small-dotted lines, whips are represented by large dashed lines and shrubs are represented by solid lines.
- Only the most drought tolerant whips survived (e.g. Triumph™ Elm had 100% survival by fall 2017, Kentucky Coffeetree 57%, and Glenleven Linden 54%). By fall 2015 all shrubs had died except one Nannyberry. The seedling survival by fall 2015 was between 20-45% and decreased to almost 0% by fall 2016 due to the drought, herbivory and competition from ground cover vegetation.



Alberta Research Trials

Top: Airdrie trial site NE loop located at the Veteran's Blvd and Highway 2 – *Cloverleaf interchange*

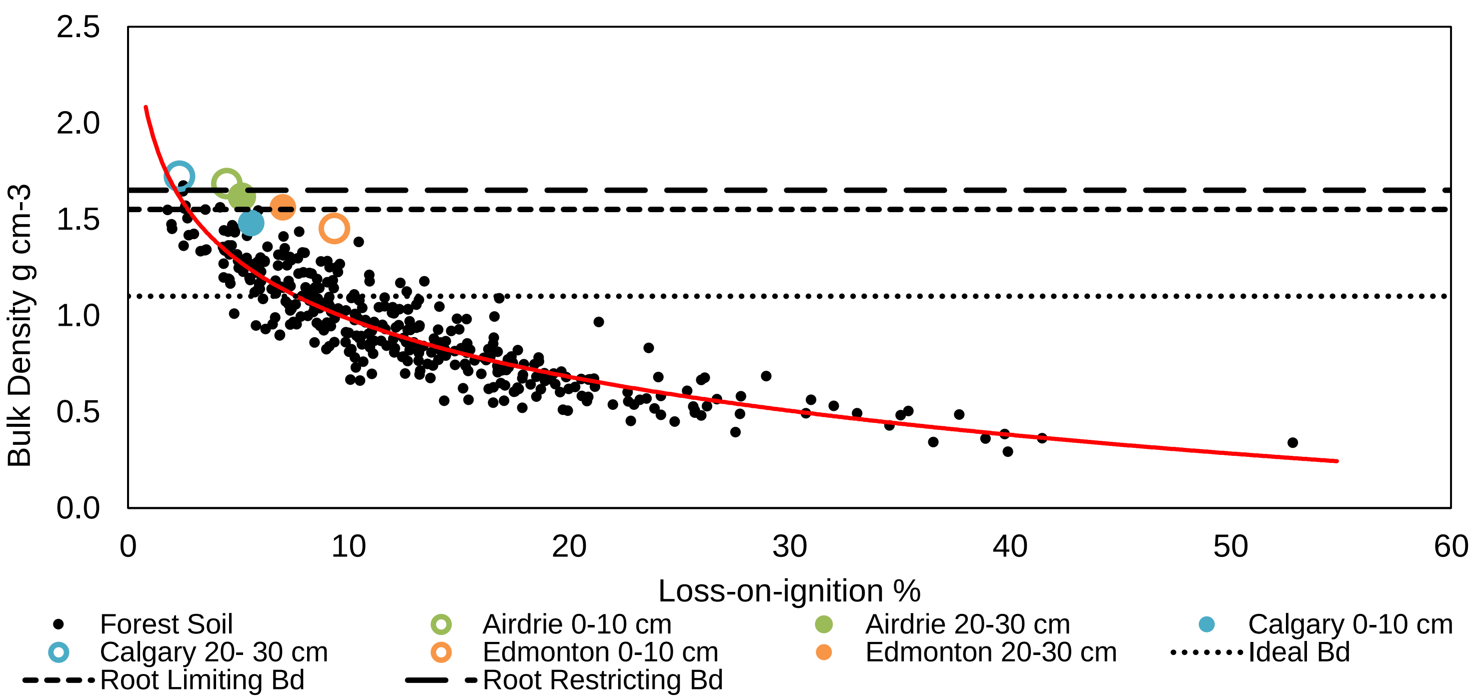
Middle: Calgary trial site located at NE loop at Blackfoot Trail and Glenmore Rd – *Cloverleaf interchange*

Bottom: Edmonton trial site located SW of Highway 216 and 17 St. NW – *Set back from highway 216 and adjacent to an agricultural field*

Alberta Highway Soil vs. Forest Soil - 2014

Results

- In 2014 soils were sampled at 3 highway sites and compared to forest soils.
- The results for Airdrie and Calgary were consistent with results from Ontario – soils had high Bd and low SOM.
- The soils from Edmonton had high SOM, which we hypothesize might be due to the relatively recent agricultural use of the land. Up until at least 2002 the Edmonton site was part of an active agricultural field. The soils also had high Bd. In 2013 a hydro tower was erected adjacent to the trial site, but no active removal of topsoil appears to have occurred. Therefore the high Bd may be a result of compaction from heavy equipment used to erect the tower.



Alberta Research Trial Methods

Experimental Design for Airdrie, Calgary and Edmonton sites

- In 2015 the sites were remediated and 6 trees ea. of 60-70 mm caliper field-dug Green Ash (*Fraxinus pennsylvanica*) and Brandon Elm (*Ulmus americana* 'Brandon') were planted into each of the treatments
- Organic amendments were incorporated at each site for treatments 1 and 2 using an agricultural tiller and were mixed to a depth of between 20-30 cm
- Treatments 1-3 are planting bed-style with at least 1 m of space from trees to treatment bed-edge. Treatment 4 is a planting pit tree installation. Native soil was excavated to accommodate the root ball.
- Trees are planted at least 3 m apart
- After planting, trees were irrigated weekly at 15 gal/tree for 14 weeks for the first growing season because of the large stock size used and city requirements for irrigation. Trees were not irrigated in the second growing season to begin to amplify treatment effects.

Treatment	Methods
1	DR + 15% PPR v/v
2	DR + 15% Municipal Compost v/v
3	DR + 0% amendment v/v
4	Control- City specification

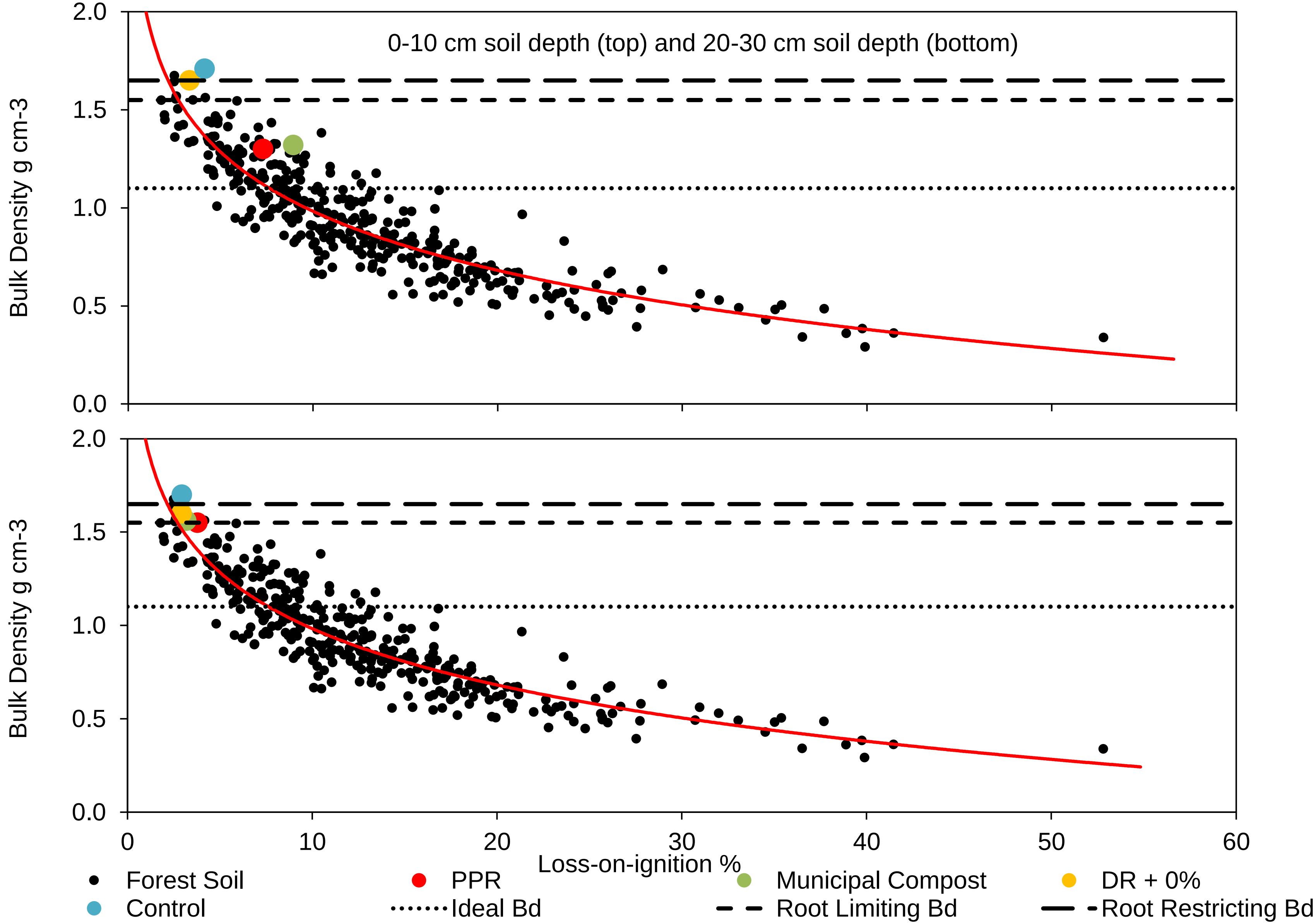
- DR – Deep-ripping to a depth of 90 cm
- PPR – Composted Pulp and Paper Residuals
- v/v – volume of OA/volume of native soil

Alberta Soil Findings 2017

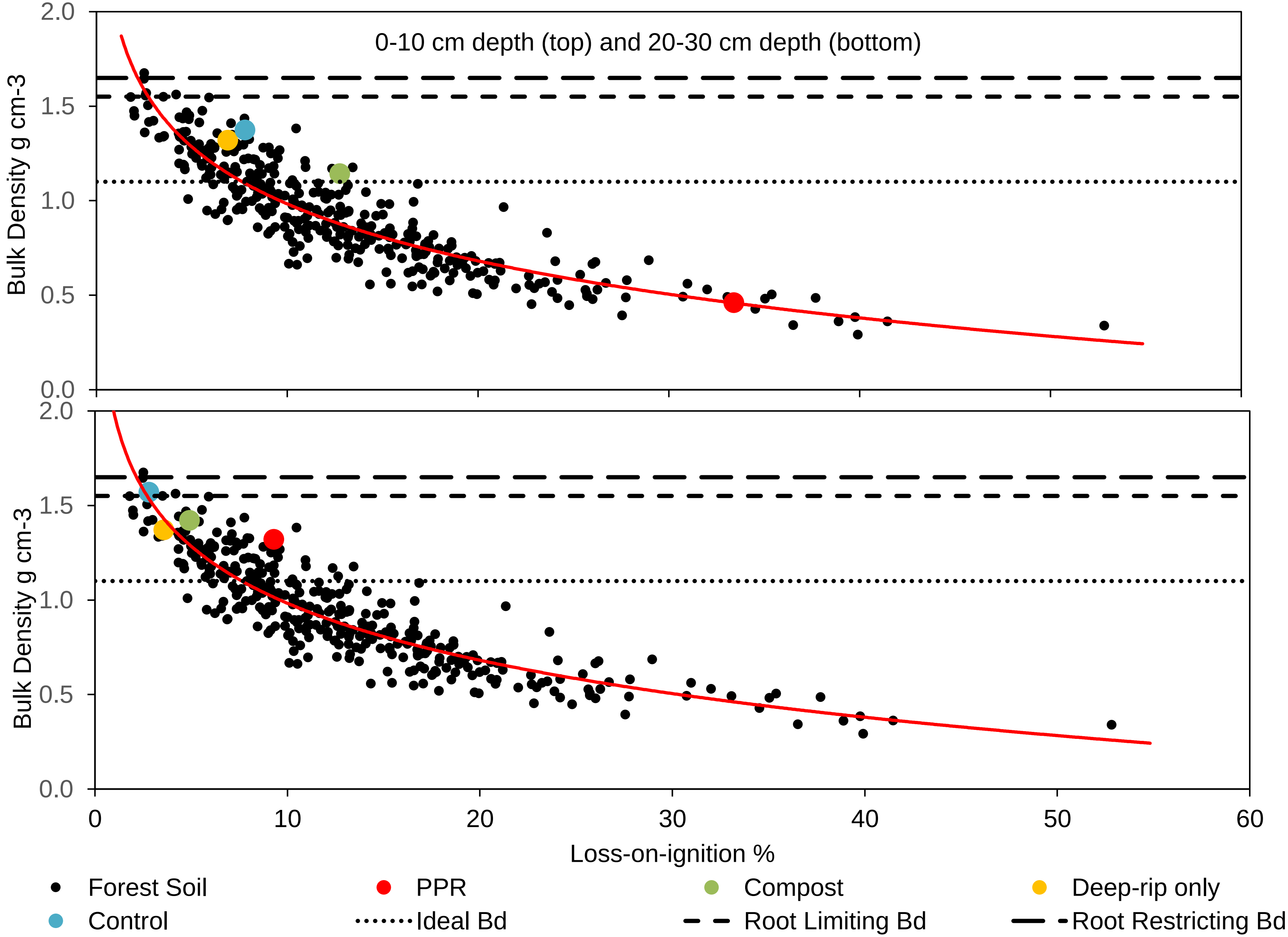
Results

- The following points summarize the significant findings from the following three slides:
  - The Calgary soil Bd and SOM results are more representative of the types of highway sites we have sampled. Airdrie had extremely high density soils prior to remediation and Edmonton had soil with high SOM and relatively high Bd.
  - There were high soil organic matter levels in the 0-10 cm depth for all sites for 2017 in treatments 1 and 2 (PPR and Municipal Compost).
  - The organic matter didn't incorporate well into the 20-30 cm depth for all the Alberta sites but is particularly evident in the graph from Airdrie where all treatments are located above the root limiting level. This is indicated by high Bd and low SOM in treatments 1 and 2 at the 20-30 cm depth. The agricultural tiller likely did not effectively incorporate the amendment into the compacted native soil.

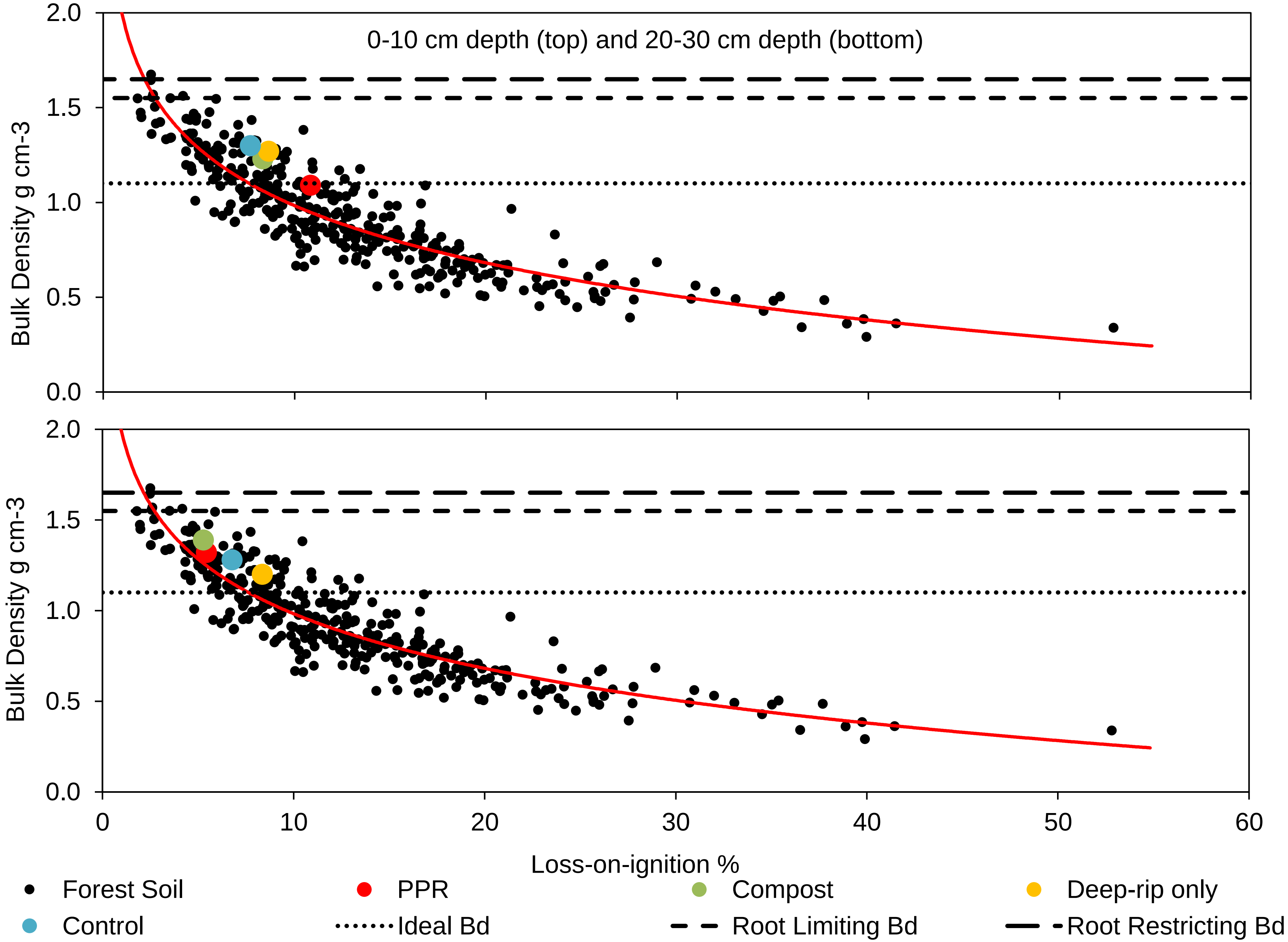
Airdrie Bd and Organic Matter - 2017



Calgary Bd and Organic Matter- 2017

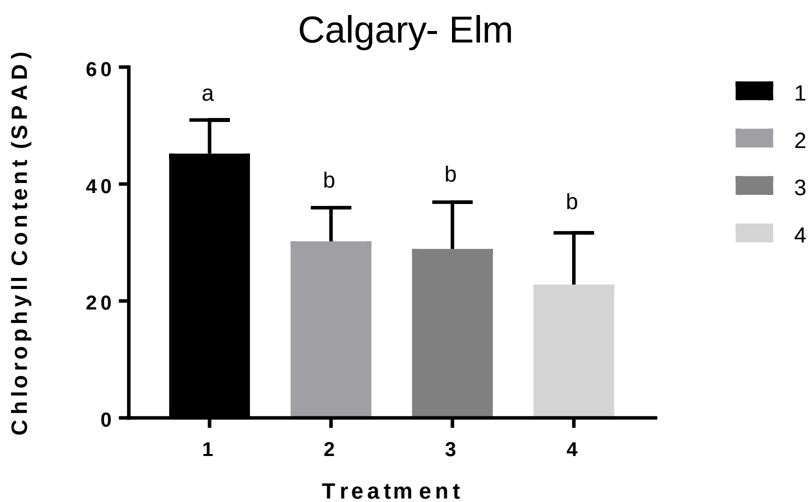


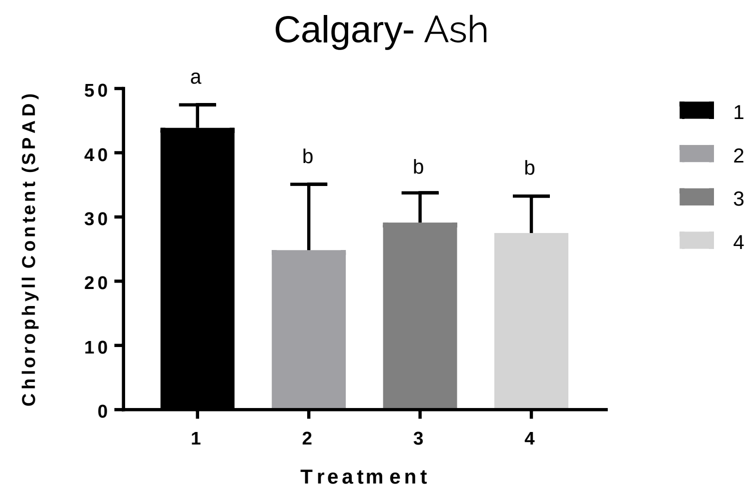
Edmonton Bd and Organic Matter- 2017

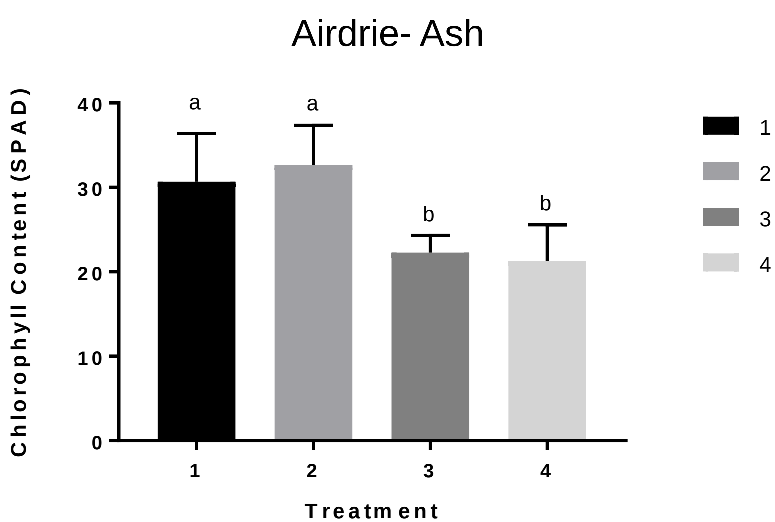


Leaf Chlorophyll Content - 2017

Alberta Results





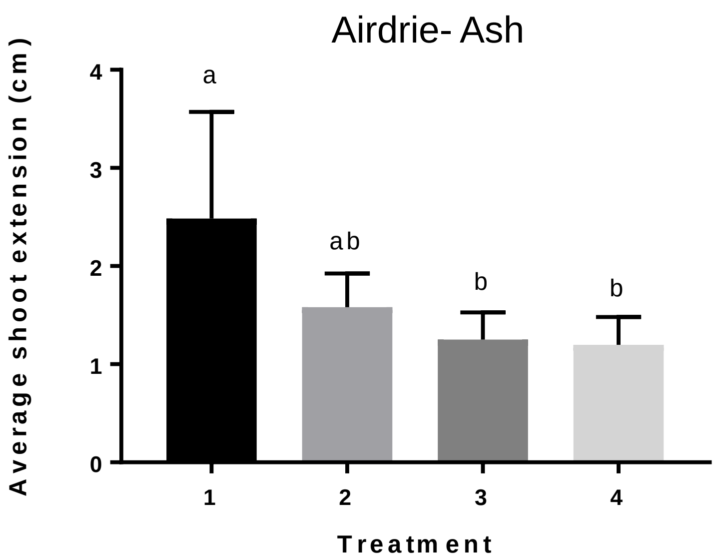


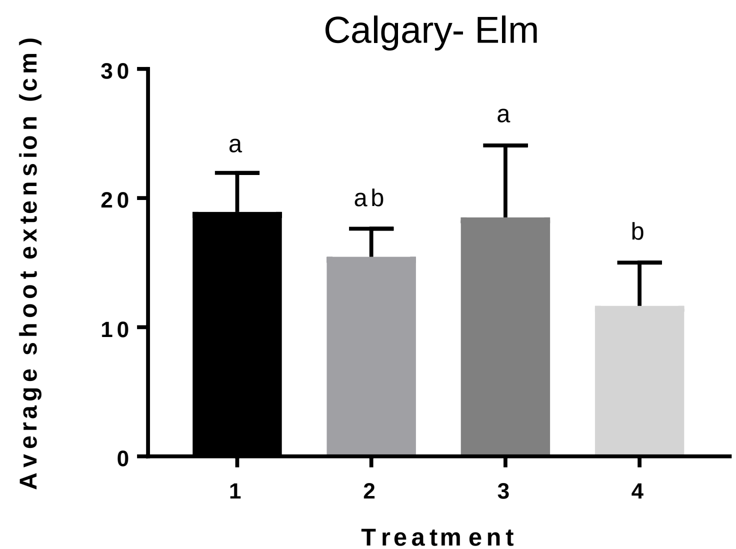
- Trees tend to experience less stress in Composted Pulp and Paper Residuals (treatment 1) as evidenced by higher chlorophyll levels when sampled in September 2017.
- Differences were significant for elm only at the Calgary site.
- No significant differences were found in Edmonton for 2017.

Shoot Extension - 2017

Alberta Results

- The general trend is that tree growth is improved in Composted Pulp and Paper Residuals (treatment 1) as compared to the control (treatment 4).
- The differences among treatments for shoot extension will be more pronounced in subsequent years because large trees undergo a longer period of slow top growth after being transplanted.
  - After large caliper field-dug trees are transplanted a root to shoot balance must be restored to compensate for the roots that were left in the nursery before normal above-ground growth can resume
  - Trees require approximately one year of growth after planting for each inch of caliper (e.g. 4 inch caliper = 4 growing seasons to regain original root system size)

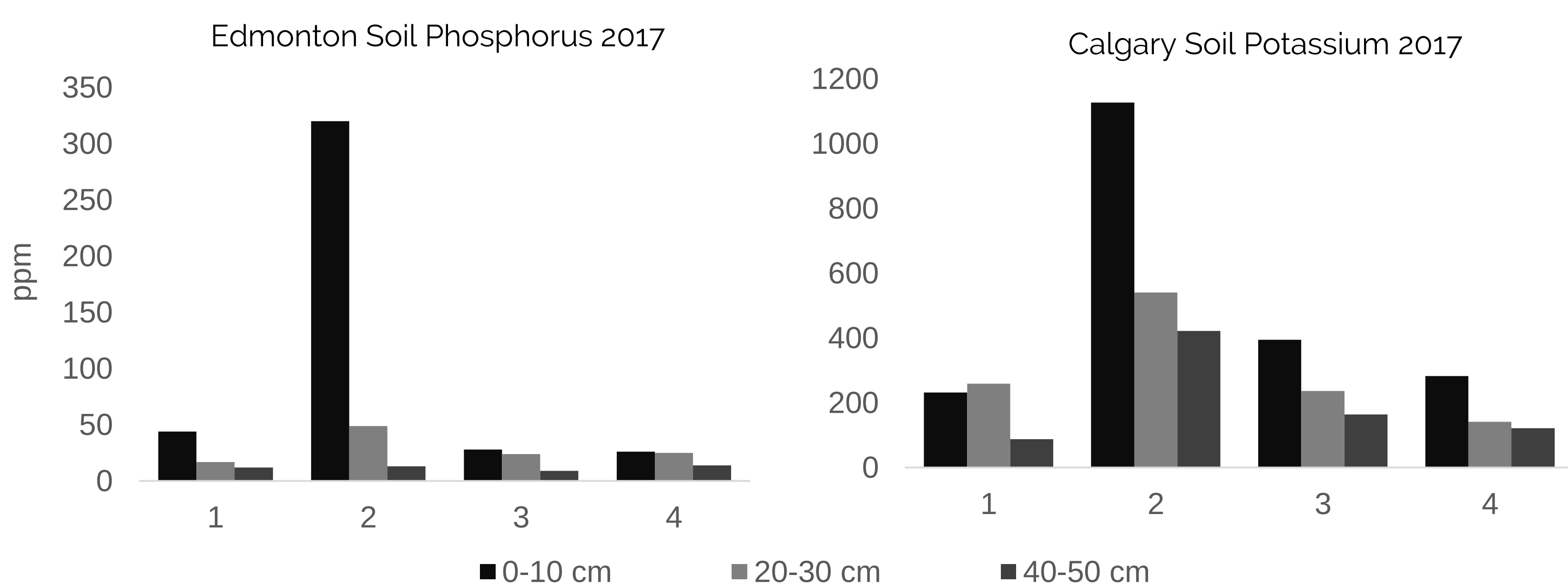




Compost Quality and Feedstock

Alberta Results 2017

- The quality of the organic amendment used can influence the nutrient cycling in urban soils.
- It is important to know the supplier's compost quality standards, review the analytics and know the feedstock source for the compost.
- Edmonton and Calgary (also supplied Airdrie) were the suppliers of municipal compost and both cities co-compost residential solid waste and dewatered sewage biosolids. Biosolids are generally high in macronutrients which may account for the high levels of phosphorus and potassium in Treatment 2 (municipal compost) demonstrated in the graphs below.
- Although we analyzed leaf tissue from September 2017, as expected, no significant differences were detected among treatments due to the slow top growth attributed to root loss during digging of nursery trees. Transplanted trees are likely still mining the soil brought in from the nursery within their root balls.



Outputs and Deliverables

Project Summary

1. Led demonstration events on the methods and results of the project. Including:
   - Highway of Heroes Tribute
     - 3 demo sites (1 site in Ajax, 2 sites in Trenton) 2
     - research sites in Port Hope (Alex Novacic – Masters Student University of Waterloo)
     - Future highway plantings will be guided by Vineland recommendations

2. Implementation of findings into standards, specifications and recommendations
   - Ontario Provincial Standard Specification
     - OPSS 801 – Tree protection
     - OPSS 802 – Construction of topsoil
   - Advising compost producers on compost quality criteria for urban applications
   - Advising municipalities on adaptation of findings for topsoil specifications.
   - Recommendations to nursery partners on suitable species and stock sizes for unmaintained highway roadside plantings
   - Completed cost-benefit analysis on Vineland recommendations

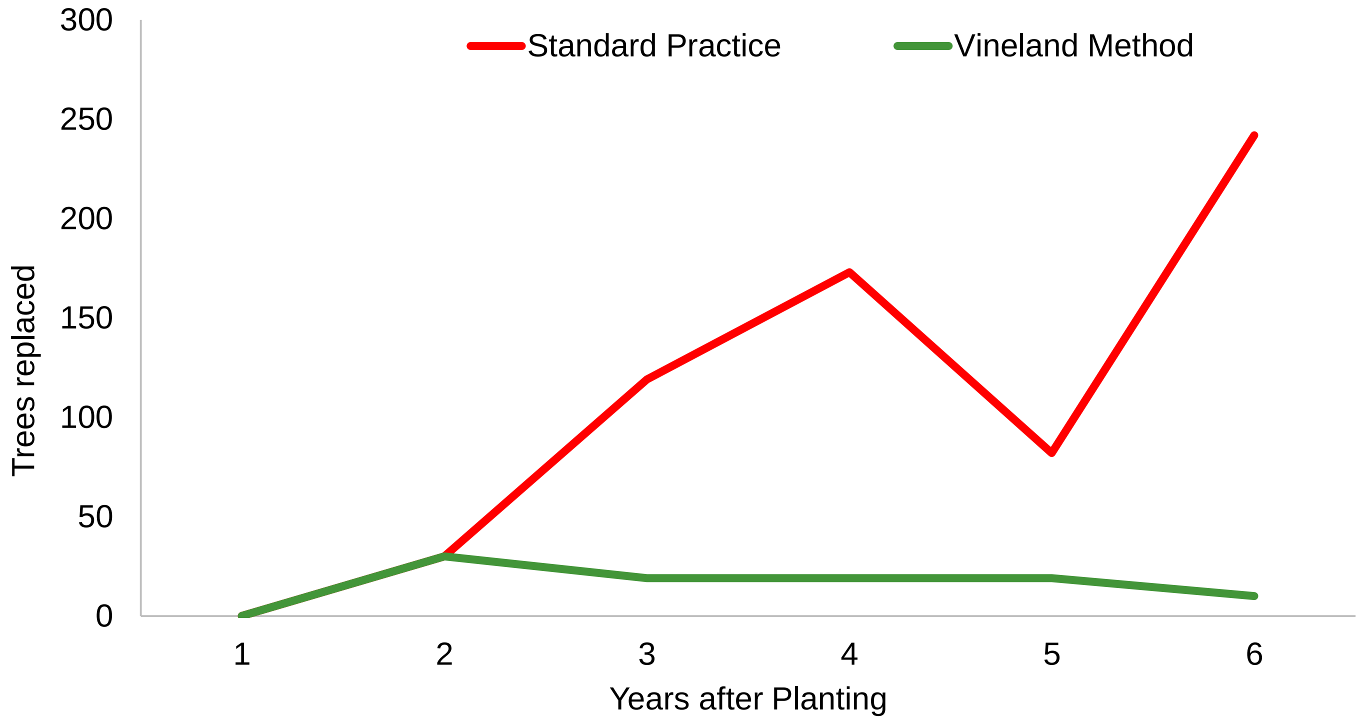
3. Train municipal land managers on Vineland recommendations using individual planting projects

4. Communication activities:
   - Presentations to nursery and landscape association partners, Ministry of Transportation, community groups
   - 1 peer-reviewed journal article published, numerous media and trade articles published, conference presentations, industry trade shows,
   - Direct outreach to urban forest managers across Canada

5. Development of new website unique to Canada to communicate information to improve tree survival in challenging urban environments

Comparison of Methods: Survival and Tree Replacement

We compared the rate of tree failure and replacement of trees from Sites 1 and 2 (the green line on the graph- standard roadside tree planting practice) to the method for remediation developed in this project. Tree replacement numbers were calculated from real values (trees that died during the study) in addition to a 30% failure rate of newly planted trees each year (which is the failure rate observed at Sites 1 and 2). We have not observed any tree mortality in our Vineland Method (deep-ripping + 25% compost v/v) on our sites yet, therefore the red line failure rate data is an estimated value from a Weibull Distribution. *Because we do not have a longer term data set on survival of un-remediated sites in from Alberta, we have only created this analysis for Ontario to date.*



Cost Effectiveness of Planting Methods

- The Standard Planting costs in the table below are estimated using a $200 per tree standard price common to Ontario roadside tree planting and includes: nursery stock, installation, soil preparation, mulch, staking and initial watering in. **Does not include replant costs.**
- The Vineland method (which is based on real costs incurred during the project execution) includes: nursery stock, equipment costs for deep-ripping and tilling, labour costs, compost delivery and application, tree installation, initial watering, traffic accommodation and planning.
- The replacement cost values are based on the real survival data from Sites 1 and 2 for Standard planting and estimated data for the Vineland method as we have not yet observed any mortality in our recommended treatment trial beds.

Estimated Costs for 1000 trees	Standard Planting	Vineland Method
Estimated Planting Costs	$200,000	$95,000
Replacement costs in year 1	0	0
Replacement costs in year 2	$6,000	$6,000
Replacement costs in year 3	$23,800	$3,800
Replacement costs in year 4	$34,600	$3,800
Replacement costs in year 5	$16,400	$3,800
Replacement costs in year 6*	$48,400	$2,000
Total	**$329,200**	**$114,400**

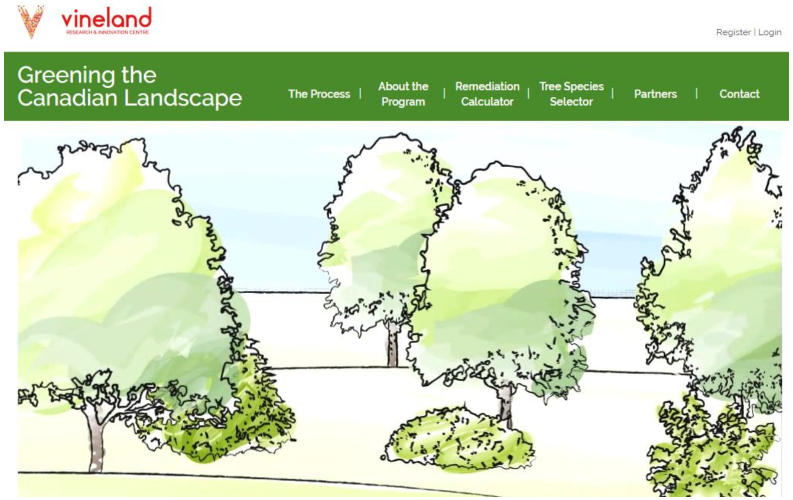
* Increased mortality in Year 6 is likely due to the drought from Year 5 (2016).

Website Launch

Project Summary

We created a website www.greeningcanadianlandscape.ca based on our research and results. Key elements of the website include:

- The Soil Remediation Calculator, which determines remediation requirements based on simple soil analysis (organic matter percent and texture).
  - Step-by-step instructions on the process (soil sampling and remediation)
  - Soil sampling glossary
  - Calculation tool for site-specific remediation and report generator
- The Tree Species Selector makes recommendations for suitable tree species based on environmental and tree characteristics for urban sites.
  - Tree glossary
  - Environmental site condition-based recommendations
  - Species planting list generator
  - A detailed information page for each species listed



Thank You

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Growing Forward 2
A federal-provincial-territorial initiative

Ontario

Canada

Acknowledgements

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vineland

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