ONTARIO

LANDSCAPE TREE PLANTING GUIDE

Contents

Introduction

This guide is a comprehensive revision of 'A Reference Guide for Developing Planting Details' published by the Landscape Ontario Horticultural Trades Association in 1994 and revised in 2005. It is intended for landscape architects, landscape designers, landscape contractors, urban forest managers, horticulturists, arborists and other professionals who understand tree attributes and tree requirements and who have a working knowledge of terms commonly used in the horticultural trades. All landscape trees should be nursery-grown and in compliance with the current edition of the Canadian Nursery Stock Standard.

This guide was reviewed by a committee established through Landscape Ontario. The information within reflects best practices of the landscape horticulture industry. The guide is subject to periodic review and may be updated at any time. Users are encouraged to obtain the most recent version from the Landscape Ontario website. Comments and suggestions for improvement are welcome. All recommendations should be sent to Landscape Ontario.

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Overview

Research on improving tree planting and establishment continues to grow in interest, alongside the increasing value placed on tree canopy cover by society. In order to capture the wealth of evidence-based information available and ensure that this guide is informed by this growing body of research, it is written to provide readers with a summary of relevant content and up-to-date research findings. Corresponding field sheets distill pertinent information from the chapters into actionable items. Planting details are included in Appendix B to illustrate the best practices discussed in the chapters and field sheets. When additional information is required to describe protocols or techniques, hyperlinks to resources are provided. Words within the text in **bold** are linked to the glossary.

The information in this guide does not extend to post-planting and establishment care. However, aftercare is often integral to tender language associated with planting contracts. In order to plan for care after planting, an overview of tasks and the potential tender language are provided in Appendix A – Post-Planting and Establishment Care.

Note on Key References

The guide was broadly informed by several key resources listed below:

Hirons, A., and P.A. Thomas. 2018. Applied Tree Biology. John Wiley and Sons Ltd. 411 pp.

Hirons, A., and H. Sjöman. 2019. Tree Species Selection for Green Infrastructure: A Guide for Specifiers. Tree Design and Action Group. http://www.tdag.org.uk/species-selection-for-green-infrastructure.html.

Lilly, S. J. 2010. Arborists' Certification Study Guide. International Society of Arboriculture. Champaign, IL. 352 pp.

Urban, J. 2008. Up by Roots. International Society of Arboriculture. Champaign, IL. 479 pp.

Urban Tree Foundation. 2014. Planting Details and Specifications. http://www.urbantree.org/details_specs.shtml.

Watson, G. and E.B Himelick. 2013. The Practical Science of Planting Trees. International Society of Arboriculture. Champaign, IL. 250 pp.

Chapter 1 - Environmental Site Assessment

All tree planting projects should start with a comprehensive site assessment. This section deals with environmental conditions – aside from soil quality, which is covered in Chapter 2 – that need to be investigated on-site to develop a planting strategy, including tree selection.

Hardiness

Action Item

- Identify the hardiness zone where the planting site is located.

Cold hardiness is the first factor to consider when selecting trees for a planting project. Two commonly used systems for determining and mapping hardiness zones in Canada are 1) the Canadian plant hardiness index and 2) the USDA method, based on extreme minimum temperatures. The Canadian plant hardiness index has been developed to incorporate a wider variety of climatic variables, including minimum mean temperatures, frost free periods, rainfall, maximum mean temperatures, snow depth and wind gusts. Both of these systems have updated maps based on data from 1981 to 2010 and are available here.

Light Levels

Action Item

- Observe the amount of sunlight new plantings will receive throughout the growing season.

Trees' physiological responses to sunlight levels can be drastically different. In general, the shade tolerances of tree species correspond with three categories of sunlight levels: full sunlight, partial shade and full shade (Table 1). Any structure on-site can contribute to shading, including buildings and existing trees. Sunlight levels are influenced by planting location, height and number of buildings and/or trees, street width and building setbacks. Although shady conditions can often preclude optimal growth of planted trees, if shade-tolerant species are selected, success in planting projects can still be achieved.

Table 1 Categories of sunlight levels during the growing season

Light level	Description
Full sunlight	Greater than six hours of direct sunlight per day
Partial shade	Less than six hours of direct sunlight or filtered light throughout the majority of the day
Full shade	Less than six hours of filtered sunlight; very little to no direct sunlight per day

Reflected Heat

Action Item

- Determine the distance between the planting site and hard surfaces like roads, concrete structures, buildings, etc. Consider appropriate interventions listed in Table 2.

Temperatures can differ in cities due to reflected heat and a lack of surrounding vegetation. Maximum temperatures in New York City's Central Park were recorded at 32°C compared to 41°C on nearby Columbus Avenue (Whitlow and Bassuk 1987). In general, city temperatures are 1°C to 6°C warmer than their surrounding suburbs, with most of that difference attributed to the high density of buildings, asphalt and concrete. These materials absorb, store, and release heat. They can represent up to 90 per cent of the space surrounding a tree in a downtown location (Watson and Himelick 2013). The released heat directly influences trees in these locations and the phenomenon contributes to the urban heat-island effect. Trees experiencing high temperatures can dissipate heat loads through **transpiration.** When transpiration is limited by a lack of available soil water, leaf temperatures can continue to rise. If these conditions are ongoing and exacerbated by increased ambient temperatures from reflected heat, branch dieback and tree mortality can eventually occur.

Taking a 360° view of the planting location helps understand the potential heat load that may affect the planting site (Coder 2014). Trees that are less than 5 m from hardscapes in multiple directions are more likely to be strongly affected by reflected heat. This effect will diminish when hardscape is present in only one direction or is farther away. To determine the influence of reflected heat on the proposed planting location, estimate how close the newly planted tree will be to impermeable surfaces. If the tree will be planted closer than 5 m to impermeable surfaces in multiple directions, some interventions and extra care should be considered (Table 2).

Table 2 *The influence of reflected heat loads on trees planted 5 m or less from impermeable surfaces in multiple directions*

Concerns	Interventions
• Dehydration • Decrease in photosynthesis and increase in respiration • Tissue death	• Frequent irrigation is necessary in prolonged periods of heat and drought • Apply **mulch** • Limit fertilizer use • Incorporate shading into design • Heat/drought tolerant species must be selected

Crown Space Requirements

Action Items

- Determine the distance to buildings, existing trees and any other potential conflicts as trees grow.
- Refer to setbacks from utility providers to determine final planting distance from utility lines.
- Choose species whose mature height and canopy fit the location size constraints. Click here (for a North American guide) or click here (for a European guide containing many relevant selections for Ontario).

When planting near above-ground infrastructure, it is essential to envision the mature size of a tree in relation to buildings, power lines and other trees. Using mature tree height and width size estimates will help to reduce expensive pruning work or tree removal in the future. Contact local utility providers to obtain recommended tree planting setbacks or refer to Hydro One's recommended planting zones. Tree form (or habit) should be considered largely for aesthetic reasons, although wide-branching species can conflict with infrastructure or result in tighter spacing between trees than desired.

De-icing Salt

Action Item

- Determine the distance between the planting site and areas where de-icers will be applied. Consider appropriate interventions listed in Table 3.

In Ontario, de-icing salts are used on roadways and sidewalks, in both granular form and as a spray solution. The distance between the planting site and areas of salt application during the winter is a critical factor when choosing species, since salt can affect trees as a soil contaminant and as an airborne pollutant. On highways, de-icing salt can spray onto trees and those located on the downwind side of the road show the greatest injury. In southern Ontario, Hofstra et al. (1979) found higher concentrations of sodium chloride (NaCl) and injury levels on *Thuja occidentalis* (eastern white cedar) trees growing on the downwind side of Highway 401. Salt spray is not likely to cause outright tree failure, but recurring damage tends to affect **crown** and branch growth (Lumis et al. 1973). For trees that are planted less than 5 m from roadways, cut-outs or sidewalks, tree mortality tends to increase, as soil contamination is more likely (Dobson 1991). Tree species selections that are tolerant to these conditions are very limited.

Table 3 Damage levels and possible interventions associated with distances between the planting site and areas of de-icing salt applications

Distance	Damage level	Salt type	Interventions
< 5 m	Severe damage	Damage from spray and soil contamination	• Use of raised curbs to limit salt contaminants moving into tree pits • Shelter trees (fences, burlap) • Select species that are known to be tolerant to soil salt contamination and salt spray • In extreme cases, it may be recommended not to plant a tree
5 to 30 m	Moderate damage	Salt spray and potential soil contamination if barriers are not used	• Shelter trees during the winter (fences, burlap) • If possible, select species with at least moderate tolerance to salt spray
30 m or more	Minimal damage	Salt spray	• If possible, select species with at least moderate tolerance to salt spray. Sensitive species may be considered if salt drift is limited.

Figure 1 *Tip needle browning is evidence of salt spray damage on evergreens. Source: Glen Lumis.*

Airborne deposits and runoff from melting snow on pavement can accumulate in the soil and negatively affect **soil structure. Aggregates** can be broken apart and clay particles can plug soil pores, resulting in reduced soil permeability and aeration (Watson and Himelick 2013). Salt that remains in the soil past the winter will influence the osmotic potential of the soil moisture, making it more difficult for tree roots to absorb adequate water during the growing season (Hirons and Sjöman 2019). Due to the central importance of water in the physiological processes of all plants, tree species that cannot tolerate soil salt will decline through disrupted photosynthesis, stunted growth and compromised cellular function. High levels of soil salts can dehydrate and damage roots and cause desiccation of the entire plant (Hanslin 2011). **Leaf necrosis** and **chlorosis** can be signs of elevated soil salt levels, especially on older leaves where sodium and chlorine ions have built up to toxic levels over a longer period of time (Hirons and Sjöman 2019). The evidence of the translocation of soil salts to shoots during the growing season includes twig dieback, **witch's broom** and **leaf scorch** occurring on leaf margins (similar to aerially deposited salt), as well as trunk lesions (Watson and Himelick 2013).

Conifers experiencing salt spray will exhibit needle browning starting at the tips and become more extensive with increased salt exposure (Figure 1). For deciduous species, twig dieback and witch's broom result from injury to vegetative buds. Injury becomes more extensive with increased salt exposure and is greater on the side of trees facing the roadway. Although salt injury diminishes with distance (Lumis et al. 1973), tree species particularly those sensitive to salt spray have been found to experience salt damage over 300 metres from a major highway (Watson and Himelick 2013).

There are ways to avoid and mitigate the effects of salt exposure. These can include: raised curbs; irrigating/improving drainage of soils to leach salt out before spring tree growth; rinsing tree buds and/or foliage in the spring before bud-break; wrapping conifers; constructing fences; applying anti-desiccant sprays and lastly; watering, pruning, and mulching trees.

Quantitative measures of salt tolerance do not currently exist, instead, patterns of performance and morphological features are used to produce relative salt tolerance rankings (Hirons and Sjöman 2019). Where salt tolerance rankings do exist, there are sometimes contradictions between sources. Therefore, most evidence-based resources only provide known tolerance rankings for a limited number of species where there is consensus and data are more reliable.

Root System Space Requirements

Action Items

- Determine the proposed planting distance to infrastructure with which roots may come into conflict.
- Refer to any setbacks identified by service providers for infrastructure and utilities.
- Use identified distances to make appropriate interventions (Table 4).

Impermeable surfaces surrounding trees have been shown to limit tree growth and life expectancy (Smiley et al. 2006), typically due to soil compaction and a lack of water and air infiltration. Landscape trees, especially in streetscapes, commonly outgrow their planned planting area, and their growth eventually becomes limited by a lack of available root space. When the root system cannot increase in size because the rooting space is filled to capacity, crown growth will slow (Watson and Himelick 2013).

Table 4 *Distances at which tree roots are likely to conflict with infrastructure*

Distance	Infrastructure	Interventions
< 3 m	Sidewalks and roads	• Root barriers • Sidewalk cut-outs • Install **root pathways** to direct roots • Modular suspended pavement systems • Use **structural soil** • Avoid aggressive rooting species • Choose deep rooting species

< 6 m	Building foundations	• Avoid aggressive rooting species • Install root pathways to direct roots • Select species and **cultivars** with small mature crowns
< 6 m	Pipes and sewers	• Avoid aggressive rooting species • Select species and cultivars with narrow/small mature crowns

Planting trees too close to pavement can result in damage. The space between pavement and a compacted soil base often provides space for roots to grow. The moisture in these areas is often high because the pavement prevents evaporation and condensation can form on the underside of pavement as it cools. Importantly, aeration is also better in these spaces than in the compacted soil below.

However, when planning does not account for root extension into these areas, roots can eventually lift and crack the pavement (as illustrated in Figure 2). There are a variety of engineering solutions designed to help mitigate the conflict between tree root growth and infrastructure. These include root barriers, sidewalk cut-outs, root pathways, use of modular suspended pavement systems (e.g. plastic structures) and structural soil (Table 4). Many of these options have been successful in improving tree growth and reducing conflict with pavement in research trials and in practice (Smiley 2008, Grabosky and Bassuk 1995, Gilman 2006). Their relative effectiveness is influenced by the conditions present on-site and the characteristics of the tree species planted.

Figure 2 *Example of a tree root lifting and cracking a sidewalk.*

The following factors increase the potential for disturbance of pavement or curbs by trees (Randrup et al. 2001):

- Large trees
- Fast-growing species
- Shallow rooting species
- Restricted soil volumes
- Shallow topsoil with compacted soil below
- Lack of base material beneath the sidewalk
- Inadequate irrigation
- Short distances (< 2 - 3 m) between sidewalks and trees
- Trees older than 15 to 20 years

Research has shown that tree roots likely do not initiate damage to pipes and foundations but are capable of exploiting cracks or voids in below ground infrastructure. In a comprehensive 1981 study undertaken by the Royal Botanical Gardens (Kew), England over 11,000 trees and surrounding buildings were assessed. The average distance between damaged foundations and contact with tree roots ranged from 2.5 to 11 m. Tree genera selected for tight urban spaces in and around buildings should be given careful consideration as root systems extend roughly 2 to 2.5 times the width of their crowns (Hirons and Thomas 2018). Therefore, where possible a 5 to 7 m setback is recommended from building foundations for species and cultivars with medium to large crowns at maturity (Hirons and Thomas 2018).

It is possible for trees to intrude into below ground infrastructure like sewer systems, particularly when pipes are old and cracked, or if pipes are joined together with a collar. Most species of trees and some shrubs are capable of root intrusions into damaged pipes or through pipe collars, although more research is needed to determine which species are of greatest concern. Roots instead, take advantage of areas where holes or cracks exist to access resources (moisture, air, nutrients, etc.), which can result in increased damage. Therefore, planning adequate distances away from infrastructure is important to minimize conflicts. In situations where trees will be planted in trenches in and around infrastructure, providing good soil conditions so roots have access to air and water will reduce the likelihood of trees exploiting the spaces in and around pipes. Where possible, a 6 m setback from existing pipes has been recommended (Watson and Himelick 2013).

Wind

Action Item

- Identify the wind direction and potential wind effects on trees at the planting site; use the information to aid in species selections (Table 5).

Table 5 Considerations for choosing species based on wind effects at the planting site

Wind effect	Species characteristics
Protected	Weaker wood and branch attachments may be acceptable; larger crowns (if the space permits)
Not protected	Multi-stem and clumping forms, mid-sized crowns with strong branches
Wind tunnel	Multi-stem and clumping forms, smaller crown, strong branch unions, well-anchored root systems (wide and/or deeply rooted)

Trees are often planted to help reduce wind speeds. Knowing the predominant wind direction throughout the year, as well as wind speeds, will help to select appropriate species. Buildings can sometimes protect trees from strong winds, but can also create a wind tunnel effect, especially in city centres where there are many large and tall buildings (Pandya and Brotas 2014). It is important to observe the situation at each planting site (Table 5).

There are both mechanical and thermal impacts of wind on trees. Mechanical effects include leaf loss and tatter, tree shape deformation, branch breakage and abrasion from soil and/or ice particles driven by wind. Thermal effects include increased moisture loss from soil and leaves (Trowbridge and Bassuk 2004). A significant amount of research has been done on the effects of wind on trees by Dr. Gilman at the University of Florida. For more information click here.

Chapter 2 - Soil Assessment

The soil quality and quantity available to a tree at a planting site should form the basis for decision-making on species selection, site preparation and tree installation. Tree roots require soil that provides adequate access to air, water and nutrients. Some tree species can withstand periods of flooding or drought, grow in low nutrient soils or tolerate compaction. However, only selecting trees with these characteristics severely limits the choices of species that can be planted. Before tree selection begins, the basic features of the planting soil should be understood, especially for disturbed soils in urban centres, recent suburban developments or anywhere where soil removal and/or compaction has occurred. These modifications often include the complete removal of quality topsoil, severe compaction and addition of **subsoil**, fill or manufactured topsoil. In contrast, planting trees into healthy and well-structured (crumbly) soils, such as those found in undeveloped areas and older neighbourhoods, require less aftercare during establishment. How soil quality can affect tree **establishment** and growth can be understood by assessing key soil properties including **texture**, drainage, compaction, **soil organic matter** and pH.

Texture and Drainage

Action Items

- Determine soil texture based on laboratory analysis or the hand texturing method. Interpret the results based on Figure 3.
- Identify drainage characteristics of the site (poor, moderate or excessive) from drainage test in Field Sheet 2.
- Using Table 7, consider possible interventions.

Soil texture is a property influencing many other chemical, biological and physical soil properties. A primary concern when planting trees, particularly in urban settings, is how texture influences drainage and **available water-holding capacity** (Table 6).

For example, coarse soils (e.g. sand and loamy sand) tend to have good drainage, but poor water-holding and nutrient retention capacities. Fine soils (clay, silty clay), do not drain as well, but they can hold nutrients and moisture more readily. Soil texture classes are illustrated in Figure 3.

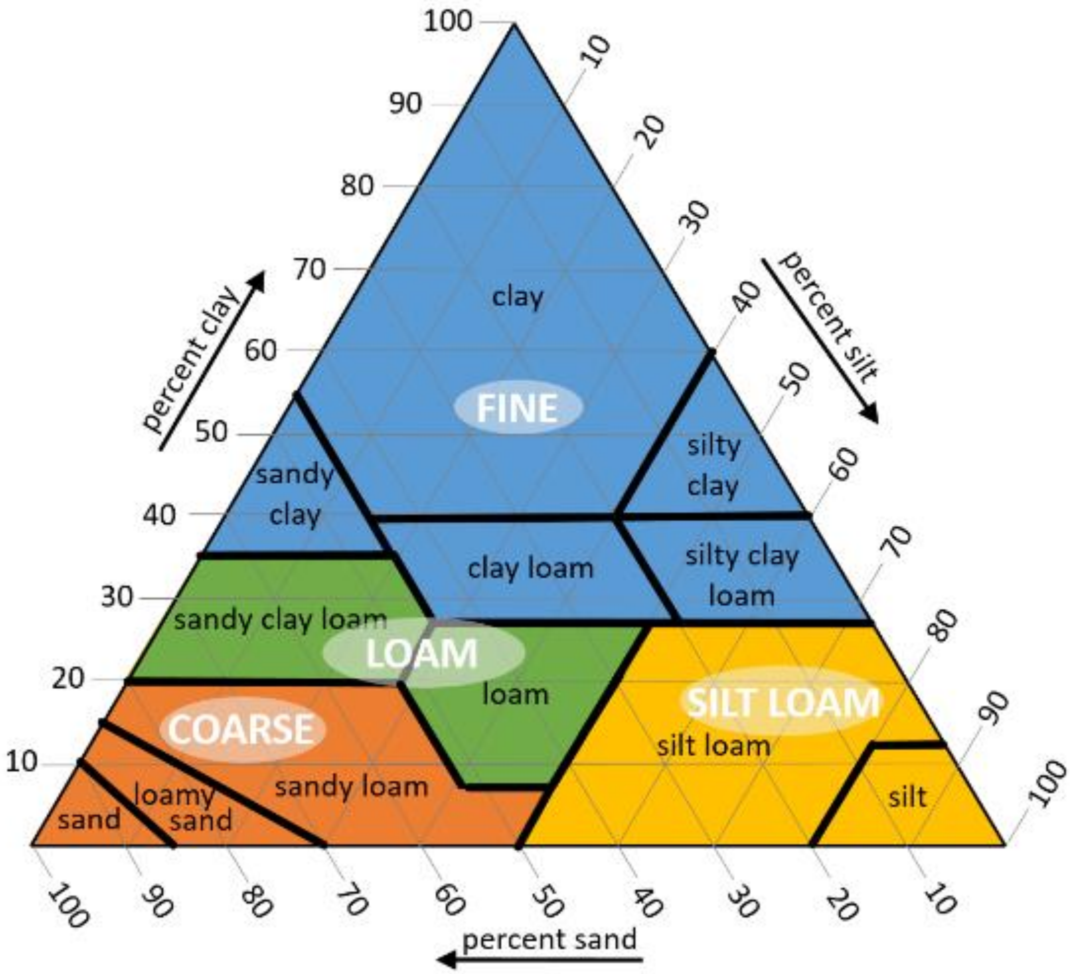

Figure 3 *Soil textural triangle and texture groupings. Source: Cornell Soil Health Program.*

Table 6 *Texture groupings from textural triangle (Figure 3) and associated key properties*

Texture grouping	Key properties
Fine	• Slow draining • Seasonal flooding • Easily compacted
Medium (which includes loam and silt loam)	• Moderate drainage • Higher available water
Coarse	• Fast draining • Low available water • Low nutrient holding capacity

Texture cannot be easily modified without large-scale removal and replacement of soil. Therefore, understanding soil texture will help identify strategies and interventions appropriate to manage water to better support tree establishment. Tree species that require well-drained soils will typically perform better in soils with higher proportions of sand.

Drainage is affected by soil texture, **soil structure**, infiltration and topography. Species that can tolerate periodic flooding are more appropriate for finer textured soils and/or where drainage is slower, in **swales**, for example. Soil aeration is also very important for tree roots. Plant roots require both water and oxygen, and overly saturated soils can significantly reduce oxygen levels. It is common for urban sites to be vulnerable to waterlogged conditions and poor aeration due to compaction. Waterlogged conditions can be as detrimental as drought conditions.

Table 7 Interpretation of drainage test (as described in Field Sheet 2; adapted from Trowbridge and Bassuk 2004)

Drainage class	Rate of water infiltration	Suggested interventions
Poor	< 10 cm/hour	• Grade the site if poor drainage is apparent in depressions • Break up the compacted soil • Follow planting instructions for poorly-drained soils (Field Sheet 6) • Regulate irrigation to avoid overwatering • Choose species adapted to wet conditions
Moderate	10 to 20 cm/hour	• None required
Excessive	> 20 cm/hour	• Incorporate organic matter • Frequently irrigate during the tree juvenility stage

Compaction

Action Items

- Refer to probing wire test compaction results from Field Sheet 2.
- Based on the compaction severity of the site soil, consult Table 8 for potential interventions.

Compaction breaks down the soil structure and subsequently restricts the movement of air, water and nutrients, while physically restricting root development. Construction activities often involve the complete removal of a **friable** high quality topsoil, the compaction of subsoil by heavy machinery and the addition of a thin layer of low quality topsoil. This type of soil will go through cycles of flooding and drought, and will provide only limited oxygen levels to tree roots. Compacted soils offer a difficult rooting environment because of their decreased pore space, both **macropores** and **micropores.**

These conditions have cascading effects on a variety of soil processes, as illustrated in Figure 4, including diminished aerobic microbial activity (e.g. **mycorrhizal fungi**), reduced nutrient mineralization and impeded soil water movement (Hirons and Thomas 2018). While some tree species have evolved physiological mechanisms and are able to tolerate some of these soil environmental conditions, there are still compaction levels at which root growth can be completely restricted (click here for more information). Soil compaction in the top 30 cm of soil is particularly detrimental as this is the most critical zone for root growth after **transplanting**.

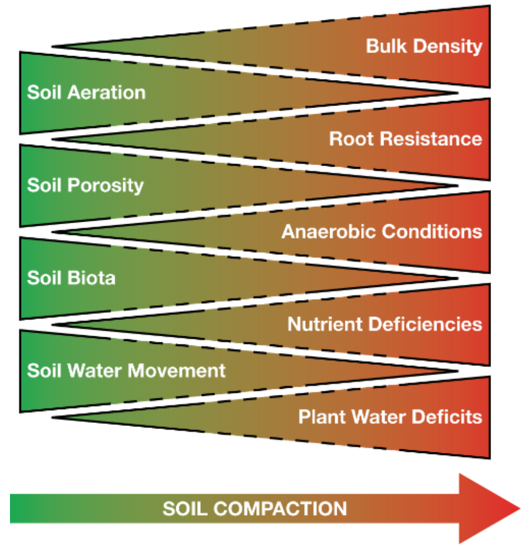

Figure 4 *Increasing or decreasing band widths indicate the likely effect of soil compaction on the soil property. Source: Hirons and Percival (2012).*

A visual site inspection for evidence of high traffic areas (e.g. equipment, foot traffic), patches of bare soil or evidence of prolonged waterlogging is a way to quickly assess the likelihood that soils have been compacted (Figure 5). Soil compaction can also be assessed using simple resistance measures, such as the 'probing wire test' (Table 8). Take a 40 to 50 cm length of high tensile wire (approximately 3 mm or 10 gauge, e.g. fence wire). Use about 10 cm to make a looped handle and attempt to push the wire into the soil. Soil moisture will influence the resistance of the soil to the wire; therefore, this test should be conducted when the soil is neither excessively wet nor dry. Refer to Field Sheet 2 – Soil Assessment to retrieve the results from your test to determine the compaction level of the planting site.

Figure 5 *Construction traffic and soil modification during construction activities can result in soil compaction, which can constrain the growth of newly planted trees. Source: Glen Lumis.*

Table 8 *Compaction levels as indicated by the probing wire test and potential interventions*

Compaction level indicated by probing wire test	Potential interventions
Severe – wire probe will not penetrate soil beyond 10 cm deep	Mechanical de-compaction (subsoil and/or backhoe method) and **organic amendments** should be used in combination (Field Sheet 4 – Site Preparation).

Moderate – wire probe will penetrate soil with difficulty 10-30 cm deep	Mechanical de-compaction and organic amendments are likely required (Field Sheet 4 – Site Preparation)
Acceptable – wire probe will penetrate soil easily to 30 cm deep and below	Follow recommended tree installation (Field Sheet 6 – Tree Installation)

Soil compaction is also commonly assessed using soil penetrometers. These instruments can be effective in estimating how dense a soil is, but are unfortunately also sensitive to soil moisture, and readings may differ on the same soil depending on whether it is wet or dry. Therefore, a penetrometer should only be used when soil is neither too wet nor too dry. Generally, readings between 0 and 1,380 kPa (0-200 psi) suggest that root growth will not be negatively affected, between 1,380 and 2,070 kPa (200-300 psi) root growth may be inhibited and when greater than 2,070 kPa (300 psi) root growth may be stopped altogether (Trowbridge and Bassuk 2004).

Compaction can also be evaluated using soil bulk density, which is the dry weight of soil in a fixed volume. Many studies have shown that high bulk density (i.e. compaction) in soils negatively influences root elongation, which in turn influences the establishment and growth of woody plants (De Lucia et al. 2013, Salifu et al. 1999, Smith et al. 1997, Zhao et al. 2010).

Soil Organic Matter

Action Items

- Review soil organic matter laboratory test results (Field Sheet 2).
- If soils have less than 5% soil organic matter, determine which interventions(s) can be used to increase soil organic matter (refer to Table 9 in Chapter 4).

Soil organic matter is composed of living microorganisms and plant residues, organic debris in various stages of decay and stabilized humus. Soil organic matter is widely understood to mediate many physical, chemical, and biological soil properties (Gregorich et al. 1994), including soil structure and **aggregation**. Soil organic matter content also exerts great impact on productivity above- and below-ground (Larney and Angers 2012). Some of these properties include water retention and infiltration, soil aeration, nutrient retention and availability, and functions of diverse assemblages of soil organisms. While plants cannot consume soil organic matter directly through their roots, the activity of **soil biota** make nutrients within organic matter available over time.

Soil organic matter ranges have been established in agricultural soils to describe the provision of several soil functions and associated benefits for crop production (e.g. the Cornell **soil health** test; Loveland and Webb 2003). However, there is less information on critical soil organic matter thresholds for landscape tree growth and establishment in urban soils (Oldfield et al. 2014). Research has demonstrated that by increasing soil organic matter to certain levels in urban soils, bulk density is decreased, thereby reducing compaction and improving tree growth (Oldfield et al. 2014, McGrath and Henry 2016). Scharenbroch et al. (2005) found that younger (recently landscaped) urban soils were deficient in macro-nutrients (nitrogen, phosphorus and potassium) because of soil disturbances that occurred during construction. The availability of soil nutrients in urban sites is directly related to the amount and quality of organic matter available in the soil as well as the soil texture. Compost-based soil amendments and surface **mulch** applications can increase organic matter content and available nutrients over time (Scharenbroch 2009).

pH

Action Items

- Review soil pH laboratory test results.
- Use Figure 6 to help identify potential pH-related nutrient deficiencies that may affect tree growth and health.

Soil pH refers to the level of acidity or alkalinity of the soil and influences the availability of various macro- and micro-nutrients necessary for tree growth. There are fourteen **essential nutrients** found in plants. The relative concentrations of different nutrients in plants are classified as macro-nutrients (required in higher concentrations) and micro-nutrients (required in smaller concentrations). Essential macro-nutrients are nitrogen, potassium, phosphorus, calcium, magnesium and sulfur and essential micro-nutrients include chlorine, boron, iron, manganese, zinc, copper, nickel and molybdenum.

Soils are considered acidic below 7.0 and alkaline above 7.0. The majority of nutrients are best absorbed by plants somewhere between a pH of 5.5 and 7.5. However, soil pH in urban settings can often be higher than 7.5 due to leaching of alkaline substances from concrete-based materials such as sidewalks, roads, and other infrastructure. In much of southern Ontario, soils have an inherently high pH because of the widespread presence of underlying limestone. Due to the alkalinity of many urban soils, **chlorosis** can affect certain tree species that grow best at a pH below 7.0.

Due to the difficulty of modifying soil pH, tree selection should reflect the pH tolerances of different tree species. An extremely acid or alkaline soil can indicate contamination, which may preclude the planting of trees, necessitate the use of a limited number of

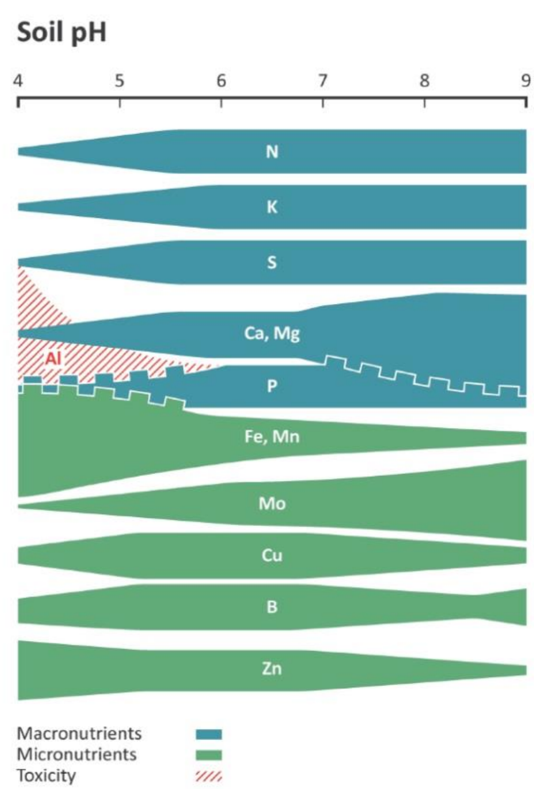

Figure 6 *(Right) The influence of soil pH on nutrient availability. Increasing and decreasing band widths indicate relative availability of nutrients to trees. Blocking on margins indicates where nutrients become unavailable. Source: Hirons and Thomas (2018).*

species or require remediation. If soil contamination is suspected, contact the Ontario Ministry of the Environment, Conservation and Parks. An understanding of previous activities on the site can be gained through soil analysis and/or an examination of records.

Soil Volume

Action Item

- Estimate useable soil volume for each tree planting location.

Figure 7 Rooting space impacts tree crown growth in a parking lot in Gelsenkirchen, Germany. Trees at the edge of the parking lot have access to a greater soil volume resulting in greater growth than the trees located within the parking lot. © Johan Östberg.

Soil volume is another critical factor influencing tree performance. It should be kept in mind that a seemingly large soil volume may not all be usable by tree roots if the soil is very compact. The amount of water available to a tree is limited by the volume of soil to which it has access. Trees growing in restricted soil volumes in urban environments often require ongoing irrigation past juvenility.

Estimating soil volume is most relevant in high density urban settings where tree root systems commonly reach the limits of a provided volume, resulting in slowed **crown** growth (Figure 7), water stress and greater susceptibility to high winds, pests and diseases (Watson and Himelick 2013). The size of the root system at maturity should be taken into consideration when planning tree placement. New technologies (e.g. **structural soil**, permeable pavement, modular soil cell structures) have been developed to help increase the amount of usable soil within restricted soil volumes.

Chapter 3 - Finalizing Tree Selection

The objective of this chapter is to aid in finalizing tree selections after environmental conditions and soil quality and quantity have been assessed (Chapters 1 and 2). Site assessments identify the most pertinent factors (climate, light levels, soil quality, salt levels, infrastructure, etc.) that will impact species selection. Other factors in this chapter deserving consideration include: mature tree size, growth rate and longevity, as well as environmental benefits, pest and disease vulnerabilities, native growing conditions, plant origin, invasion potential, diversity requirements, ornamental qualities and planning for climate change.

Tree Species Selection

Action Items

- Use key resources (in the box below) and research highlights in this chapter to understand criteria for tree species selection.
- Select tree species using information from Chapters 1 and 2, the information below and from Field Sheets 1 and 2.

greeningcanadianlandscape.ca – Launched in 2018, Vineland Research and Innovation Centre developed the Greening the Canadian Landscape website, based on an extensive literature review and synthesis of current research and extension information. It is meant to aid in the design of plantings in urban, suburban and natural settings. It offers a tree species selector with over 200 species for use in Ontario. Unique to the website is a soil remediation calculator that enables users to input information from a basic soil test and receive recommendations on how to restore degraded soil.

woodyplants.cals.cornell.edu/home – The Woody Plants Database is an excellent resource for northeastern North America developed at Cornell University, through the School of Integrative Plant Science and the Department of Landscape Architecture. It includes an extensive database for selecting trees, shrubs, groundcovers and vines based on site conditions. The focus of the website is on matching environmental tolerances of species to planting sites.

tdag.org.uk/species-selection-for-green-infrastructure.html –Tree Species Selection for Green Infrastructure – A Guide for Specifiers is a 2019 publication produced by researchers in the United Kingdom and Sweden. It provides background information on the principles of site assessment and tree selection for enhancing green infrastructure. The interactive guide contains a database of 280 species with a focus on selections for Europe but much of its content is still applicable to Ontario and Canada. The guide offers a rigorous assessment of species' environmental tolerances and includes information on species' natural habitats, ornamental qualities and potential management issues.

Research Highlights

Cold Acclimation

The origin of the genetic material, the location where trees were grown and whether the species is marginally hardy to the planting zone may further inform tree selections. If trees are not able to adapt physiologically and become hardy quickly enough in autumn, or lose cold hardiness too quickly in the spring, tree dieback or mortality can occur. Trees that are not adequately adapted can experience freezing stress resulting in increased incidence of disease. Root damage from extreme cold is influenced by several factors such as soil temperature in the root zone, depth of freezing, soil moisture levels, depth of snow cover and duration of extreme low temperatures. Species variations in terms of below-ground tissue hardiness differ widely (e.g. ornamental trees in northern temperate regions that experience root killing temperatures between -5°C and -23°C. Tree age also plays a role in root hardiness, where older lignified roots can be as much as 11°C more cold hardy than younger non-lignified ones (Watson and Himelick 2013).

Native Growing Conditions/Habitat

Tree species have evolved to adapt to environmental conditions unique to their native habitats. Globally, differences in temperatures, soil types, precipitation, seasonality, winds and competition from plants and herbivorous animals have produced an abundance of species adaptations and environmental tolerances. While some understorey humid forest species may have only a minimal tolerance to drought and highly exposed conditions (e.g. *Acer pensylvanicum* [striped maple]), other species can compete with other fast-growing plants in open landscapes (e.g. *Populus tremuloides* [trembling aspen]). Although most forest ecosystems represent a drastically different environment compared to settled landscapes, understanding the natural environment in which species have evolved can help inform the selection process.

Native and Non-Native Species

A growing movement toward preferential planting of native trees in urban landscapes is exerting greater influence on tree selections. This movement has been driven by environmental concerns around wildlife habitat loss, pollinator health and the increasing spread and negative impacts of certain non-native, invasive species. There is substantial literature examining various aspects of plant origin, which is beyond the scope of this guide. When selecting species for specific planting site conditions such as restricted soil volumes or high pH, tree environmental tolerances will largely determine the success of the planting, regardless of the native origin of the tree. Because native trees have evolved in this region does not necessarily mean they are better adapted to urban conditions in Ontario compared to non-native trees. Although native trees have evolved, broadly speaking, to the climatic conditions across Ontario, urban environments can be drastically different from those natural environments.

Invasiveness and Invasive Potential

There is a great deal of interpretation of the term 'invasive', as well as the invasive potential of different tree species. It is important to understand which tree species are currently considered invasive in a region, in addition to which species have been identified as potentially invasive. Botanical gardens can be good resources for information on unfamiliar species. They often have a first glimpse into the potentially invasive characteristics of introduced species due to their large collections of diverse tree species from around the world. The Canadian Botanical Conservation Network curates a list of invasive plants, which can be found here. It is especially important to consider the invasiveness of non-native tree selections if planting sites are located close to any natural areas. The provincial government's Invasive Species in Ontario webpage provides links to relevant resources.

Cultivars

Cultivars are propagated from an original selection, meaning all propagated individuals are genetically identical within the cultivar. Therefore, tree performance and ornamental qualities will remain relatively consistent and reliable. Many cultivars provide targeted modifications to either tree performance (pH tolerance, cold hardiness, drought tolerance, pest and disease resistance, etc.) or appearance (size, shape, leaf colour, etc.). It is important to understand that most cultivars are not rigorously tested against improvement claims in tree performance. Attributes such as tree shape, size and fall colour can be observed relatively easily but traits such as drought tolerance and cold hardiness require extensive testing for validation. While cultivars offer many benefits, their limitations often revolve around a lack of genetic diversity. For instance, overplanting one cultivar offers less genetic diversity than overplanting a single species grown from seed.

Biodiversity

The diversity of forest tree species varies enormously within Ontario, from the most tree species-rich ecotype in Canada represented by southern Ontario's Carolinian forest (about seventy tree species), to the species-poor boreal forest (about twenty tree species). In Ontario, a colder climate typically limits the number of tree species that can grow farther north. In comparison to natural forest ecosystems, urban forests tend to be, on average, more diverse, at least in terms of species richness (number of species). Much of this diversity can be attributed to the many wide-ranging species (native and non-native) and cultivars of ornamental trees planted on private property. Although species richness is high in urban environments, typical urban forests are still dominated, population-wise, by a few individual species and cultivars (e.g. *Acer platanoides* [Norway maple], *Gleditsia triacanthos* [honey locust]).

In recent years, the interest in increasing tree diversity has been gaining momentum and is reflected in urban forest management plans. This practice aims to hedge against the potential for widespread and rapid tree mortality that may occur in the event of the introduction of a destructive pest or disease (e.g. Dutch elm disease and emerald ash borer). Although species diversity is important, diversity at the genus or family level can be more important in reducing the vulnerability to pests and diseases. A common rule of thumb for achieving a target diversity level suggests planting no more than 10 per cent of any species, 20 per cent of any genus or 30 per cent of any family (Santamour 1990) within an area. Although many municipalities have not achieved this level of diversification, work toward this goal should include conducting an inventory of existing trees and employing evidence-based processes for introducing new or underutilized selections. Of course, choosing species should always be based on above- and below-ground site conditions (Chapters 1 and 2).

Pests and Diseases

As a result of global trade, the frequent introduction of new pests and diseases is becoming a contemporary reality. Several tree species/genera in Ontario have already succumbed to these introductions: *Castanea dentata* (American chestnuts) from chestnut blight, *Juglans cinerea* (butternuts) from butternut canker, *Ulmus* (elms) from Dutch elm disease and, most recently, *Fraxinus* (ashes) from the emerald ash borer. Emerging pests and diseases of concern in Ontario include: Asian long-horned beetle (Figure 8), oak wilt, sudden oak death, beech bark disease and the hemlock woolly adelgid. For detailed information on invasive plant pests and diseases, visit the Canadian Food Inspection Agency website.

Figure 8 *Asian long-horned beetles present a major threat to Ontario's urban and natural forests. Source: Bruce Gill.*

Less serious but common pests and diseases for ornamental trees include: anthracnose (many species), verticillium wilt (many species), two-lined chestnut borer (*Quercus* spp. [oaks] and *Castanea* spp. [chestnuts]), black knot (*Prunus* spp. [cherries]), leaf blotch, fire blight, tent caterpillar and canker. Some species are generally more susceptible to a range of pests and diseases and are often short-lived. When stressed (e.g. drought stress), most trees become more vulnerable to a variety of pests and diseases. Although a detailed discussion is beyond the scope of this guide, useful Ontario-based resources include the Ontario Nursery Crops website maintained by the Ontario Ministry of Agriculture, Food and Rural Affairs and the recently developed BugFinder app.

Cultivars can be developed with enhanced pest and/or disease resistance. New cultivars often stem from the observation of an individual tree of a certain species that exhibits either less severe or an absence of symptoms to serious pests and/or diseases. Species can also be hybridized which can impart some resistance to the resulting hybrid. For example, research and breeding is being carried out to develop cultivars and hybrids of elm trees resistant to Dutch elm disease. Many such hybrids and cultivars have been released in recent years with varying levels of success.

Environmental Benefits

Planting trees can restore environmental functions such as habitat provision, storm water management and shading or cooling. Resources are available to help estimate the type and amount of benefits gained through tree planting and different tree selections. The fundamental concept underpinning these resources is that trees need to become established, grow to a large size and tolerate the environmental conditions present at the planting site in order to provide significant environmental benefits.

Green Infrastructure Ontario Coalition – The Green Infrastructure Ontario Coalition is comprised of many organizations with the shared goal of helping Ontario realize the full range of economic, social and environmental benefits of green infrastructure.

i-Tree – The United States Department of Agriculture and Forest Service has developed the now widely used i-Tree program. There is a suite of i-Tree tools available related to understanding and valuing environmental and economic benefits provided by trees. These include tools for forests, as well as large and small tree planting projects, including individual trees.

i-Tree Species – i-Tree Species helps planners select from a range of species that will provide varying degrees of environmental services based on geographic location and tree size. It helps calculate the effectiveness of different trees in: air pollution removal, air temperature, wind and ultraviolet radiation reduction, carbon storage, pollen allergenicity, building energy conservation and storm water management.

Conservation Ontario – Conservation Ontario represents Ontario's 36 conservation authorities, which are community-based agencies responsible for watershed management. They are mandated to ensure the water- and land-based natural habitats present within their watersheds are protected, through conservation, restoration and responsible management. When planning a naturalization planting, it is important to consider how naturalization can be achieved economically and re-establish ecological integrity. Ontario's conservation authorities are some of the main coordinators of such plantings and provide access to information and funding for eligible landowners.

Every tree planted may host a wide range of insect herbivores and pollinators, as well as provide nesting habitat and food. There is an abundance of information on the palatability of foliage for different herbivores. Consult your local extension office, crop specialist or conservation authority for information on species that can provide good quality habitat or specific recommendations for how to restore habitat for at-risk species.

Ornamental Qualities

It is not the place of this guide to delve into the aesthetic principles of landscape design. The visual appeal of different trees will vary from person-to-person and is likely the most subjective aspect of tree selection. It is important that the ornamental qualities of a tree are envisioned at maturity, as **crown** size and form, leaf density, branching and much of the visual appearance of a tree will become most noticeable once larger. Planting site environmental conditions dictate the vast majority of limitations during the selection process. There are often multiple choices of commercially available species or cultivars that provide certain ornamental qualities. Work with a landscape architect or designer to help make aesthetic decisions or use resources that help select visually compatible trees.

Precipitation and Irrigation Requirements

During the **establishment** period, all trees are susceptible to water stress because most have lost substantial root mass before transplant (i.e. field-dug trees) and/or are experiencing **transplant shock**. Additionally, for container trees, growing media used in the nursery (usually peat and compost bark-based mixes) are prone to drying after planting. For these reasons, all large trees are recommended to receive at least some irrigation after planting. Aside from these issues are species' natural tolerances and strategies to contend with a lack of available water. Because water availability is critical to the physiological processes of all plants, it is often considered the most important characteristic after cold hardiness when selecting appropriate material for a project. Also, precipitation levels that may be sufficient for trees in open or natural settings may not provide enough moisture where soil volume is limited, soil quality is poor or pavement reduces water infiltration (Hirons and Sjöman 2019). The heat island effect in built-up areas, as well as micro-climatic considerations such as wind tunnels, may also demand improved drought- and heat-tolerant selections.

Expected Maintenance

Regular branch pruning may be required if trees are planted too close to utility power lines. However, if trees are planted directly underneath utility lines, improper practices such as topping are sometimes employed, which have detrimental effects on tree health (Figure 9). Low branched trees planted near pedestrian walkways will need to be pruned for clearance. Trees that drop large, messy or otherwise undesirable fruit, or are prone to branch breakage, should be avoided near high-traffic public areas.

Figure 9 *Trees planted too closely to utility wires are at risk of severe pruning or removal. Trees in the photo above were topped to avoid conflicts with the overhead utility wires.*

Typically, branch breakage is a concern during episodes of high wind or ice/snow storms. However, certain trees are prone to dropping branches readily (e.g. poplars, willows, silver maples), which poses a significant public safety risk and potential costs associated with utility power line damage. Branching that results in narrow angled branch unions with **included bark** tends to be more vulnerable to breaking.

Future Climate Scenarios

Trees must be cold hardy to their planting locations and also able to thrive in normal summer temperatures. Cold hardiness and heat tolerance are particularly important for long-lived trees that will experience a changing climate. Climate change scenarios include predictions of increased temperature, increased frequency and intensity of storms, cold snaps and heat waves. Scientists at Natural Resources Canada have produced a series of species-specific models and maps for plants, including many tree species. These species have been mapped in order to estimate ranges in which they are hardy in current and future climate conditions (NRCan 2017). Many tree species in Ontario are predicted to expand their northern-most ranges (McKenney et al. 2007) due to forecasted increases in precipitation and temperature (Eskelin et al. 2011).

Chapter 4 - Site Preparation

When soil on-site is compacted (according to the probing wire test, Table 8 in Chapter 2) and/or organic matter is less than five per cent, soil preparation may be necessary. Locates must be acquired and set-backs followed. Depending on budget and access to equipment, methods for loosening soil can vary. This chapter will outline several techniques that can alleviate compacted soil on all types of sites.

Action Items

- Ensure locates are completed and set-backs are followed prior to site preparation.
- If using one or more of the site preparation methods, use Field Sheet 4 and the information below to provide guidance.

Based on the soil assessment (Chapter 2 and Field Sheet 2), determine if site preparation is necessary:

- Determine if mechanical de-compaction is required.
- Determine whether amendments are required.
- If the existing soil on-site is not adequate to support tree growth or is specified for replacement, then refer to the information on installing imported manufactured soil at the end of this chapter.

Mechanical De-compaction

Compaction can lead to a breakdown of **soil structure**, leading to reduced soil **aggregation**, aeration and water infiltration. While root growth, **soil biota** and frost action can improve soil aggregation and counteract compaction over time (Jackson 2014), if compaction is severe on a planting site, several de-compaction methods may be used. Depending on soil conditions, when a combination of soil de-compaction and **organic amendment** incorporation are used, tree establishment and growth rate increases have been demonstrated (Layman et al. 2016, McGrath and Henry 2016, Oldfield et al. 2015).

Subsoiling


Figure 10 *An excavator with a ripping tine is effective for subsoiling compacted soils on larger sites.*

Subsoiling is a well-researched method for de-compacting soil (Andrus and Froehlich 1983, Kolka and Smidt 2004, Rolf 1991). It involves the use of heavy equipment capable of pulling chisels or tines through the soil (Figure 10). Due to the size of the equipment needed, subsoiling is generally suited to preparing multi-tree beds on medium and large planting sites with limited underground utilities. Additionally, subsoiling is often limited to flat, gentle and moderate slopes. The USDA Forest Service (2008a) recommends subsoiling 5 cm below the deepest layer of compaction. In urban landscapes, soils are typically compacted to depths greater than 50 cm. Therefore, subsoiling to a depth of 60 to 90 cm is preferred. Subsoiling to this depth helps ensure water can drain past the root balls of newly planted trees. It is also important in avoiding the creation of a perched water table when topsoil or other amendments are added to a site. Perched water tables occur when **subsoil** is impermeable and water becomes trapped above that layer, creating waterlogged conditions. Subsoiling helps create space for air and water to move downwards in the soil and helps blend the artificially distinct layers common in urban soil.

Backhoe Turning Method

The Backhoe Method also called Soil Profile Rebuilding is another soil preparation process and involves applying organic amendment and using an excavator bucket to scoop native soil and amendment (Day 2016). The operator then tips the bucket and lets it fall. This action breaks up compacted soil and creates veins of amendment deeper within the soil profile. Research has shown that soil profile rebuilding improves tree growth and reduces soil bulk density as compared to conventional topsoil application methods (Layman et al. 2016). Backhoe turning is a technique suitable for small to medium-sized sites.

Surface De-compaction

Small to medium, light-duty tools like chisel plows, rotary spaders (Figure 11), agricultural rototillers and vibrating subsoilers can be used when compaction layers are shallow or when underground utilities are close to the surface. When deeper soil layers are compacted, small to medium-sized tools will only scarify the uppermost surface of the soil (USDA 2008a).

Other implements, like agricultural rippers or tillers often reach only a depth of approximately 15 cm, although disc blades and rotary spading implements can cultivate deeper. In cases where deeper soil loosening methods (e.g. subsoiling or backhoe) are used, some kind of surface cultivation is often required to level the soil surface and can be used to incorporate organic amendments. For more information, click here.

Figure 11 Surface de-compaction and incorporating organic amendment can be accomplished with different agricultural implements. Pictured above is a PTO-driven rotary spader (a type of spade tiller).

Research studies have demonstrated the benefits of subsoiling, tilling and backhoe turning for tree growth in compacted soil (Layman et al. 2016, McGrath et al. 2016, Somerville et al. 2018, Sinnett et al. 2008). Specifically, the subsoiling method has been found to improve tree growth more effectively when municipal compost was also incorporated into the soil to a depth of 30 cm using a spading implement following subsoiling (McGrath and Henry 2016). Improved tree growth was attributed to decreased soil compaction, increased organic matter content, nutrient availability and water holding capacity.

Radial trenching is a technique that is most commonly used for established trees to provide roots access to loosened soil (Watson et al. 1996, Watson 2002, Figure 12). Radial trenches are channels of loosened soil that are dug to expand root-able area outside the planting hole. Trenches should be filled with loosened soil, ideally mixed with a suitable organic amendment. Although this method is typically used for mature trees where roots are already established, it can be used on smaller sites where the use of large equipment for mechanical de-compaction is not possible. Another technique that is meant for established trees but is suitable for new planting on small sites is **vertical mulching** which uses air cultivation to reduce compacted soil. It can be used around existing trees or closer to building foundations or roads. Vertical mulching uses compressed air to drill large holes or excavate segments in compacted soils around trees and backfill with organic amendment. Research findings on this method have been mixed (Watson et al. 2014). Research on *Pterocarya stenoptera* (Chinese wingnut) and *Acer saccharum* (sugar maple) revealed no benefit when using vertical mulching (Pittenger and

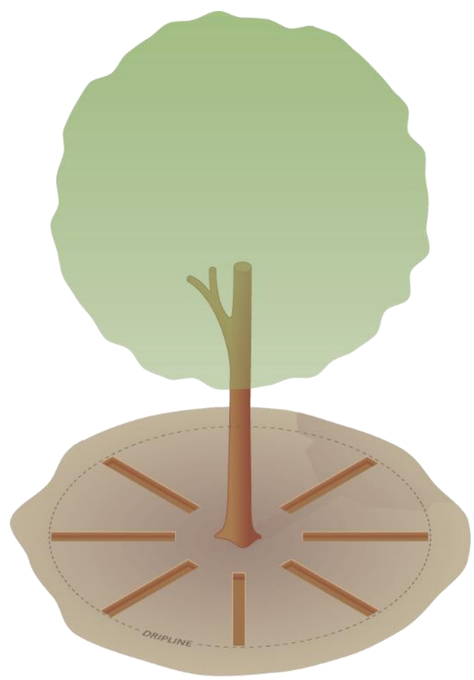

Figure 12 In existing plantings or for new plantings where there is limited space to bring in equipment, radial trenching can be used to reduce compaction and increase organic matter. Radial trenching involves using air tools to excavate channels to the projected dripline and backfilling with mulch or other organic amendments. Source: Hirons and Thomas (2018).

Stamen 1990, Kalisz et al. 1994). Other studies found increased root growth in *Pinus radiata* (Monterey pine), *Tilia platyphyllos* (large leaf linden) and *Platanus* x *acerifolia* (planetree) trees (Nambiar and Sands 1992, Sheriff and Nambiar 1995, Watson et al. 1996).

Other Techniques for Improving Drainage

When soils cannot be significantly modified or replaced it may be necessary to install a drainage system. A subsurface tile drain can be installed by placing a corrugated pipe (with perforations all around) into the centre of a trench approximately 30 cm wide and 25 cm deep (Smiley n.d.). The pipe should be surrounded by coarse sand and be placed on a downhill slope to an appropriate drainage area. Vertical drains, which are auger holes filled with gravel, are another solution to allow water to drain below the root zone. Strip drains can also be used for vertical drainage
(Urban 2008).

Soil Amendments

There are many different soil amendment options available to be used in preparing planting beds, ranging from commonly used ones such as compost and sand, to less well-known ones such as lava sand. Generally, organic amendments are the most effective in improving a wide range of soil conditions during site preparation before planting. The following sections briefly summarize types of organic and mineral amendments, with an emphasis on organic amendments due to their ability to modify soil chemical, physical and biological properties. Organic amendments are composed of (typically composted) plant and animal residues and other organic wastes. Mineral amendments are natural or processed materials used to modify **soil texture,** most commonly to improve drainage (Urban 2008). Depending on the on-site soil conditions, it may be advisable to use a combination of organic and mineral amendments to achieve the desired soil conditions.

Organic Amendments

Urban soils typically lack adequate organic matter. If the planting soil has less than 5 per cent organic matter, it is strongly recommended to add some type of organic amendment and preparing a planting area but adding organic amendment into planting holes is not recommended. Studies have evaluated different organic amendments (compost, **mulch**, biochar and biosolids) as well as methods and rates of application and their effect on tree response, soil properties and the environment (Olson et al. 2013, Larney and Angers 2012, Layman et al. 2016, Sparke et al. 2011). Table 9 outlines a number of organic amendments that may be used for tree planting. Different techniques are used to apply organic amendments, depending on the project requirements. For instance, if aftercare will be provided on an on-going basis, regular additions of mulch and compost can be surface applied. If less aftercare is expected, then a one-time incorporation (excluding mulch, which should always be surface applied) of organic amendment before planting may be more practical.

Table 9 Summary of benefits and limitations of organic amendments for landscaping

Organic amendment type	Benefits	Limitations
Compost	• Widely available • Improves soil fertility • Improves soil structure • Improves moisture retention • Microbially active	• Variability by feedstock and among batches • Weed seeds may be present
Organic mulches	• Widely available • Improves moisture retention • Improves soil structure • Slow release of nutrients • Can be inexpensive	• Should not be incorporated into soil due to high carbon to nitrogen ratio
Biochar	• Improves moisture and nutrient retention • Stable and persistent	• Expensive • Limited availability • May not apply uniformly and can be dusty
Bio-solids	• Can improve soil structure through additions of organic matter • Source of nutrients • Can improve moisture retention • Inexpensive	• Controversial due to mixed public perception • Concerns around presence of pathogens and/or metals • Lack of landscape-grade products

Composting is defined as a natural process through which organic material is converted into a soil-like product or humus. The process works with the help of microorganisms such as bacteria and fungi combined with air and moisture. High quality compost products contain diverse and abundant microbial communities (such as bacteria and fungi), as well as active microbial food sources. The combination of organic matter and microorganisms in compost can be important catalysts for improving plant available water and soil aeration and increasing nutrient levels and cycling. Initially, the incorporation of organic amendment can reduce soil bulk densities simply due to the lower weight per volume of organic material (Khaleel et al. 1981). High lignin, bark-based composts, as well as yard waste compost are two of the most common and suitable products for trees (Urban 2008).

A quick way to assess compost quality is through a visual and odour assessment. High quality compost should have a dark brown to black colour and an earthy smell. For more information on compost quality, ask the provider for the compost analytics which will provide information on important chemical, biological and physical characteristics of the compost. Key characteristics include: maturity, soluble salts, organic matter, carbon to nitrogen ratio, pH, trace metal content, nutrient content, weed seed and soil pathogens. Compost properties can vary widely, however, within Ontario compost quality should be checked against the established standards. Click here for more information.

Compost maturity is very important because if the composting process is not completed yet and compost is immature, the composting process will re-initiate after application on-site. This occurrence can raise soil temperatures and immobilize nutrients. Maturity is tested by the Solvita maturity index, which monitors the respiration of microorganisms. Soluble salt levels are a good indicator of nutrient levels in compost, however, if salt levels are too high they can be detrimental to trees. Soluble salt levels can be measured with **electrical conductivity** (Sæbø and Ferrini 2006). Carbon to nitrogen ratios are also important because they indicate how quickly nutrients are made available from compost. Ideal ranges for trees are between 15 and 25 per cent (Sæbø and Ferrini 2006, Urban 2008). Recommended pH ranges for compost are between 5.5 and 8.0 but should be close to the pH of the soil on-site.

Organic mulches are composed of various plant materials, most commonly bark and wood chips, which are used for landscape trees. When considering organic mulches as an amendment, research has demonstrated that regular topdressing of organic mulch can improve soil properties and tree growth (Chalker-Scott 2007, Scharenbroch and Watson 2014). Mulches should not be incorporated into soil due to their high carbon to nitrogen ratios. They do not decompose as quickly as most composts and can immobilize nitrogen if incorporated.

Biochar is a high carbon-content, stable product derived from organic material that is heated in the absence of oxygen. It is another organic amendment that has generated an interest for improving soil properties such as nutrient and water retention and is stable and can persist in the soil. Most research has focused on agricultural applications, however, interest is growing in testing tree response in forest restoration and urban tree plantings. Findings have indicated a significant potential for positive growth response when using biochar, with a greater effect in tropical and boreal systems than in temperate ones (Thomas and Gale 2015). Furthermore, scientific studies have shown much variability in tree growth response, although few field studies have been conducted. The properties of biochar vary greatly depending on feedstock and production processes, which may account for differing results (Thomas and Gale 2015). Biochar is expensive in comparison to other amendments and is not as widely available, thus limiting its use on a broad scale.

Biosolids are the nutrient-rich organic materials derived from the treatment of sewage sludge and other wastewater (e.g. pulp and paper residuals) and have been used in the reclamation of agricultural, forest and disturbed lands. Biosolids can increase soil fertility and improve soil physical properties. Scharenbroch et al. (2013) found that applying biosolids to an urban tree planting site increased the available nitrogen, microbial respiration and tree growth. Depending on how biosolids are treated, pH values may differ substantially, so it is important to ask for available analytics or do additional testing before use in the landscape. The Ministry of Environment, Conservation and Parks regulates the use of biosolids in Ontario.

Although peat moss is widely used as a potting medium ingredient in the nursery sector, it is not recommended as a soil amendment in the landscape. Peat tends to shrink when it dries and causes soil settling as it decomposes. It can also resist re-wetting once it dries and is costly.

Mineral Amendments

Mineral amendments offer a lasting impact on soil modification – usually through improved drainage. Sand is frequently incorporated into soil and manufactured soil based on specifications to improve drainage, although only large amounts of coarse sand (greater than 50 per cent by volume) will have a significant impact in fine textured soils (Urban 2008). Sand that is surface applied is not effective for improving drainage and can erode. Other mineral amendments include expanded shale, clay and slate (ESCS), calcine clay, lava sand, among many others, depending on local availability. Although there are many products available, very little research has evaluated the effectiveness of most products (Sloan et al. 2012). Therefore, cautious use of these amendments is advised as the research on their efficacy is rather limited and they can influence soil pH.

Imported Manufactured Soil

Imported manufactured soil should be used when planting trees in a city setting and when the existing soil will not support plant growth and will need to be replaced. It can be comprised of mineral and organic soil components, as well as speciality materials that are mixed to obtain soil properties necessary for tree growth (refer to Chapter 2). There are two basic categories of imported manufactured soil. **Soil blends** can be used in combination with structures that support hardscapes (e.g. modular load-bearing plastic structures, Figure 13) and in any other circumstance where soil is replaced (Table 10).

Figure 13 *Installation of DeepRoot Green Infrastructure Silva Cells. Source: DeepRoot.*

Structural soil is composed of a mixture of angular crushed stone and soil (including both mineral and organic content) that resists compaction while providing pore space for root penetration (Table 10). Structural soil was developed as an alternative to compacted soil required to bear the weight of paved infrastructure in urban areas (Smiley et al. 2006). The soil occupying the space between the stones in structural soil is non-compacted, which allows for air exchange, water holding and root growth. When using structural soil, it is important to pay attention to nutrient requirements of the tree species selected because it has a limited ability to provide and retain nutrients compared to soil blends (Smiley et al. 2006). There are different proprietary structural soils, perhaps the most well-known being the product created by Cornell University known as CU Structural Soil®, which has been well-researched (Grabosky and Bassuk 1995, Grabosky et al. 1998, Grabosky et al. 2002).

Table 10 Overview of general properties and recommended uses for manufactured soil

Type of manufactured soil	General properties	Recommended uses
Soil blends	• Mixed to meet specifications or requirements • Designed to improve drainage • Can have high organic matter content (improved nutrient availability and **porosity**) • Organic matter added to blends should not be greater than 10 to 15 per cent by volume • Should have low salinity • Recommended soil texture is sandy loam (greater than 50 per cent medium or coarse sand)	• Tree planting in urban settings where native soil is absent or of poor quality • In conjunction with structures that support hardscapes (e.g. modular load-bearing plastic structures)
Structural soil	• Comprised of highly angular graded crushed stone, clay loam and **hydrogel** • Creates accessible soil volume and pore space for water, air and root growth • Prevents settling and subsidence under pavement • Nutrient deficiencies may arise for certain species	• To create expanded soil volumes under pavements • Choose species adapted to nutrient-poor conditions

Chapter 5 - Tree Procurement, Transport, On-site Inspection and Handling

Individual growers may use different production techniques to improve tree quality. It is helpful to ask production-related questions and become familiar with a nursery's practices. This helps ensure the correct production type is chosen for a project and that quality production strategies are employed.

> Action Item
>
> - Get to know the nursery and how they produce their trees. Use this chapter and Field Sheet 3 for additional guidance.

Selecting trees grown in a nursery relatively close to the planting site increases the likelihood that they are adapted to the local climate. The source of the rootstock for grafted trees is not always known, however, material should be purchased from a hardiness zone similar to (or lower than) the planting site.

Whenever possible, visit the nursery where the trees will be purchased. Inspecting and selecting trees (i.e. 'tagging') at the nursery help ensure that quality trees arrive at the job-site, minimizing the amount of rejected material. Select quality trees by assessing both the **crown** and the roots, to the extent that it is possible. If appropriate or required, mark a specific side of the trees so that they can be planted in the same orientation as in the nursery. This being said, little research substantiates the importance of trunk orientation at planting. Trees produced in nurseries should meet or exceed certain basic standards. The Canadian Nursery Stock Standard provides minimum guidelines for nursery trees. All trees purchased for planting should be:

- True to name, type and form
- Representative of the quality of their species or **cultivar**
- Healthy and undamaged
- Free from all pests, including pernicious weeds, insects and diseases
- Well-formed with roots and a crown that will not restrict growth or impede the life of the tree

Types of Nursery Stock

There are three main nursery production methods: **bare root**, trees with a soil ball (e.g. **balled and burlapped**, machine dug into wire baskets) and **container-grown** trees (including above- and below-ground **pot-in-pot systems**).

Action Items

- Using a site assessment (Chapters 1 and 2, and Field Sheet 1) and planting specifications, select stock type appropriate for the planting.
- Where first choices are not available, work with the nursery to make suitable substitutions.

To ensure the successful **establishment** of planted trees, proper site assessment (above- and below-ground) and species selection should be followed by an evaluation of nursery production types (Table 11) and quality. Suitable trees should be selected based on specific levels of aftercare (e.g. irrigation, **mulching**, weed control) envisioned, which will help dictate the correct stock size, root ball characteristics and production methods (Gilman and Sadowski 2007). For plantings in high quality, well-drained and irrigated soil, any production type (bare root, soil ball and container-grown) should perform well. However, when irrigation is limited or absent, and/or soil quality is poor, choosing the appropriate production type for the site is important (Gilman and Sadowski 2007).

Table 11 Common nursery production systems and their benefits and limitations

Nursery production system	Benefits	Limitations
Bare root	• Cost-effective • Easy to move and handle on-site • Circling roots are not common and can be seen and easily corrected • Strong lateral root development can be achieved	• **Transplanting** is seasonal (during dormancy) • Root dry-out can occur during shipping and handling on-site • Roots are lost during digging • Size is usually limited to smaller **caliper** trees (< 50 mm) • Post-transplant recovery reduced in areas that experience extreme heat and drought • Cultivation in field soil can reduce fine root mass • Irrigation after planting is more critical compared to trees with a soil ball • Usually require staking

Trees with a soil ball (e.g. balled and burlapped, in-ground fabric bags, wire basket, field-potted)	• Larger tree sizes are available • Processed with soil ball, which can reduce post-transplant water stress • Use of root pruning procedures can increase root density at the exterior of the root ball • May not need staking	• More costly to purchase and ship (fewer trees per truck) • Challenging to handle on-site due to greater weight (equipment usually required) • Transplanting is seasonal • Roots are lost during digging • Structural roots can be positioned too deep in the root ball and can be challenging to detect
Container-grown (above-ground, pot-in-pot)	• Flexible planting season • Easy to move and handle on-site (lighter weight than field soil) • No roots lost – no digging	• Misdirected – including circling – roots are common and can be challenging to detect and correct • Structural roots can be too deep in the container • Soilless substrate in the container is subject to dry-out • Usually require staking

Above-ground Quality Assessment

Action Items

- Select quality trees using criteria in this section and in Field Sheet 3.
- Upon delivery, trees should be inspected for above-ground and below-ground quality using information in this chapter and criteria in Field Sheet 5.

Only trees with well-formed crowns should be selected for planting. Trees with co-dominant leaders (except pyramidal and multi-stemmed forms) should not be selected. Branches should be well spaced around the trunk of the tree to form an evenly distributed crown. It is important to retain the natural characteristic shape of the tree. Branch angle should be adequately wide to prevent the formation of included bark in the future. Branches and co-dominant stems with included bark are vulnerable to failure (Figure 14). Pruning cuts should be closed and no larger than 2.5 cm in diameter or 25 per cent of the circumference of the trunk. Bud unions should be visible above the soil line. The relationship between caliper and height should be evaluated and only trees that comply with the latest edition of the Canadian Nursery Stock Standard (CNSS) should be selected. Specialty tree types (e.g. dwarf, formal, top-grafted, columnar, fastigiated and multi-stemmed) should comply with the latest edition of the CNSS.

Figure 14 *(A) Included bark formed on a mature tree demonstrating why looking for branch angle and signs of included bark at the nursery are important. The white arrows indicate where the bark inclusion seam formed. (B) Failure occurs at the inclusion due to weakening at the junction between two stems of similar diameter. Included bark can form between co-dominant stems, which increases the risk of failure. ©Duncan Slater.*

There should be no major wounds on the trunk, nor signs of dead, diseased, broken or injured branches. There also should be no evidence of nutrient or moisture deficiencies, including reduced size, wilting or early colour change in leaves. Shoot growth should demonstrate normal growth for the current and last few growing seasons (e.g. two to four years depending on the tree age and type), and for trees of that species. Although shoot extension is variable, each species or cultivar has its own growth characteristics.

Nurseries might not prune lower temporary lateral branches, as they help promote **trunk taper** (Wrigley and Smith 1978). Removing lower branches too early in the nursery can reduce trunk taper and inhibit root development.

Below-ground Quality Assessment

Action Items

- Locate the root flare on trees and probe root balls to find the depth of structural roots.
- Learn about root management practices employed by the nursery.

Trees with a damaged root ball should not be selected or accepted. Roots/root balls should be moist throughout and if the tree foliage is wilted or shows signs of prolonged stress from moisture loss, trees should not be selected or accepted. The upper part of the **root flare** should be at or very close to the surface of the root ball, or in the case of bare root trees, at or very close to the soil line (Figure 15). The root flare (also called **root collar**) area is where the root system connects to the base of the trunk, and may or may not have a flare-like curvature, depending on the species and age of the tree.

The top-most structural roots should ideally be no deeper than 5 cm from the surface of the soil (Gilman and Sadowski 2007). In the field, deep roots can be the result of soil cultivation that deposits additional soil on top of tree root systems, burying the natural root flare. Trees with uppermost roots positioned too deeply will struggle to survive when planted into less favourable soil conditions of an urban site (Day and Harris 2008).

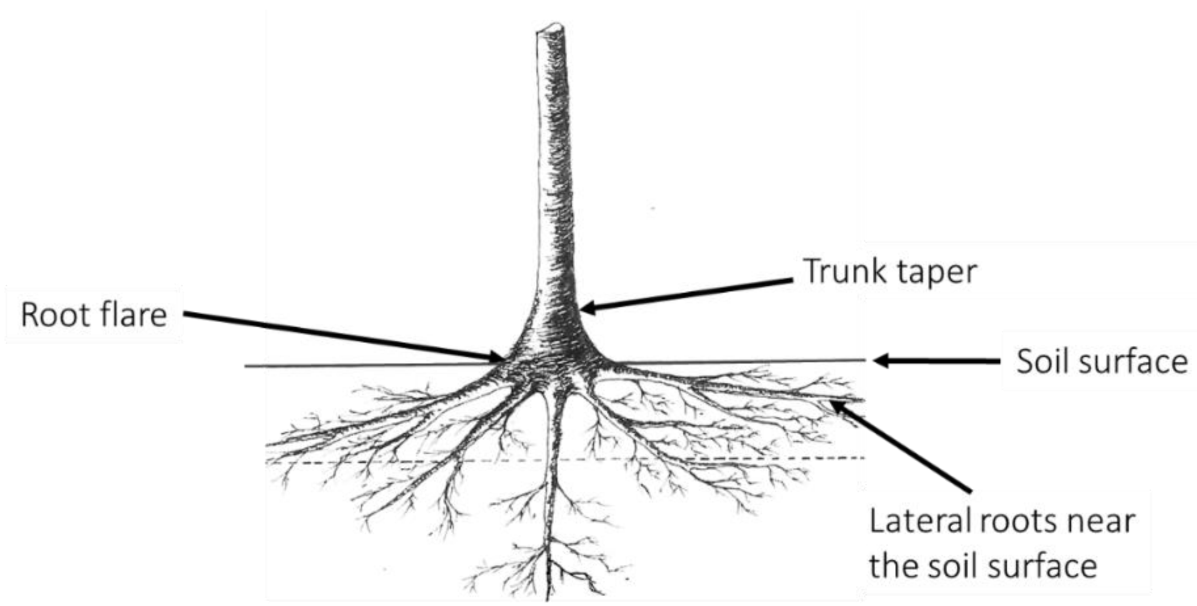

Figure 15 *The root flare is the region where the top-most roots meet the trunk of the tree and should be visible near the soil surface on nursery stock. Illustration by Keith Sacre, Barcham Trees, England.*

In container production, the combination of using too much potting media, settling of media and topping-up with media and/or mulch can result in deep root systems (Hewitt and Watson 2009). To find the root flare, remove the soil or media around the base of the trunk until the top-most structural roots are visible. The root flare should not be confused with the slight trunk curvature and different textured barks present on trees propagated by **budding**. The bud union will be well above the root flare (Figure 16).

Figure 16 *The bud union is the slightly enlarged area pictured above. The arrow is pointing to a structural root below the bud union. Source: Glen Lumis.*

Bare root trees with fewer than three well-distributed structural lateral roots originating from near the base of the trunk should not be selected or accepted, as some species have been found to transplant poorly when this is the case (Graves and Wilkins 1991, Nambiar 1980). One-sided root systems should also be rejected.

Root defects (or misdirected roots) should be identified during inspection and corrected prior to planting. Roots should not be misdirected upward (ascending), downward (descending), circling or kinked, as this can influence the distribution of coarse roots, water and nutrient acquisition abilities of the tree and future stability. Urban soils are commonly compacted and waterlogged, leading to low oxygen conditions. Root defects can result in poor distribution and deep placement of structural roots. In urban soils, severe root defects can exacerbate already difficult growing conditions, resulting in inhibited root growth, delayed tree establishment and in severe circumstances contribute to tree mortality. Roots that circle near the surface of the soil can girdle the tree, effectively cutting off the transportation of resources and potentially causing mortality over time (Gilman and Masters 2010).

To assess root quality for container-grown material, lift the tree out of the container to examine the root structure and look for misdirected roots. Correction of misdirected roots at planting can improve the ability of trees to root into the soil (Gilman et al. 2017). Root ball shaving is an effective method to remove misdirected roots on the exterior surface of the root ball (Gilman et al. 2010). When root defects in trees are a result of the final stage production practices, the outer 5 cm of the root ball may be shaved off with a saw or sharp shovel. This practice should be used cautiously in order to keep the rest of the root ball intact. Research by Dr. Gilman at the University of Florida has tested the effects of root ball shaving. For more information on his research and details on proper shaving techniques, click here.

Trees may have been grown using more than one type of production system. The different methods used throughout production can influence the final quality of nursery trees. Care should be taken to avoid selecting trees with evidence of **imprints** from previous nursery production stages. Multiple layers of circling roots that have developed within the root ball from successive production stages cannot be corrected at the final stage with root ball shaving. It is challenging to detect multiple layers of root ball defects, particularly in container-grown material. Therefore, it is imperative to learn about root management practices. Ask the nursery to provide information on root management techniques used to correct misdirected roots at each step of production. When selecting field dug trees, pertinent information such as when large trees were transplanted or root-pruned should be available upon request from the nursery.

When nursery producers use active root management techniques, root quality is improved. For instance, nurseries that either root-prune in the field, root ball shave or use air-pruning at each stage of upsizing, will produce higher quality tree root systems (Gilman et al. 2015). Nurseries around the world are making an effort to improve their production practices in order to grow well-distributed, fibrous and vigorous root systems free of major defects. Some container nurseries are beginning to track trees' growing times and sell or up-size before misdirected roots can form.

Transport and On-site Handling

Action Items

- During transportation, ensure that all trees are protected and roots have been kept adequately moist.
- While unloading trees on-site, avoid handling roughly or dropping.
- Inspect trees immediately and report any rejected material, ideally before the delivery truck leaves.
- Protect trees on-site and ensure that they have adequate moisture for their roots systems.

Transportation of trees should be restricted to a covered (e.g. mesh tarpaulin) or closed vehicle to prevent the desiccation of plant tissue (leaves, needles and branches). Trees dug during the growing season or moved from shade houses or greenhouses need to be hardened-off prior to being moved. Bare root trees should be moved only when dormant and require more protection during handling and transportation. Adequate moisture must be provided to the roots to avoid desiccation of the root system. Trees should not be held by their branches and bundles of trees should be handled gently to avoid scraping the bark. Walking on the load needs to be avoided. Handle with care to maintain the firmness of the root balls for balled and burlapped trees. Trees in wire baskets should be lifted by their basket at three or four points or by supporting the root ball from below. While lifting, be careful not to damage stems, branches and roots.

Trees should be inspected upon arrival and nurseries notified immediately of any rejected material recorded on official shipping documents. At the time of delivery, root balls should be inspected for adequate moisture levels and if required, the root balls should be re-wetted. For container trees, it is important to assess moisture by feeling the growing medium. After unloading, bare root tree roots should be covered and protected immediately from the effects of frost, sun and wind. In addition, as needed, the roots should be soaked with water and/or dipped in **hydrogel** after inspection. Until planted, bare root trees need to be protected from desiccation. If bare root trees are delivered with dry roots, they should be rejected, as should any trees with unacceptable root quality.

Holding Material

Action Items

- Keep soil and roots moist.
- Keep trees protected from wind and sun if necessary.
- Correct any root defects/extra root growth that may have occurred during the holding period.

The delivery of plant material should be scheduled to minimize the amount of holding time on-site. It is recommended that the storage of plants on-site be limited to a maximum of 36 hours (CLS 2016). When planting is postponed, the material stored on-site should be protected and irrigated. All balled and burlapped, container and wire basket trees should be stored in an upright position and spaced out enough to allow the light to reach the bottom of the trunks to avoid **sunscald** when planted (CLS 2016).

If trees with a soil ball or container are to be held on-site for any significant length of time before planting, then the root ball should be checked daily and kept moist. If possible, leave the trees in a shady area. If container-grown trees are held for a prolonged period of time, roots should be assessed for structural defects that may form along the container walls, which should be removed before planting.

When possible, bare root trees should be planted before bud break and within 24 hours of receiving the shipment. Trees (especially their roots) should be kept in the shade and covered to prevent dry-out. If trees are not planted within 24 hours, they should be **heeled-in** as quickly as possible. A shorter-term strategy to store bare root trees involves the dipping of their roots into a slurry of hydrogel and water to prevent desiccation of the roots (Apostol et al. 2009, Englert et al. 1993). Finer grade hydrogel products provide better coverage of fine roots. After dipping, protect roots from drying out using plastic bags, tarps, containers, etc. until the tree is planted. Plastic bags may not be practical for a large number of trees.

Figure 17 *Installation of an experimental Community Gravel Bed System testing different substrate types. Pea gravel is pictured in the bed above. Source: Dr. Kelby Fite, Bartlett Tree Research Laboratories.*

A longer-term solution involves the storage of bare root trees in a bed of irrigated pea gravel (Urban Tree Foundation, 2014) or in loose **friable** material (e.g. soil, sand or arborist wood chips). Pea gravel has been a preferred material for this type of solution (Figure 17), as some research has found greater mortality of trees in wood chip beds attributed to high temperatures that can occur if wood chips begin composting (Starbuck et al. 2005). However, new research by Dr. Fite at the Bartlett Tree Research Laboratories is showing promising results using arborist wood chips to promote fine root growth, if managed properly (Fite, personal communication).

Community Gravel Beds, also known as the Missouri Gravel Bed System, have been in use by nurseries, cities and researchers for over 20 years. Originally developed by Dr. Starbuck at the University of Missouri, the gravel bed system was designed to heel-in bare root trees and promote the development of fibrous roots. This system has been found to increase nutrient and water uptake and minimize **transplant shock.** Research has shown that bare root trees can be held for three to six months, allowing for the successful transplanting of bare root trees throughout the year (Starbuck 2000). For more information on this system and specifications on how to install one, click here.

Chapter 6 - Tree Installation

Post-planting stress, also called **transplant shock**, can last up to five years, depending on production type, tree size and species and site conditions. The objective of site preparation (Chapter 4), timing of planting and proper planting, is to minimize post-planting stress and increase the rate of tree **establishment**.

Timing is critical to minimize post-planting stress and to maximize tree survival. Tree roots typically begin growing when soil temperatures rise above 7.5°C (Trowbridge and Bassuk 2004). Because successful tree establishment is dependent on roots growing into the new soil environment, timing planting around optimum temperatures is important. Decisions of when to plant trees should be based on weather conditions local to the site. Additional aftercare may be required if trees are planted during less favourable times (e.g. too late in the fall when temperatures are below 5°C).

Action Items

- Determine if minimal corrective pruning is needed.
- Refer to Field Sheet 2 soil drainage results to determine root flare position and identify if soil modification is required to improve drainage.
- Determine planting hole depth and root flare position.
- Determine planting hole width.
- Determine proper tree placement.

Corrective Pruning at Planting

A significant amount of research has gone into the benefits of structural pruning of trees particularly the role it can play in shaping tree architecture, increasing structural integrity and health and minimizing the risks posed by trees (Miesbauer et al. 2014). For more information on structural pruning click here. At the time of planting, trees should have been pruned according to structural pruning principles so only minor corrections should be made on the on-site. Cuts on damaged branches or **interfering branches** are appropriate, as are cuts to aggressive upright branches that may compete with the leader (Figure 18). When pruning trees, use only clean, sharp tools. Most trees can be tipped over to prune before planting.

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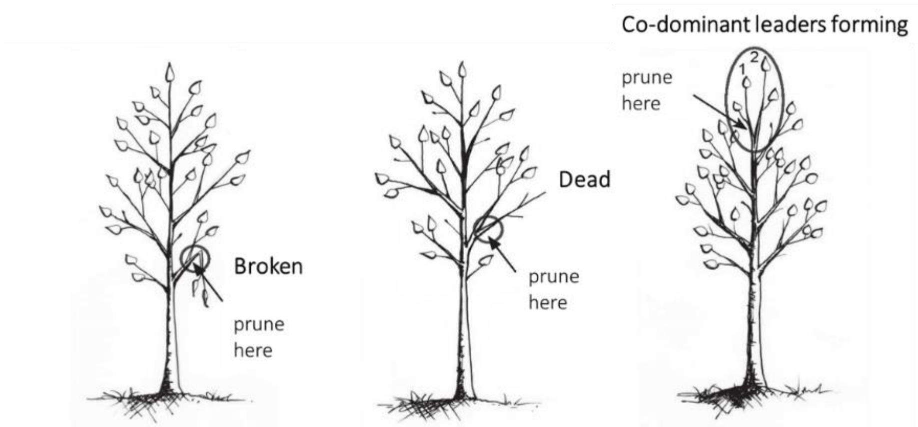


Figure 10 Examples of appropriate pruning cuts to make at planting are outlined in the illustration on trees already possessing well-structured crowns. Image from USDA, 2008.

Planting Hole Depth

Research has shown that the correct depth at planting is very important for tree survival. For instance, if trees are planted too high it can lead to sunscald and cold damage on the exposed **root shank**. Trees that are planted too deeply have no visible **trunk taper** as the **root flare** is buried below the soil surface (Watson and Hewitt 2012, Rathjens et al. 2007). Deep planting is a problem for tree establishment and some species are particularly sensitive to being planted too deeply (Berrang et al. 1985). Trees planted too deeply can sometimes experience more stem-**girdling roots** (Gilman et al. 2010, Wells et al. 2006) and may become oxygen deprived, both contributing to tree failure (Arnold et al. 2007, Bryan et al. 2011). In contrast, trees planted too shallowly can dry out quickly and become less stable during wind events (Bryan et al. 2011, Gilman et al. 2015). Root systems may also become exposed through erosion and frost heaving. Therefore, digging the correct depth of planting is very important for trees in the landscape.

To determine how deep to dig the planting hole, first locate the root flare on the tree and remove the excess soil or substrate covering it. For **container-grown** trees, remove loose substrate from the bottom of the root ball. The height from the top of the root flare to the bottom of the root ball should be measured. Use this measurement, along with drainage test results, to determine the correct planting hole depth. For well-drained soil, it is recommended to plant the tree with its root flare at soil grade or no more than 5 cm above grade. In poorly-drained soil, the planting hole should be dug shallower than the measured root ball height (Watson and Himelick 2013). It is recommended if planting in poorly-drained soil, where drainage correction is impractical or impossible, to select flood-tolerant species and plant the tree with its root flare 7.5 to 10 cm above the soil grade (CLS 2016). In situations where poor drainage is severe, it may be appropriate not to plant trees. Soil should be undisturbed at the base of the planting hole to prevent soil settling after planting. If the hole was dug too deeply, add soil and firm.

Planting Hole Width

Figure 19 A wide saucer-shaped planting hole two to three times the width of the root ball at the soil surface. Source: Glen Lumis.

In well-drained soils, the planting hole width should be two to three times the diameter of the root ball for all stock types (Watson and Himelick 2013). Widening the planting hole produces a hole with a greater volume of loose cultivated soil that allows for rapid root growth. Width is the only recommended way to increase the planting hole volume. Research has shown that trees benefit from wider planting holes (Watson et al. 1992, Arnold and Welsh 1995) because roots gain access to a greater volume of loosened soil.

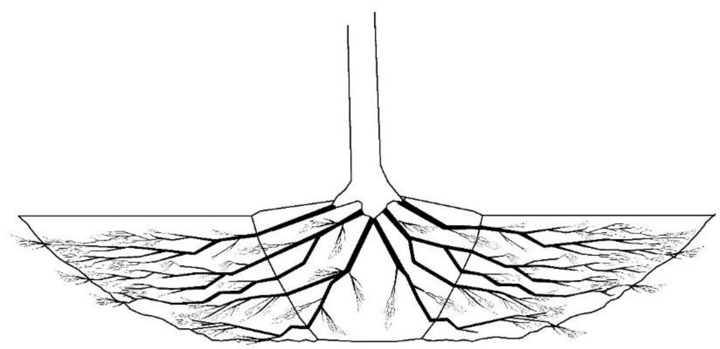


Figure 20 Digging a saucer-shaped planting hole with inward sloping sides provides increased space for roots to grow closer to the soil surface where oxygen and nutrients are in the greatest abundance. Illustration by Sean James.

In natural environments, most of the tree root growth is in the top 50 cm of soil where oxygen and mineral nutrients are more readily available (Hirons and Thomas 2018). In urban environments, it is common to find impenetrable soil layers near the surface due to construction compaction and buried debris, which can result in shallower root systems compared to natural settings (Day et al. 2010). A broadly recommended practice based on Watson et al. (1992) is to dig a hole two to three times the diameter of the root ball (three times in poorly-drained soils), with inward sloping sides (Figure 19). This hole will be wider on the top and narrower on the bottom, or saucer-shaped (Figure 20). Digging the planting hole with inward sloping sides lessens the amounts of soil that needs to be dug deeper down the soil profile but still provides additional loosened soil closer to the surface (Watson and Himelick 2013). Wide planting holes with sloping sides have been found to improve tree establishment particularly in finer **textured soils** (Watson et al. 1992, Arnold and Welsh 1995).

Planting Hole Modifications in Poorly-drained Soil

In poorly-drained soils (Field Sheet 2, < 10 cm/hour), dig the planting hole as recommended above. Soil should be broken up and loosened around the perimeter of the planting hole (30 to 60 cm outward), using either a shovel or machinery (e.g. backhoe bucket, **subsoiling** blade, spading implement or chisel plow). De-compaction around the planting hole perimeter should be as deep as possible without exceeding the root ball depth. Ensuring that the soil is permeable in and around the upper portion of the planting hole will benefit root growth and establishment. Every effort should be taken to avoid **glazing** of the planting hole surfaces during excavation. Even a well-prepared planting hole cannot counteract severe drainage problems, in which case a larger scale planting bed/soil restoration approach or imported substrate may be needed.

Tree Placement

During planting, trees should be held upright in the centre of the hole. Some large diameter, straight roots should be close to the final grade so they are positioned to explore loose cultivated soil (Coutts et al. 1990, Gilman and Wiese 2012). All bud unions should be visible above the final soil grade. Trees may be positioned in the planting hole using the same orientation as they grew in the nursery to keep light levels on the young bark consistent. Some nurseries mark their trees and will know the orientation of the mark from the field. Little research substantiates the importance of trunk orientation at planting.

Trees with a Soil Ball

For trees with a soil ball, back fill excavated soil to about one-half of the root ball height. All tying materials such as rope, twine and burlap should be removed from the trunk and top of the root ball at this point. Synthetic burlap and twine have been found to decompose slowly and some are treated to prevent decomposition (Kuhns 1997). Therefore, removing synthetic ties is essential to prevent constriction to the tree trunk. For a root ball in a wire basket, it is appropriate to remove the top horizontal wire and the attached loops (Lumis 1990). However, do not remove more than the upper third of the wire basket as research has demonstrated that full and partial removal of packaging materials increases tree instability after planting (Koeser et al. 2015). Furthermore, a nine-year study by Klein et al. (2019) supports past research findings by Lumis and Struger (1988) as researchers found no ill effect on tree growth (above or below ground) when the wire basket and packaging materials are left on at transplanting. If the tree is in a low profile wire basket where the top horizontal wire is 10 to 15 cm below the shoulder of the ball, removing the loops may be sufficient. Cut and remove the wire rather than bending it back around the side of the root ball.

Container-grown Trees

For container-grown trees, all containers must be removed before planting. At this point, the root ball should be examined and misdirected structural roots should be pruned at the point of deflection, including any potential stem-girdling roots. If the root ball is container-bound, shave the outside of the root ball (up to 5 cm) with a sharp shovel or arboriculture saw. Any substrate at the bottom of the root ball that does not contain roots should be removed. Care should be taken if the tree has been potted recently to ensure that the root mass will retain its shape and not collapse.

Bare Root Trees

Bare root trees will need careful attention during planting. Bare root tree roots may require some pruning. Damaged, misdirected or circling roots that may become girdling roots should be removed. The ends of roots that have been damaged or dried out can be pruned back to healthy tissue. Spread out all roots radially from the trunk in the prepared hole, ensuring that roots are directed away from the trunk. Roots of bare root trees should fit in the planting hole without bending.

Finishing Installation

Planting hole backfill typically should not be amended and consist only of the excavated soil. Research on this topic indicates that amending the planting hole backfill with **organic amendment** does not improve root development or tree growth and can be detrimental to tree performance and survival (Watson and Himelick 2013, Schulte and Whitcomb 1975, McGrath and Henry 2016). If the soil quality is determined to be poor based on completion of Field Sheet 2 – Soil Assessment, then a preference should be given to using planting beds or imported manufactured soil (discussed in Chapter 4).

The following instructions generally apply to finishing planting for all production types. Backfill in layers, lightly tamp and water to eliminate air pockets in each layer. Avoid injuring the roots or root ball or disturbing the position of the tree. When trees are planted above grade, create a gradual slope of backfilled soil from the top of the root ball extending out to at least the outer edge of the planting hole. Build a 10 cm high berm of soil extending 15 to 20 cm around the periphery of the root ball. The berm soil should be firmed and is intended to keep water from flowing away during irrigation (Figure 21). When the berm is in place, thoroughly water the root ball within it. Lastly, remove all plant identification tags, ribbons and any trunk protection or packaging material from the nursery.

Figure 11 *A soil berm, also referred to as a 'tree-well', helps to hold precipitation and irrigation water within the root ball of the tree. Source: Glen Lumis.*

Chemical and Biological Additives

Chemical and biological additives are compounds or products that can be added at planting to help support tree growth by improving nutrient availability (e.g. fertilizers) or resource acquisition (e.g. biostimulants). The most effective way to support tree establishment is to ensure soil conditions are suitable for fine root development and that levels of soil compaction are not limiting to root growth. If these requirements are met, then nutrients typically will not be limiting (Hirons and Thomas 2018). Additives can be costly therefore, it is important to first understand and address soil properties at the site which may be limiting for growth before trying to address specific deficiencies. If soils are very compacted then adding chemical or biological additives may prove ineffective over the short and long-term.

Chemical Additives

Chemical amendments are inorganic fertilizers and compounds developed to adjust nutrient levels and/or soil pH. Nutrient levels and soil pH can be determined from soil testing (See Field Sheet 2 – Soil Assessment). Generally, survival and growth after planting have not been found to be improved through the use of chemical fertilizers during the **establishment phase** after planting (Watson and Himelick 2013). If it is determined that certain nutrients are needed (e.g. due to deficiencies), refer to reliable resources for information on fertilizer types, rates, timing and techniques for application (e.g. Lilly 2010). If using inorganic fertilizer, apply it in a slow-release form and avoid fertilizer with a high salt index (preferably below 50) (Lilly 2010). Organic fertilizers can be used as a slow-release product. It is difficult to lower soil pH, requiring repeated treatments. A one-time application will offer only temporary reductions. This fact is particularly important in southern Ontario where many soils tend to have a high pH because of their limestone base. Additionally, urban soils tend to have elevated pH due to leaching from concrete-based infrastructure.

Biological Additives

Biological additives are products that supply condensed organic compounds and/or beneficial microorganisms to influence soil biology and chemistry. Both the research and professional communities show an interest in the benefit of using biological additives or biostimulants during **transplanting.** Biostimulants are diverse compound formulations and microorganisms that, when applied to plants and soil, are marketed as improving plant vigour, yield and tolerance to biotic and abiotic stresses. Commercial products are comprised of different communities of microorganisms including bacteria, fungi, protozoa and nematodes. The use of biostimulants during tree planting has been increasing, as a greater understanding is emerging on the critical role soil microorganisms play in plant health and soil function.

The use of **mycorrhizal fungi** has been the primary focus of biostimulants for tree plantings. Mycorrhizal fungi form symbiotic relationships with the roots of vascular plants. Mycorrhizal fungi receive sugars and other compounds from plants in return for water and nutrients foraged by the fungi. Mycorrhizae are found on over 80 per cent of the world's vascular plants, including most tree species (Hirons and Thomas 2018). The net benefit to the tree is influenced by the interactions between the fungi, the species of tree and the microbial communities present in the **rhizosphere** which, in combination, will influence nutrient availability (Prescott and Grayston 2013, Hirons and Thomas 2018). Due to these complex relationships, the benefits of commercial mycorrhizal inoculants are not clear-cut. When inoculants have been used on urban trees during planting, the growth rates of trees have generally not been improved (Morrison et al. 1993, Martin and Stutz 1994, Gilman 2001, Ferrini and Nicese 2002, Appleton et al. 2003, Abbey and Rathier 2005, Corkidi et al. 2005, Broschat and Elliot 2009, Wiseman and Wells 2009). New products comprised of a consortium of mycorrhizal species may increase the likelihood that the inoculum will be compatible with the target trees (Hirons and Thomas 2018). A mycorrhizae product that is comprised of 20 endo and ectomycorrhizal species was found to mitigate water stress of newly transplanted *Thuja occidentalis* 'Smaragd' (emerald pyramidal cedar) and *Acer rubrum* 'Brandywine' (Brandywine red maple) (Dixon et al. 2015).

Compost teas can enhance the functioning of soil biology, as they contain populations of bacteria, fungi, protozoa and nematodes, which are multiplied by aerating water inoculated with compost. Compost teas also contain low concentrations of soluble nutrients that may act as biostimulants (Watson et al. 2014). However, there is a lack of research findings supporting the use of compost teas as a replacement for fertilization (Scharenbroch et al. 2011). Other organic amendments such as compost and mulch have resulted in comparatively greater tree growth (Scharenbroch and Watson 2014). Other products like **humates** and plant extracts have also been tested but little benefit for tree establishment has been found (Watson et al. 2014). Generally, healthy soils will support diverse and robust soil biological communities and will result in natural recruitment of **soil biota** (Watson et al. 2014).

Chapter 7 - Stabilization, Trunk Protection, Mulching and Irrigation

Tree Stabilization

Action Items

Determine if tree stabilization will be required after planting. Key factors that would support the use of stabilization include:

- Small root systems that will not support the movement of the tree.
- Very windy planting sites.
- Risk of unprotected trees being vandalized, uprooted or damaged by vehicles and equipment.

If stabilization is required, determine which method is appropriate:

- Staking – deciduous trees with a **caliper** less than 100 mm or evergreens less than 300 cm in height.
- Guying – deciduous trees with a caliper greater than 100 mm or evergreens greater than 300 cm in height.
- Root ball anchoring – can be used as an alternative to staking or guying for **container-grown** trees and trees with a soil ball.

Commonly cited reasons for stabilizing newly planted trees include: helping root systems develop in a new soil environment, preventing toppling because of wind and prevention of vandalism (Alvey et al. 2009, Appleton et al. 2008, Eckstein and Gilman 2008, Patch 1987). In some instances, however, trees may not need to be stabilized (Gilman and Sadowski 2007). A review of the literature on this topic by Appleton et al. (2008) found that stabilization should only be undertaken when necessary, not as a default practice. Tree stabilization can be detrimental to tree growth. Decreased caliper and **trunk taper**, increased tree height, asymmetrical trunk growth and reduced root growth have been observed when improper stabilization practices have been used, especially when stabilization measures were left in place too long (Harris 1969, Burton and Smith 1972, Wrigley and Smith 1978, Ellyard 1984, Schuch and Kelly 2004). If the **subsoil** and backfill are stable and can hold the root ball in place even in high winds, then stabilization may not be needed.

However, in many circumstances, **transplanted** trees will need support due to the fact that root systems need time to grow into the landscape soil. Therefore, when warranted and immediately following planting, trees should be stabilized using non-damaging methods, allowing free movement for trunk taper and **crown** development. The three most common techniques for stabilizing trees are staking, guying and root ball anchoring (Labrosse et al. 2011). After planting, systems that allow for the greatest trunk movement will result in the development of trees with significantly more taper (Svihra et al. 1999). Stabilization should ensure that normal forces such as wind and snow loading do not move the root ball in the backfill. Most stabilization should be removed between 12 and 14 months after installation. In instances where stabilization remains in place for a longer period of time due to special considerations, trees should be checked regularly to ensure that materials are not interfering with normal tree growth.

Staking

Staking is the use of one or more wood or metal stakes driven into the soil next to the root ball. The most commonly used stakes are 5 x 5 cm or 5 cm diameter round wooden stakes, as well as steel t-bar stakes. One to three stakes can be used for deciduous trees up to 100 mm in caliper and coniferous trees up to 300 cm in height. Stakes must be set in undisturbed soil (outside the root ball), deep enough that they will not move when subjected to wind. If using the two-stake system, it is critical that stakes are driven into the ground to a sufficient depth to ensure stability (Eckstein and Gilman 2008). Research has found that three stakes provide better support and should be considered at sites with strong winds (Alvey et al. 2009).

The first stake should be set upwind from the prevailing wind direction. If using two stakes, the second stake should be opposite the first stake. If using three stakes, the first stake should be set upwind from the prevailing wind, with the remaining two stakes set at equal distances around the planting hole. Stakes should be attached to the tree with broad, smooth, flexible ties (biodegradable material is preferred, e.g. folded denim or coco rope) that allow trunk movement but stabilize the root ball.

Very few studies have specifically evaluated the effect of tie attachment height on staked trees. A study by Leiser and Kemper (1968) suggests a maximum point of attachment of two-thirds the height of the tree. This was based on modelling that predicted that trees can withstand greater physical force (e.g. wind) if more of the trunk is allowed free movement. When a tie is attached too high on a tree, and force is applied over a shortened length of the stem, it is more likely that the tree will break. Research has shown that holding the trunk firmly at the base of the crown or higher, results in a reduced diameter growth at the base of the tree (Patch and Hodge 2012). Current best practice recommends staking as low as is effective for stabilizing the root ball and positioning ties well below the first set of branches on the trunk on limbed-up deciduous trees (Appleton et al. 2008) in order to increase tree stability and trunk growth. When staking is required on coniferous trees (less than 300 cm in height) and deciduous trees with branches close to the ground (less 100 mm caliper), attach ties as low as is effective for stabilizing the root ball. Ties should be secured to the stakes and placed on the tree such that they will not slide down or otherwise be displaced.

Guying

Guying involves using three guy wires spaced equally around a tree anchored to the ground at an angle. The first anchor should be placed upwind from the prevailing winds. Guying is recommended for deciduous trees greater than 100 mm in caliper and coniferous trees taller than 300 cm. Three-point guying systems have been found to provide effective support when stabilizing newly transplanted trees

(Alvey et al. 2009, Eckstein and Gilman 2008, Gilman et al. 2016). It has also been found that guying systems produced taller trees with smaller trunk diameters one year after landscape planting compared to both root ball anchoring and using no stabilization techniques (Gilman et al. 2016). A careful use of guying is advised in order to avoid negatively influencing the growth of trunk caliper.

Anchors for guy wires must be set below or flush with the soil surface so that they do not present a tripping hazard. Guy wires must be marked with flagging tape for visibility. Tree ties used to secure guy wires should be of a material that will not damage the bark (biodegradable is preferred), be at least 2.5 cm wide and remain soft and pliable in all weather conditions. They should be attached above the first set of branches on limbed-up deciduous trees. There is no research on specific attachment heights for conifers. It is commonly recommended to attach ties as low as is effective for stabilizing the root ball and at a branch intersection to prevent them from sliding down. Finally, trees should be permitted a reasonable degree of movement under normal forces such as wind without causing damage.

Root Ball Anchoring

Above-ground root ball anchoring, often called strapping, is a method that involves driving wooden stakes into the ground outside the root ball (Eckstein and Gilman 2008). The stakes are then fastened to horizontal straps (e.g. wood or fabric) across the top of the root ball. When installed, two horizontal straps hold the root ball in place on opposite sides of the trunk (Figure 22). Below-ground stakes should be driven into the soil so the horizontal straps rest firmly on the root ball. To minimize tripping hazards apply a wide ring of **mulch** around trees. Root ball anchoring has been found to provide greater trunk movement in wind compared to staking, while still effectively stabilizing the root ball (Eckstein and Gilman 2008, Alvey et al. 2009). This method ensures there is no risk of trunk damage and it allows for free movement of the crown. Root ball anchoring is suitable for soil ball or container-grown trees.

Figure 12 *Root ball anchoring uses a system of four wooden stakes and two pieces of horizontal strapping, preferably biodegradable. Source: Dr. Edward Gilman.*

Trunk Protection

Action Items

Assess the site and determine if trunk protection (e.g. tree guards or wraps) is required. Scenarios in which trees may require protection include:

- Line trimmers and/or mowers will be used on-site.
- Rodent, rabbit or deer damage is likely (e.g. non-mowed sites, near natural areas, etc.).
- Thin-barked (juvenile) and sensitive bark species are planted that are vulnerable to **sunscald.**

Plastic guards can be used to protect the base of tree trunks against equipment, animals (e.g. stem girdling) and, to a lesser degree, sunscald. Tree guards are essential for plantings where line trimmers are used and for sites where rodents and/or rabbits are present. Tree guards should be flush to the soil surface to protect the base of the trunk. Most importantly, the guards should not constrict the trunk and be fit loosely to prevent moisture buildup and facilitate air flow. Guards must be removed once the tree becomes established. Other tree protection options include deer and rabbit repellent sprays, and in areas of high deer populations, fencing around trees should be considered.

Sunscald and frost cracks can be common, particularly on thin- or smooth-barked species. In the winter, trunk tissues can swell in direct sunlight and then quickly shrink as cold temperatures return, resulting in injury to the cambium and bark splitting. Wrapping is sometimes recommended for species with a thin, smooth bark (e.g. *Carpinus*, *Fagus*, *Platanus*, etc.). If used, the best types of wraps are light in colour and biodegradable. Trunks should be wrapped starting from the bottom to the top so that layers overlap and shed water. Research has cautioned against the use of wraps due to persistent issues with excess moisture retention, insect damage and trunk constriction if follow-up inspections are not regular enough. The use of trunk wraps is therefore only cautiously recommended for species highly susceptible to sunscald, should be used only in the winter and must be loosened to prevent constriction of the trunk (Watson and Himelick 2013).

Mulching

Action Items

Determine the type of mulch product that will be used:

- Organic mulch – products composed of plant residues that will slowly decompose over time.
- Inorganic mulch (rock and landscape fabric).

Apply at an appropriate depth (5 to 10 cm) and distance away from the tree (not touching the bark).

All mulch products should be free of invasive and noxious weed seeds, soil, salts and other harmful chemicals. Either organic or inorganic mulches can be used for weed suppression, moisture retention and maintaining elevated soil temperatures during the winter months. Inorganic mulches include rocks of varying sizes, shapes and colours and landscape fabric, however, they will not improve soil quality. Crushed limestone should not be used as it can become compacted and create a barrier to water and air infiltration. Landscape fabrics should not inhibit the infiltration of water but should reduce the establishment of weeds. Impermeable plastic materials should be avoided. Organic mulches can include a wide variety of materials, such as bark, wood chips, straw and coir pith (e.g. coco-discs). Compared to inorganic mulches, they have been found to result in improved plant performance through enhanced water conservation and a slow release of nutrients and other benefits (Chalker-Scott 2007) (Figure 23). Most landscape tree roots do not grow well in turf grass. Research has shown increased root growth when grass underneath trees is removed. Growth further enhanced with the addition of organic mulch (Watson and Himelick 2013).

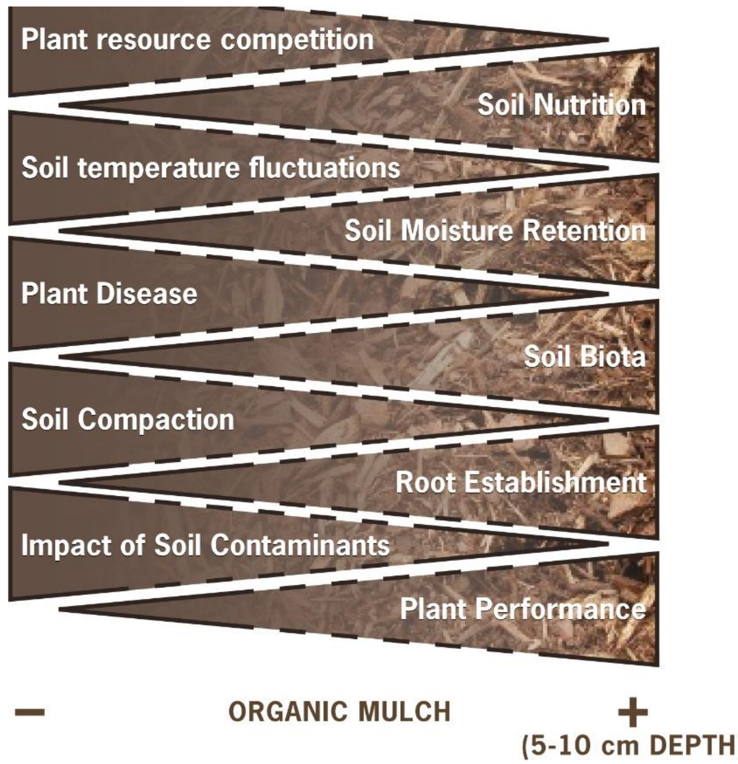


Figure 13 *The potential benefits of applying organic mulch to the root zone of a tree at the recommended depth of 5 to 10 cm. The segments represent increases or reductions of each factor with mulch application. Dashes indicate general trends, not necessarily linear relationships.*
Source: Hirons and Percival (2012).

After planting and finishing grading, organic mulch can be applied. The mulch application depth is recommended to be approximately 5 to 10 cm after settling and applied at least 15 cm away from the base of tree trunks to avoid moisture accumulation. Mulch rings should be at least 100 cm in diameter, but the larger the mulched area, the better. Depending on the rate of mulch break-down, plantings should be checked annually to maintain a total mulch depth of 5 to 10 cm.

Rock mulch should be spread evenly, avoiding contact with the trunk and placed on top of landscape fabric. Landscape fabric should be applied prior to planting by laying fabric over the planting area and cutting openings allowing for tree planting. After planting, any exposed landscape fabric should be evenly covered by either rocks or a coarse organic mulch to prevent weed seed germination. In the first few months following planting, when root spread is limited to under the mulched area, light rainfall may not adequately infiltrate the soil to support root growth. Increasing the amount of irrigation or delaying application of mulch may be necessary in such cases.

The benefits of properly applied mulch are well-documented for trees and research efforts have focused on organic mulch due to its wide-ranging advantages over inorganic mulch. Organic mulch can increase growth and **establishment** success of newly planted trees (Arnold and McDonald 2009, Cogger et al. 2008, Ferrini et al., 2008, Percival et al., 2009, Ni et al. 2016). Organic mulch also improves soil properties including replenishment of organic matter and nutrients to the soil (Scharenbroch and Watson 2014). Benefits to newly planted trees come from increased moisture availability and reduced **evapotranspiration** from the soil surface (Maggard et al. 2012). Organic mulch can be especially beneficial in cooler climates. Watson et al. (2014) demonstrated that organic mulch resulted in soil being 6°C warmer in the winter compared to non-mulched soil. Additionally, organic mulch has been found to reduce salt and pesticide contamination and the effects of salt toxicity on plant growth (Landis 1988). When applied correctly, organic mulch offers many benefits. Be aware that if it is applied too deeply or if its particle size is too small (e.g. sawdust), it can become a barrier to water infiltration and can reduce the amount of moisture and oxygen reaching the root ball (Gilman and Grabosky 2004, Arnold et al. 2005).

Watering and Irrigation

Action Items

- Create a plan for watering newly planted trees.
- Determine the irrigation quantity and frequency based on site considerations and contract specifications.
- Consider the sources of irrigation water and potential impacts of pH and soluble salts on irrigation water.

It is strongly recommended that all new plantings be irrigated after transplanting. Proper care until the tree is established is essential for successful tree planting and warrants a separate reference guide. However, it is worth noting that the irrigation timing and frequency in the post-transplant phase are critical.

At some planting sites, the irrigation infrastructure may already be installed, which should be considered when creating an irrigation plan. Additionally, if there is a maintenance contract, it may specify a particular method that needs to be followed.

Quantity and Timing of Watering

Due to the loss of roots prior to transplanting of **bare root** trees and trees with a soil ball, more frequent access to water than is supplied by precipitation alone may be required. Newly planted trees should be irrigated to some extent between one and five years (depending on tree size, stock type, etc.) during the **establishment phase**. Trees will experience greater water stress if any of the following scenarios apply to the planting site:

- Limited soil volume (limited water storage volume and limited catchment opportunity)
- Poor quality soils (especially in soils with less than 5 per cent organic matter)
- Sites with high heat loads (e.g. reflected heat)

- During periods of drought or low rainfall amounts, or if rainfall interception is interrupted by pavement or other less permeable surfaces
- If tree roots are in competition with turf for resources

The type of nursery trees planted and the species selected will help to dictate the irrigation strategy required for newly planted trees. Drought-sensitive trees should also be monitored and watered during periods of drought even when mature. In areas where the soil quality is poor (i.e. highly compacted and/or low soil organic matter), it is important to design an irrigation schedule.

Research has demonstrated that recently transplanted trees establish quickest with frequent irrigation especially when ensuring water is applied directly to the root ball (Beeson and Gilman 1992, Gilman et al. 1994, Gilman et al. 1996, Gilman 2001). The watering frequency depends on weather conditions and soil drainage. Soils that drain quickly require more water than those that drain slowly. For these reasons, it is very challenging to provide generalized irrigation recommendations and a thorough understanding of the environmental site conditions is required in addition to making informed choices regarding production type and species.

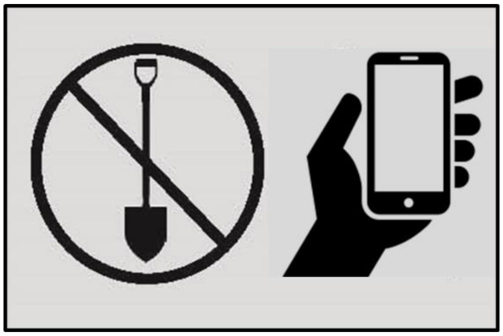
With respect to the quantity of water to apply, the size of the tree can be used to roughly estimate how much water to apply during irrigation. Roughly 4 litres (one gallon) per 25 mm (inch) of trunk diameter is appropriate for newly planted trees in climates similar to Ontario (e.g. extension information from the University of Minnesota can be found here).

The choice of irrigation delivery method needs to be considered based on cost, site access, as well as determining the best way to deliver water to the root ball of establishing trees. There are many different delivery options that exist, including (but not limited to): sprinklers, sprays, micro/mini emitters or bubblers, subsurface drip (below the mulch), water walls, water rings or bags, subsurface storage or water trenches. Water delivered in an adequate volume to the root zone, rather than targeting only the surface soil layers is critical to tree establishment. For a thorough explanation of irrigation delivery methods, techniques and tools for urban trees, click here.

Water Quality

The quality of irrigation water used is important. Although it may not be possible to test irrigation water before planting, if nutrient deficiencies or other signs of stress are observed, the quality of irrigation water may be a contributing factor. The chemistry of irrigation water can influence nutrient and water availability to tree roots, influence root growth and therefore, tree health. The pH of irrigation water should ideally be between 6.0 and 7.5 because pH can affect the availability of dissolved nutrients (Hirons and Thomas 2018). In many groundwater sources of irrigation water in southern Ontario, the high amounts of bicarbonates (HCO_3^-) from underlying limestone make water sources more alkaline.
Soluble salts in irrigation water can also affect plant growth. The amount of salts of can be assessed by measuring **electrical conductivity** (EC) because it measures the amount of dissolved ions in the water. High electrical conductivity values in irrigation water can interfere with root function. A value of < 0.2 S/m is acceptable for the irrigation water of trees (Hirons and Thomas 2018). Checking EC during the growing season is especially important if irrigation water is from a source where soluble salts collect (e.g. road run-off into a storm water management pond).

Field Sheet 1 - Environmental Site Assessment



All required locates must be requested and received for each planting site before any soil sampling, site preparation or planting takes place.

Contact Ontario One Call (1-800-400-2255; https://www.on1call.com/).

Materials

- ☐ Clipboard/note paper and pen
- ☐ Phone (camera)
- ☐ Tape measure

Hardiness Zone

To identify hardiness zone click here Zone: ______

Light Level

Estimating light levels will help to make informed species selections. In general, the shade tolerance of tree species corresponds with three categories of sunlight levels: full sunlight (> 6 hours direct), partial shade (< 6 hours direct or > 6 hours filtered) and full shade (< 6 hours filtered, very little direct). Consider that any on-site structure can contribute to shading, including buildings and existing trees.

☐ Full sunlight ☐ Partial shade ☐ Full shade	Notes:

Reflected Heat

Less than 5 m from hardscape surfaces in multiple directions increases drought stress during summer months.

Utility Lines

Consider ***recommended planting zones***

- Trees underneath utility wires should be small stature trees and shrubs (e.g. maximum height of 3 m)
- 5 to 8 m away from utility wires, medium-sized trees may be planted (e.g. maximum tree height of 8 m)
- 8 m away from overhead wires, tall-growing trees can be planted

Below-ground Infrastructure

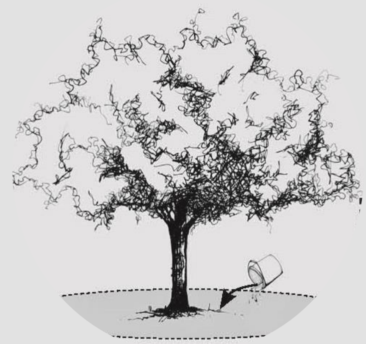
Where possible, a 6 m setback from existing pipes and other infrastructure is recommended.

Sidewalks and Roads

If closer than 3 m, roots may disrupt infrastructure.

De-icing Salt

Less than 5 m to roadways, cut-outs and sidewalks tends to increase tree mortality. Other factors to consider are topography and wind direction.



At the planting location, it is important to note both the above-ground and below-ground space available to a full-sized, mature tree.

Estimate the distance of the planting location and record it below:

Utility lines _____

Buildings _____

Below-ground infrastructure _____

Road _____

Sidewalk _____

Wind

Large structures can protect trees from wind or increase wind speed by creating wind tunnels.

☐ Protected

☐ Not protected (e.g. open field)

☐ Wind tunnel

Notes:

Next Steps

1) Refer back to Chapter 1 to help interpret your results.
2) Proceed to Field Sheet 2.

Field Sheet 2 - Soil Assessment

It is important to gain an understanding of the variability of soil conditions, as they can differ significantly, even within small sites. Therefore, establishing multiple representative sampling locations is recommended for determining soil quality.

Materials

- ☐ Clipboard/note paper and pen
- ☐ Phone (camera)
- ☐ Tape measure
- ☐ Shovel/soil auger
- ☐ Water source and bucket/hose
- ☐ Plastic sandwich bags
- ☐ Permanent marker
- ☐ Wire probe (description below)

Conducting a Drainage Test

1) Assess topography to understand drainage patterns on-site.
2) Dig hole(s) 30 cm deep where you want to assess drainage.
3) Fill the hole with water to thoroughly wet surrounding soil and let drain. Repeat twice.
4) Fill the entire hole with water and measure the water height. Wait 15 minutes and measure the change in water height.
5) Multiply the change in water height by four to get the rate of drainage per hour and check the appropriate box below.

- ☐ Poor drainage – less than 10 cm/hour
- ☐ Moderate drainage – 10 to 20 cm/hour
- ☐ Excessive drainage – more than 20 cm/hour

Notes:

Conducting a Soil Compaction Test

Take a 40 to 50 cm length of high-tensile wire (approximately 3 mm or 10 gauge, e.g. fence wire). Use about 10 cm to make a looped handle. When the soil is neither very wet nor very dry probe the soil with the wire at multiple locations on the site, using the following steps:

1) Hold the wire by the loop.
2) Attempt to push the wire into the soil. Do not force the wire – use only slight pressure.
3) Record the depth of penetration at each sampling location.

- ☐ Severe – wire probe will not penetrate beyond 10 cm
- ☐ Moderate – wire probe will penetrate soil with difficulty between 10 and 30 cm
- ☐ Acceptable – wire probe will penetrate soil easily to 30 cm and below

Notes:

Collecting Soils for Laboratory Analysis

On large sites and/or if changes in topography, vegetation or drainage are evident, break the site up into sections based on these characteristics. Collect multiple samples within each section. Samples should be labelled to indicate their collection area within the site.

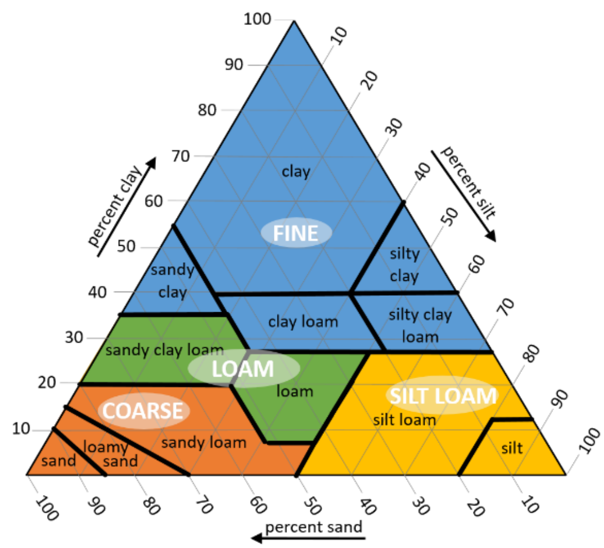
On small sites and/or where sites appear uniform, collect multiple samples from the area(s) most likely to be planted. Collect samples using a soil auger or shovel to a depth of 30 cm. One cup of soil per sample is usually required for most analyses. Click here for a list of accredited soil testing laboratories in Ontario.

Soil Texture

Soil texture influences drainage and usually cannot be significantly altered. Therefore, texture and drainage should be considered during species selection.

The two main methods for assessing texture include a field-based method, hand texturing (requires practice for calibration), and laboratory methods (e.g. the hydrometer method), which provide accurate assessments of texture classes.

If you are not experienced with the hand texturing method, collect soils and submit to a laboratory for analysis.



Identify the soil texture grouping at the site using the texture triangle figure (courtesy of the Cornell Soil Health Laboratory).	
☐ Fine	Notes:
☐ Medium (loam or silt loam)	
☐ Coarse	

Organic Matter

Common laboratory analysis packages include **soil organic matter**. A minimum of 5 per cent organic matter is recommended for supporting trees during establishment.

☐ Less than 5%	Notes:
☐ Between 5 and 10%	
☐ Greater than 10%	

pH

Nutrient availability is influenced by soil pH. Many tree species selection resources use pH to provide recommendations.

Soil pH is _____

Soil Volume

Estimate the useable soil volume per tree _____ m^3. For further reading and resources click here.

Next Steps

1) Refer back to Chapter 2 to help interpret your results.
2) Make your species selections using Chapter 3.
3) Proceed to Field Sheet 3.

Field Sheet 3 - Selecting Nursery Trees

Becoming educated about nursery production practices will help to make informed decisions about tree quality. Where opportunities exist, attend seminars, participate in nursery tours and visit nursery growers to learn about how quality trees are grown. Important production considerations include:

- Choosing the appropriate stock type (e.g. bare root vs. container) for the planned maintenance activities of the site (e.g. staking, irrigation and mulching)
- Root management practices used to promote quality (e.g. use of air pruning containers, chemically treated containers, root ball shaving before upsizing, root pruning of field-grown stock)
- Trunk and branch structure and pruning practices

If possible, visit the nursery to inspect and tag desired trees based on the following above- and below-ground qualities.

Materials

- ☐ Metal skewer or screwdriver
- ☐ Phone (camera)
- ☐ Clipboard/note paper and pen

Assessing Above-ground Quality

Ensure the size of trees roots, trunk and crown are balanced. Refer to the Canadian Nursery Stock Standard for size requirements (Section 5 for coniferous trees and Section 7 for deciduous trees).

- ☐ Trees possess a central and dominant leader where appropriate
- ☐ The main branches of the **crown** are well-distributed along the trunk and undamaged
- ☐ The branch angles are adequately wide to prevent future included bark
- ☐ The tree trunk is straight and vertical
- ☐ The trunk scars from branch pruning are closed or possess well-formed wound wood
- ☐ All graft unions are completely closed, healed and are visible above the soil line

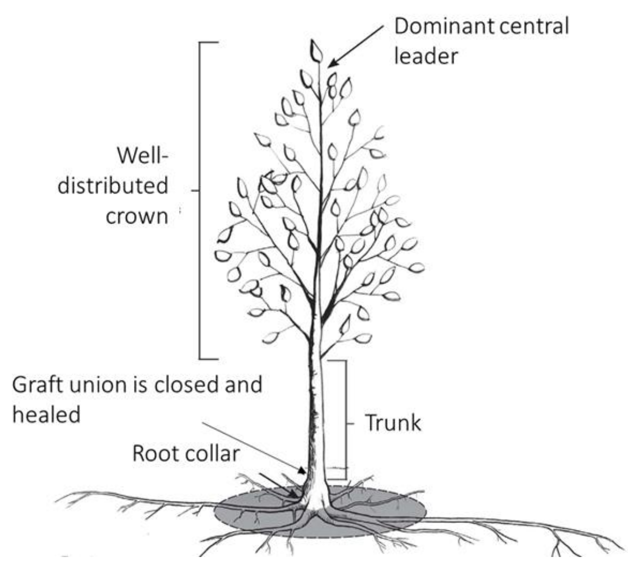


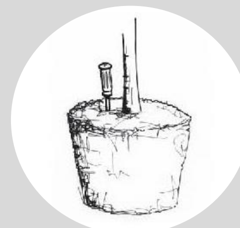
Image adapted from USDA, 2008b.

Assessing Below-ground Quality

Use the figure below to help assess trees for the following qualities:

- ☐ Upper-most lateral (structural) roots are near the surface
- ☐ Visible trunk taper
- ☐ Container-grown trees have few misdirected (encircling) structural roots
- ☐ Bare root trees have at least three well-distributed structural roots, with some fibrous roots also present (i.e. roots less than 2 mm in diameter)

Where the root flare is not visible use stiff wire (e.g. BBQ skewer) or a screw driver to gently probe the soil to assess the depth of the top most structural roots. Image from USDA, 2008.



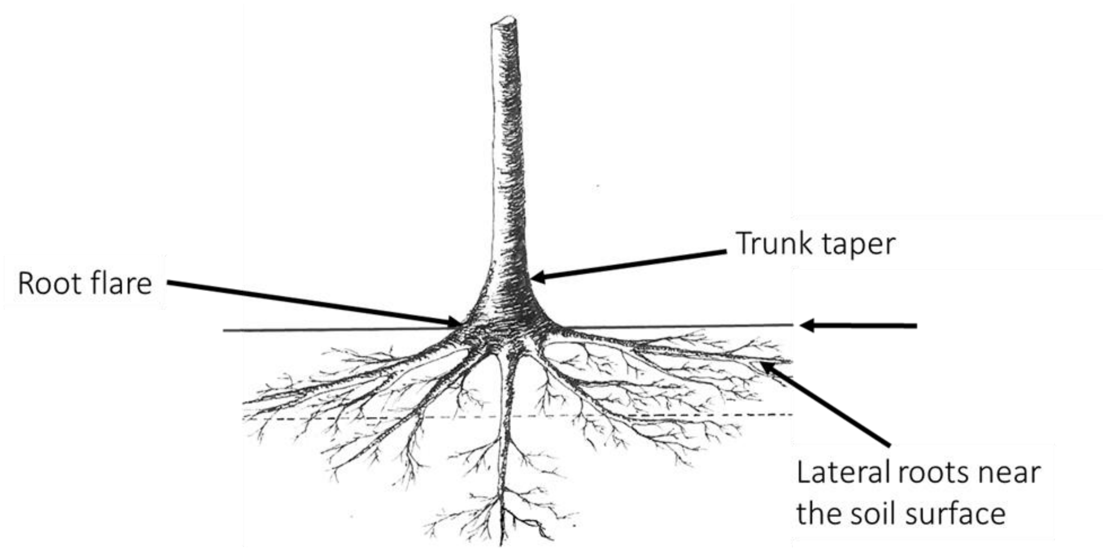


Illustration courtesy of Keith Sacre, Barcham Trees, England.

Next Steps

1) Refer to Chapter 5 for more details on tree procurement.
2) Proceed to Field Sheet 4.

Field Sheet 4 - Site Preparation

In addition to when it is specified in contract documents, site preparation is generally recommended in the following situations:

- Soils are severely compacted (wire probe will not penetrate soil beyond 10 cm)
- Soils are moderately compacted (wire probe will penetrate soil with difficulty 10 to 30 cm)
- Soils have less than 5 per cent organic matter and trees will be planted into multi-tree beds

Materials and Equipment

It is important to source the appropriate equipment for the job. Soil conditions of the site, depth of below-ground utilities and the size of the job will help to inform decisions.

- ☐ Locates report
- ☐ Subsoiling equipment or backhoe
- ☐ Organic amendments
- ☐ Tracked equipment to move amendment
- ☐ Surface de-compaction equipment (e.g. rotary spader, vibrating chisel plow, agricultural rototilling implement)

Subsoiling

Mechanical de-compaction with subsoiling can be used on medium and large sites where soils are compacted at depths greater than 30 cm (and where locates allow for it). For more information on equipment, consult Chapter 4.

Instructions

1) Fracture the subsoil in the direction of the flow of water on-site. Space rips approximately 30 to 60 cm apart (pictured right).
2) Work backwards away from rips to avoid driving on treated soil.
3) After subsoiling is completed, organic amendment can be applied on the surface of the soil and incorporated.

Backhoe Turning

This method is effective for soils that are compacted at depths of 30 cm and below, and on small- to medium-sized sites for de-compacting subsoil and mixing organic amendment. For specifications of the backhoe method called "soil profile rebuilding", click here.

Instructions

1) Apply organic amendment across the entire planting bed/trench.
2) Using an excavator, scoop up the soil and lift it about 60 cm above the ground.
3) Tip the bucket and allow it to fall. Repeat the process until clumps are smaller than a soccer ball.
4) Work backwards to avoid driving on treated soil.

Source: Rachel Layman.

Surface De-compaction

When soils are only compacted in the top 30 cm, surface de-compaction may be used. The equipment can also incorporate organic amendment into bed-style plantings (see the picture below). To determine how much amendment is recommended for preparation of planting sites with no planned aftercare, click here.

Instructions

1) Spread the organic amendment.
2) Back-blade the amendment to achieve a relatively uniform application depth.
3) Make multiple passes across the site with the equipment to ensure the incorporation depth reaches about 30 cm. If you are unsure about the mixing depth, dig a test pit to confirm.

Next Steps

1) Refer to Chapter 4 for more details on site preparation.
2) Proceed to Field Sheet 5.

Field Sheet 5 - Transport, On-site Handling and Inspection

Careful preparation for the movement of trees is critical to ensure that tree quality is not compromised during shipping or unloading. Trees should be inspected upon arrival and nurseries should be notified immediately of rejected material. Record any rejections on official shipping documents.

At the time of delivery, root balls should be inspected for adequate moisture levels and if required, the root balls should be re-wetted. When trees cannot be planted within the required timeframe (based on stock type, see below), proper care must be taken to ensure tree health is maintained during storage on-site.

Materials

- ☐ A record of trees ordered
- ☐ Water source and hose
- ☐ Tarps or bags to protect bare root trees
- ☐ Equipment required to move large trees

Transportation and Handling

Proper transportation and handling include the following steps:

- ☐ Trees are covered (e.g. tarps) or in closed vehicle during transport
- ☐ Trees are handled carefully so soil balls remain intact
- ☐ Trunks are protected during movement
- ☐ Trees are not held by branches or handled roughly
- ☐ Root system/root ball moisture is maintained at an adequate level

On-site Tree Inspection

Upon delivery, and prior to the delivery truck leaving, trees should be inspected for the following:

- ☐ Trunk scars (from branch pruning) and bud unions are healed
- ☐ Leaf size, colour and appearance are appropriate to time of year and stage of growth
- ☐ No signs of prolonged moisture stress or over-watering (wilted or dead leaves)
- ☐ No evidence of dead, diseased or seriously injured branches
- ☐ Bud unions are visible above the soil line
- ☐ Roots/root balls should be moist throughout
- ☐ Root balls are undamaged
- ☐ Bare root trees have at least three well-distributed structural roots, with some fibrous roots present (i.e. roots less than 2 mm in diameter)

Holding Container-grown and Field-grown Trees

Trees should be planted within 36 hours of delivery.

When planting is not possible and trees must be held on-site for an extended period, use the following checklist to ensure tree health and quality are maintained.

- ☐ Check soil moisture daily (and irrigate as required)
- ☐ Trees are stored in a shady area
- ☐ Check for misdirected roots in container-grown material
- ☐ Check that roots of field-grown trees are not growing into the ground

Holding Bare Root Trees

Bare root trees should be covered and placed in the shade and planted as quickly as possible because they do not have a soil ball or root ball packaging to protect roots from drying out. When bare root trees need to be held on-site, the following instructions will help ensure tree health and quality are maintained.

- ☐ Keep roots moist at all times
- ☐ If trees must be held on-site for periods longer than 24 hours, trees should be **heeled-in** to soil or consider constructing a gravel bed to provide additional protection (refer to Chapter 5 for more information)

Next Steps

1) Refer to Chapter 5 for more details on transportation and handling.
2) Proceed to Field sheet 6.

Field Sheet 6 - Tree Installation

Materials

- ☐ Pruners
- ☐ Measuring tape
- ☐ Shovels/equipment for digging
- ☐ Soil drainage results

Corrective Pruning at Planting

Only minor correction cuts on damaged, dead or **interfering branches** should be made on-site before or just after installation. Where co-dominant leaders are apparent, remove the competing leader. Use only clean and sharp tools. Most trees can be tipped over to prune before planting. Pole pruners can be used for taller trees.

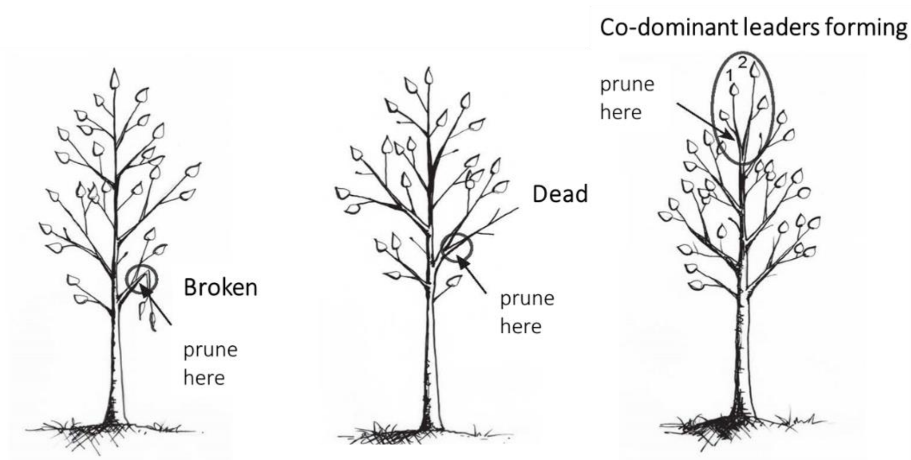
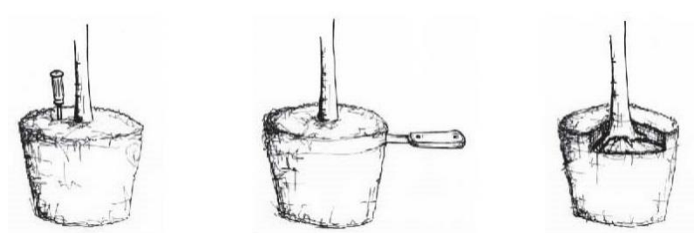


Image from USDA, 2008b.

Planting Hole Depth

1) Locate the root flare on the tree. Use a stiff wire (e.g. BBQ skewer) or a screwdriver to locate the top-most structural roots.
2) Remove excess soil or substrate covering the root flare and any loose substrate at the bottom of root balls of container-grown trees.



The root flare should be within the top 5 cm of the soil surface. Image from USDA, 2008b.

3) Measure the height from the top of the root flare to the bottom of the root ball. Based on the soil drainage results, adjust the planting hole depth to properly position root flare during planting using the soil drainage results from Field Sheet 2.

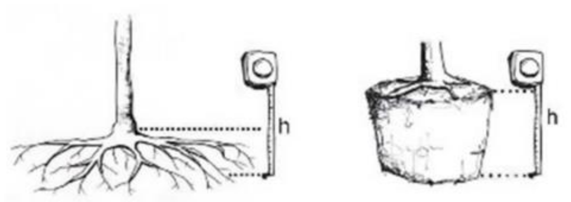


Image from USDA, 2008b.

Root flare position in poorly-drained soil

- ☐ 7.5 to 10 cm above grade

Root flare position in well-drained soil

- ☐ At grade to 5 cm above grade

Planting Hole Width

Dig a saucer-shaped planting hole with inward sloping sides. Consult soil drainage results from Field sheet 2 to help guide planting hole width requirements.

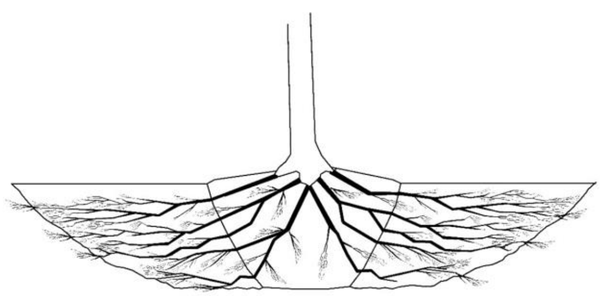


Illustration by Sean James.

Well-drained soil

- ☐ Planting hole is two to three times the width of the root ball diameter at the soil surface

Poorly-drained soil

- ☐ Planting hole is three times the width of the root ball diameter at the soil surface
- ☐ Soil is loosened around the planting hole (30 to 60 cm outward using a shovel or equipment) without exceeding the root ball depth

Tree Placement

All trees should be placed on a firm, undisturbed soil base. If the hole is dug too deeply, add additional soil and firm. Bud unions on all trees should be visible above grade.

Container-grown trees

After removing the container, remove any misdirected structural roots and potentially stem-girdling roots. Shave the outer edge of container-bound root balls (up to 5 cm) with a sharp shovel or arboriculture saw.

1) Backfill the bottom half of the planting hole with previously excavated soil. Lightly tamp to eliminate air pockets.

Trees with a soil ball

1) Backfill the bottom half of the hole with previously excavated soil. Lightly tamp to eliminate air pockets.
2) For trees in a wire basket, remove the top horizontal wire and attached loops (no more than one-third of the upper part of the basket). If the tree is in a low profile wire basket where the top horizontal wire is 10 to 15 cm below the shoulder of the ball, removing the loops may be sufficient.
3) Remove and discard all twine and burlap from the top of the root ball.

Bare root trees

1) Prune any broken or misdirected roots and then spread all roots out radially from the trunk in the prepared hole, ensuring that root tips are directed away from the trunk and not bent.
2) Backfill the bottom one-third of the planting hole with previously excavated soil.
3) Lightly tamp the backfilled soil to eliminate air pockets. Water the root zone.
4) If staking is required, confirm position of stake(s) during backfilling to avoid injuring structural roots.

Finishing Installation

1) Continue backfilling in layers using the previously excavated soil. Lightly tamp to eliminate air pockets and water each layer.
2) If the root ball is planted above grade, create a gradual slope of backfill soil from the top of the root ball extending out to at least the outer edge of the planting hole.
3) Build a 10 cm high and 15 to 20 cm wide round-topped berm around the root ball periphery. Tamp the berm.
4) Thoroughly water the soil and root ball.
5) Remove all plant identification tags, ribbons, trunk protection or packing from the nursery.

Next Steps

1) Refer to Chapter 6 for more details on tree installation.
2) Proceed to Field Sheet 7.

Field Sheet 7 - Tree Stabilization

All stabilization supports should be removed between 12 and 14 months after installation except where otherwise specified or required. Any method used should allow the movement of the **crown** in the wind, while stabilizing the root ball. If stabilization is deemed necessary choose from the following options to determine which method is most appropriate:

Staking or root ball anchoring

- ☐ Deciduous trees with a caliper less than 100 mm
- ☐ Conifers < 300 cm in height

Guying or root ball anchoring

- ☐ Deciduous trees with a caliper greater than 100 mm
- ☐ Conifers > 300 cm in height

Staking Materials and Instructions

- ☐ Stakes (diameters and lengths appropriately sized for the tree, e.g. 5 x 5 cm stakes)
- ☐ Smooth, broad (> 2.5 cm wide), pliable, biodegradable ties (folded denim, coco rope)
- ☐ Sledge hammer

Installation Instructions

1) Place the first stake upwind from prevailing wind direction.
2) If using two stakes, place the second stake opposite the first stake.
3) If using three stakes, place remaining two stakes at equal distances apart.
4) Drive the stakes into undisturbed soil outside of the root ball until stakes are secure.
5) Attach ties to the tree, still allowing for trunk movement.
6) Ties should be attached to the tree as low as is effective for stabilizing the root ball. For limbed-up trees, ties must be well below the first set of branches.
7) Ties should be secured to the stake to prevent them from sliding down.

Guying Materials and Instructions

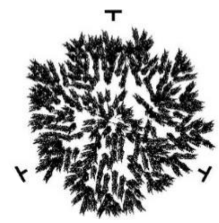
- ☐ Guy wires, anchors and sledge hammer
- ☐ Smooth, broad (> 2.5 cm), pliable, biodegradable ties (e.g. folded denim, coco rope)
- ☐ Flagging tape

Installation instructions

1) Place the first anchor upwind from the prevailing wind direction.
2) Place remaining two anchors at equal distances around the planting hole.
3) Drive the anchors into undisturbed soil outside of the planting hole and flush with the ground. Anchors should be kept within the area of where mulch will be applied to avoid creating tripping hazards.
4) Attach ties for guy wires to the trunk. Guy wires should allow for crown movement, while effectively stabilizing the root ball.
5) Flag guy wires for visibility.

For deciduous trees greater than 100 mm in caliper or conifers greater than 300 cm in height, use three guy lines per tree. Three point guy anchoring position is pictured below.

Attachments should be on the trunk above the first set of branches on limbed up deciduous trees. For all types of trees, place attachments as low as is effective for stabilizing the root ball and at a branch intersection so ties do not slide down the trunk.



Position of guy wire anchors. Illustration by Sean James.

Root Ball Anchoring Materials and Instructions

- ☐ Four 5 x 5 cm untreated wood anchors
- ☐ Two untreated wood braces (cut to fit the root ball)
- ☐ Wood screws
- ☐ Sledge hammer

Installation Instructions

1) Drive each anchor outside, but tightly against the root ball, on four corners until the top of the anchors are flush with or slightly above the top of the root ball.
2) Place wood braces horizontally so that their ends fit on top or beside each pair of vertical anchors
3) Secure braces using wood screws.

Root ball anchors should be installed after backfilling the planting hole. It is not recommended for bare root trees. Source: Dr. Gilman.

Next Steps

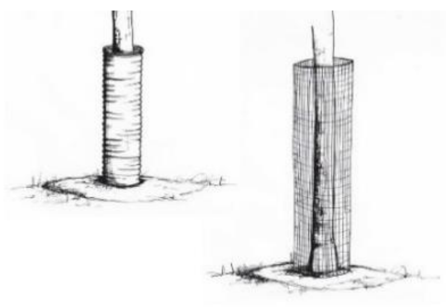
1) Consult Chapter 7 to review information on tree stabilization.
2) Proceed to Field Sheet 8.

Field Sheet 8 - Trunk Protection, Mulching and Irrigation

Materials

- ☐ Trunk wraps (if needed)
- ☐ Trunk guards
- ☐ Shovels
- ☐ Mulch
- ☐ Water source (hose and buckets)

Trunk Guards



Guards are recommended if equipment will be used around trees or if rodent or rabbit damage is likely. Image from USDA, 2008.

Installation Instructions

1) Install guards at the base of trees using loose fitting products or products that will not constrict caliper growth.
2) Guards should be snug against the soil line.
3) After installation, guards should stand 15 cm or taller.
4) Guards should be removed or replaced to accommodate the growth of the trunk of the tree.

Applying Organic Mulch

The use of organic mulch is strongly recommended because of the benefits it provides trees. All mulches should be free of invasive and noxious weed seeds, soil, salts and other harmful chemicals and applied at the proper depth.

Image from USDA, 2008.

Installation Instructions

1) Apply mulch evenly in a broad ring at least 100 cm in diameter. The larger the mulched area, the better.
2) Pull the mulch about 15 cm away from the base of the trunk.
3) The depth of mulch should be 5 to 10 cm after settling.

Irrigation

Supplemental watering is recommended for all new plantings for at least the first two growing seasons. It is important to consider if existing irrigation (e.g. lawn irrigation) will affect the watering or irrigation planning for newly planted trees.

Consider the following factors when creating an irrigation schedule, as trees will experience greater water stress in the following scenarios:

- Limited soil volume and/or impervious surfaces covering the root system
- Poor water-holding capacity of soil
- Located in inner city plantings
- Drought or low rainfall periods

In the first few years after planting many of the tree roots are still inside of the nursery production soil volume. Frequency of irrigation will depend on soil drainage and precipitation.

The size of the tree can be used to roughly estimate how much water to apply during irrigation events. For example:

- 25 mm caliper, apply 4 to 6 L
- 50 mm caliper, apply 8 to 12 L
- 75 mm caliper, apply 12 to 18 L

Apply water to the roots around the trunk within the dripline of the tree.

Appendix A - Post-Planting and Establishment Care

The information in this guide does not extend to post-planting and **establishment** care, however aftercare is often an integral part of the tender language associated with planting contracts. From the beginning of a new project it is critical to think about how trees will be maintained during the establishment phase and what is required during the warranty period time (e.g. one year or two years), as outlined in the contract.

In the table below, the following maintenance activities may be included in tenders and planting contracts. Examples of potential language in tenders are provided, as well as tasks that might be specified.

Table 9 Examples of potential language in contracts regarding maintenance and associated tasks

Activity	Maintenance tasks
Replace/adjust unacceptable trees	• Replace trees that are dead or do not meet the minimum standards as set out in the contract language • Reset any trees that have settled or are leaning as soon as the condition is noticed
Soil water management	*Provide all water required to keep soil within and around the root zone at moisture content specified in the contract language or in the detail or as necessary for healthy growth.* • Ensure automatic irrigation systems are working and provide adequate water for trees • Refill watering bags • Visit sites and manually water trees where watering bags or automatic irrigation systems are not installed or not being used
Weed management	*Keep all plantings free of weeds or other unintended plants that do not appear on the planting plan.* • Cultivate large planting areas to control weed growth • Remove weeds around the base of trees by hand • Apply herbicides to keep planting areas free from weeds (only when specified)
Mulch management	*Replenish* **mulch** *once a year (or as specified) to maintain complete coverage in accordance with the planting detail.* • Apply new mulch according to the requirements in the specification • Keep mulched areas free from weeds
Pruning	*Prune trees to address defects and maintain desired structural form.* • Remove rubbing or **interfering branches**

	• Shorten, subordinate or remove **co-dominant leaders**; remove broken, damaged, dead, diseased branches
Manage supplementary tree support systems	• Maintain guys in a taut condition • Maintain stakes in upright, supportive position • Replace broken, missing or inadequate stakes or anchors • Tighten and repair guys • Remove tree stabilization at the end of the contract or warranty period, or when the tree no longer needs support (removal of stabilization should occur between 12 and 24 months)
Manage trunk protection features	*Keep trunk protection, including wrap and guards, in proper repair.* • Repair or replace damaged tree wrap • Repair and replace trunk guards • Remove trunk protection features at the end of the warranty period or when determined to be unnecessary
Manage harmful diseases, insect pests and abiotic injury	*Manage disease, insects and other pests and abiotic injury as per contract language or at manageable levels defined as damage to plants that is noticeable by a professional.* • Apply insecticides, miticides, fungicides or other pertinent control methods or treatments (removal of affected part, hand picking of insects, etc.)
Soil nutrient levels	*Ensure there are adequate nutrients for the growth of newly planted trees.* • Collect soil samples and have tested by an accredited laboratory • Apply fertilizers at rates recommended by soil tests

Site inspections are normally done as a separate function of contract compliance to ensure maintenance requirements are being met. A work order generally provides instructions to the planting contractor or third party contractor. The third party contractor is given specific instructions which are often generated by a municipal inspector. In the table below, commonly specified inspection activities and criteria are outlined.

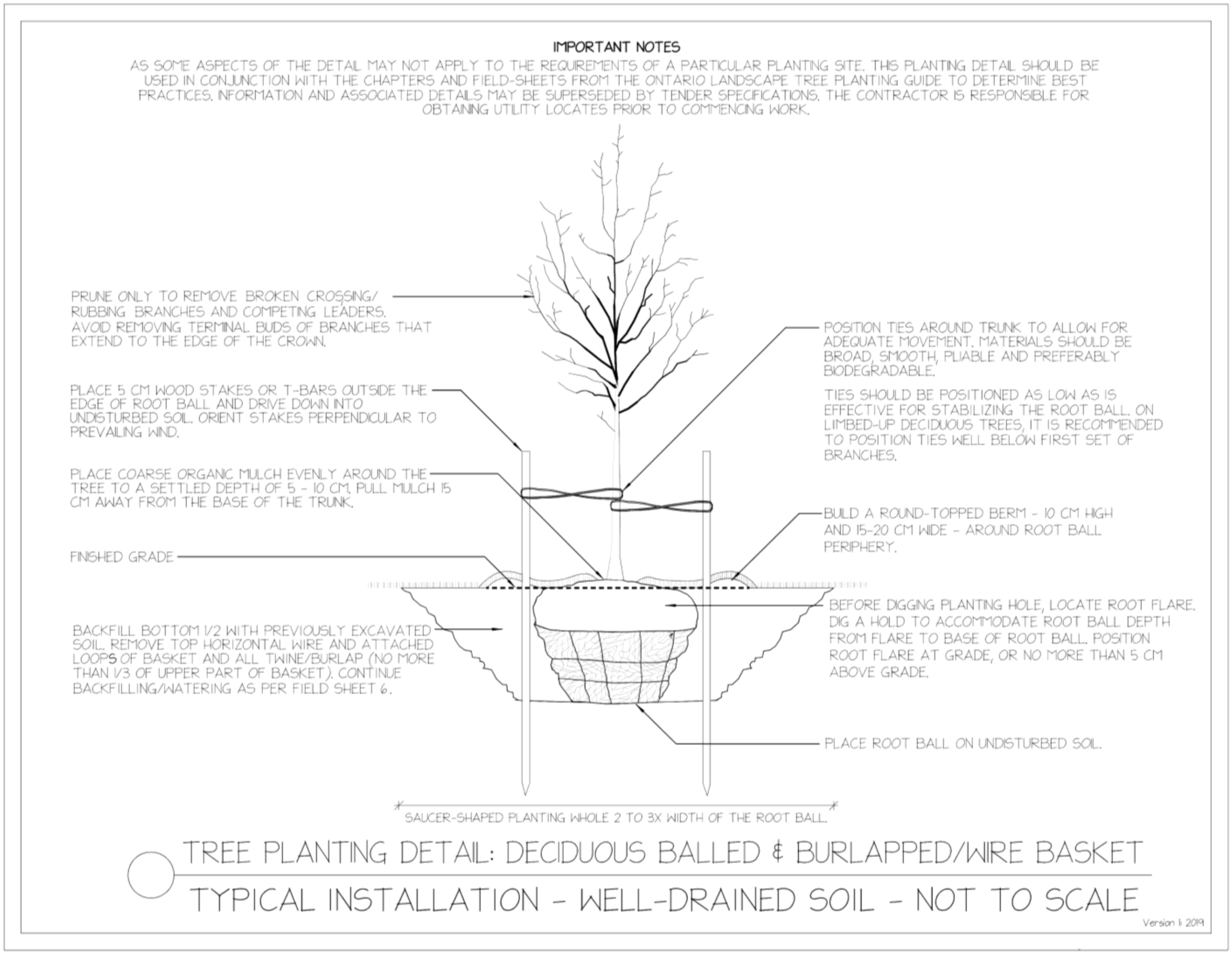
Table 10 Example of potential language in contracts regarding inspection and associated tasks

Inspection activity	Inspection criteria
Condition of plant	• General health • **Crown** structural stability • Root establishment (determine if it is time to remove stabilization)
Crown quality	• Mechanical damage to branches and trunk • Broken, dead, damaged or diseased branches • Tip dieback in crown

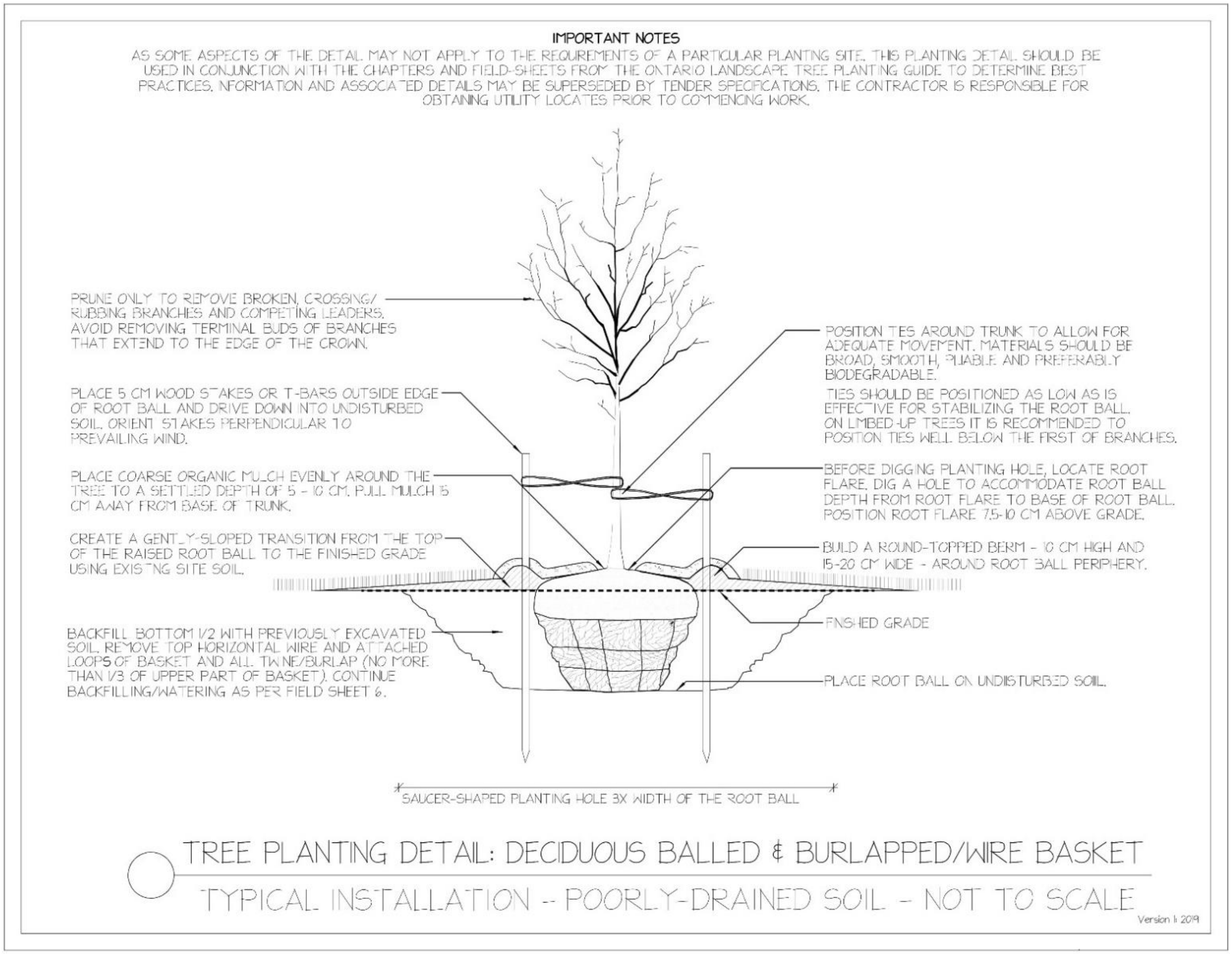
Functioning of trunk stabilization as intended **(stake and tie, guying or root ball anchoring)**	• Stakes are still serviceable/firmly in the ground and not rubbing against branches or trunk • Ties still attached and supporting trunk • Ties are flexible to permit trunk movement • Ties not strangling or girdling the trunk • Guy wires are still taut
Mulching as per contract language or planting detail description	• Correct depth • Mulch is pulled back from the trunk
Soil berm	• Berm is still functional • Removal by raking level as per contract language where appropriate
Trunk protection features	• Not girdling or restricting normal trunk development • Guards and wraps are still providing protection against damage
Pest scouting	• Pests are identified • Required management is scheduled
Watering and fertilizing requirements	• Trees are assessed for water stress and nutrient deficiencies

Appendix B - Planting Details

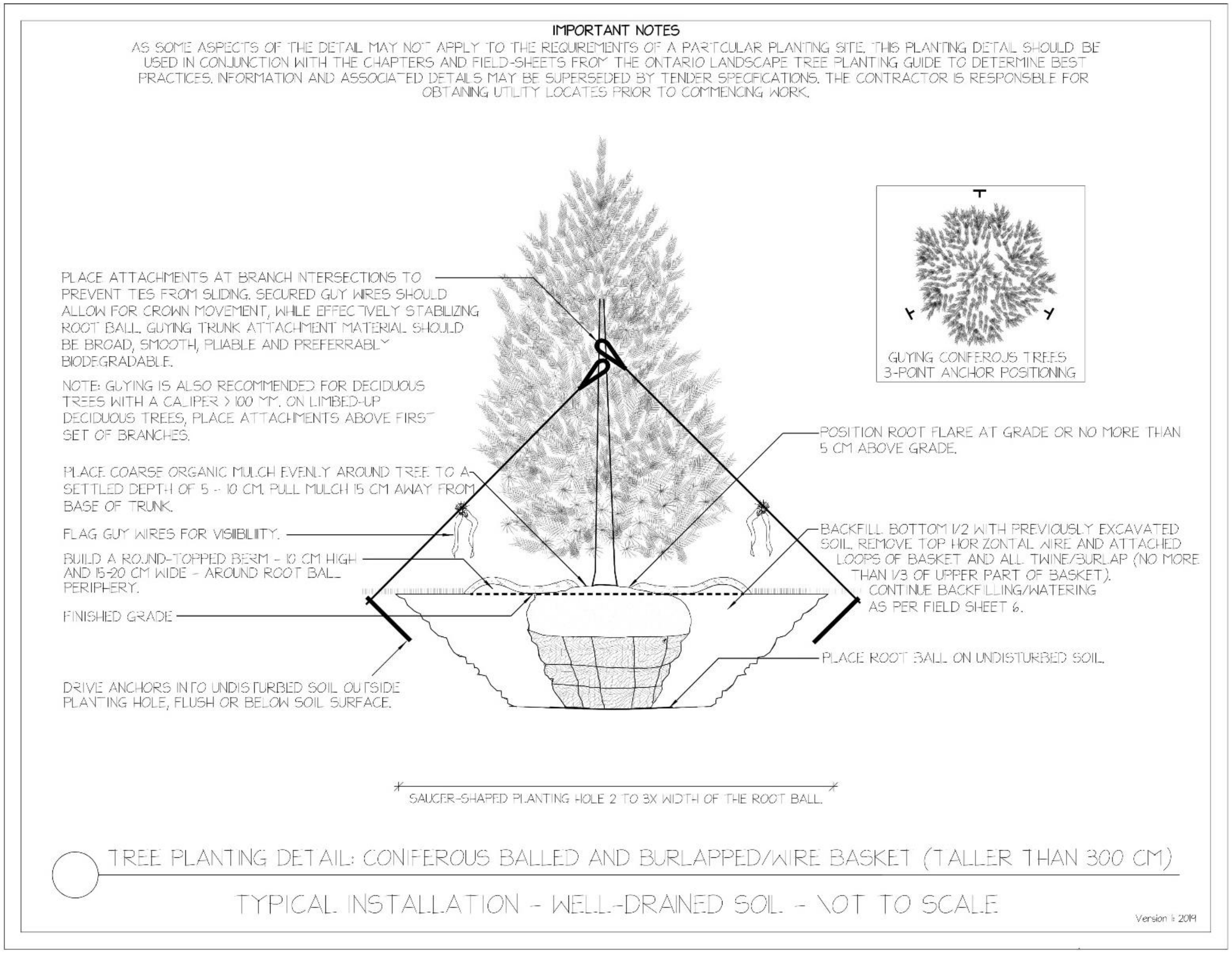
Deciduous Balled & Burlapped/Wire Basket (Well-Drained Soil)



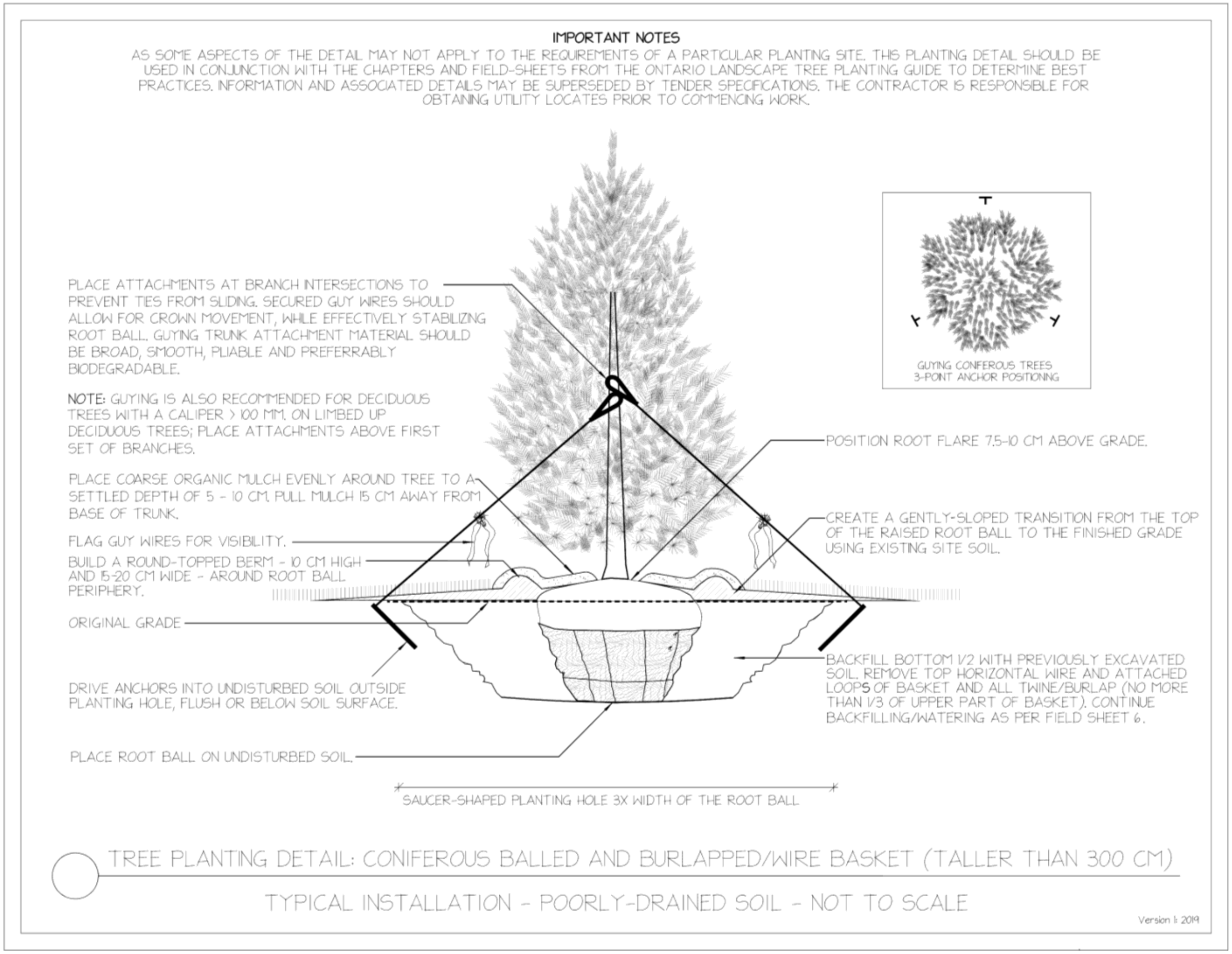
Deciduous Balled & Burlapped/Wire Basket (Poorly-Drained Soil)



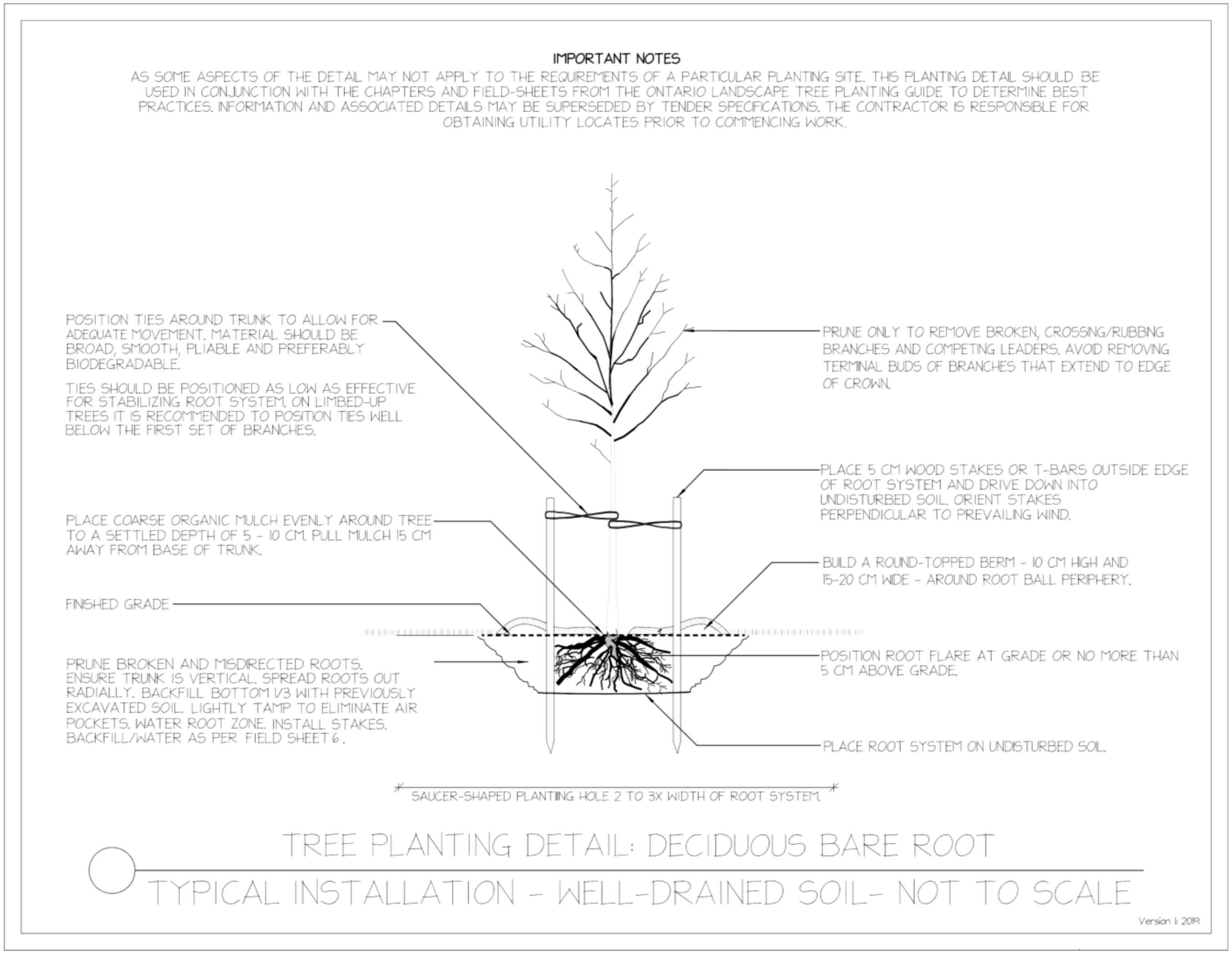
Conifer Balled & Burlapped/Wire Basket (Well-Drained Soil)



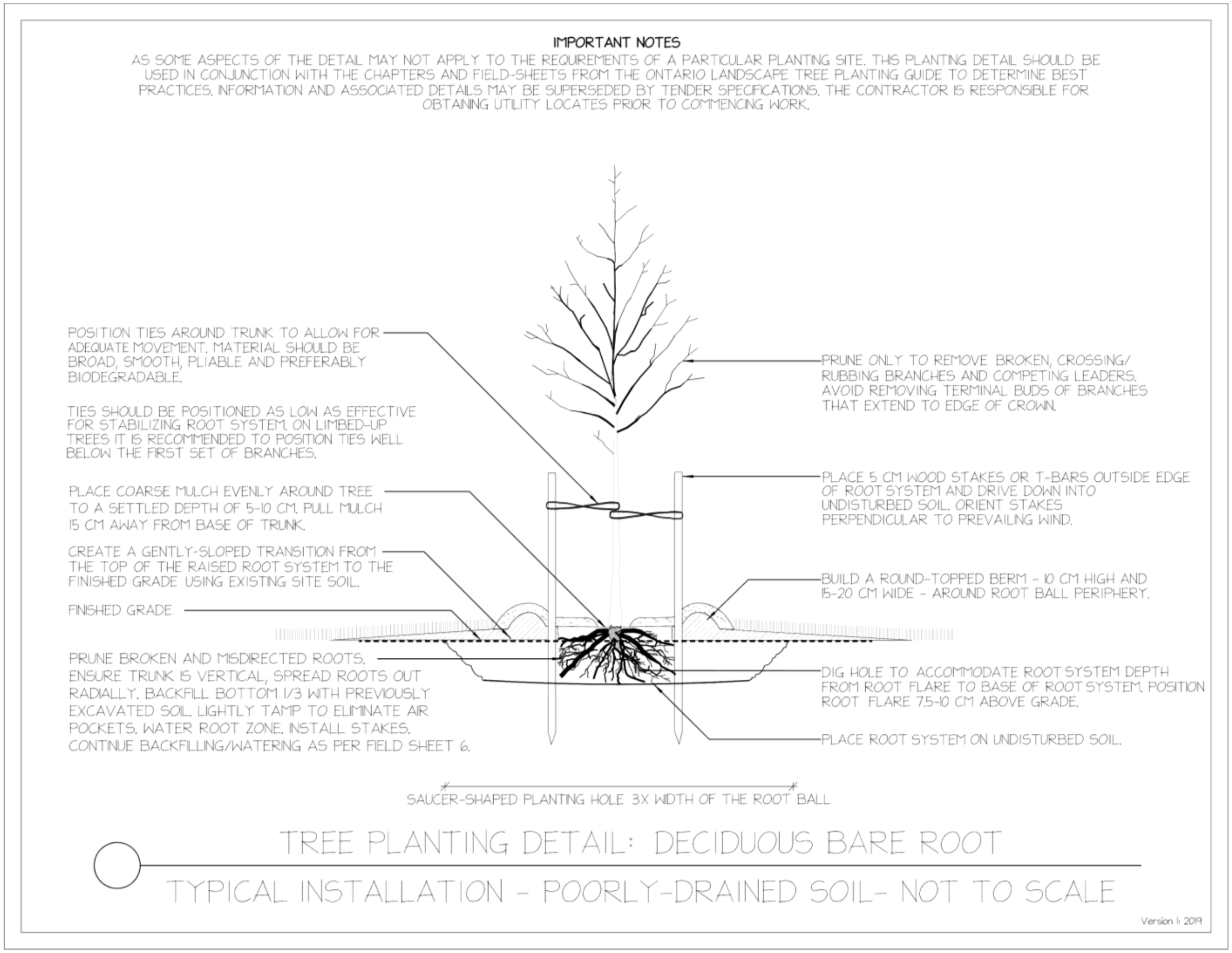
Conifer Balled & Burlapped/Wire Basket (Poorly-Drained Soil)



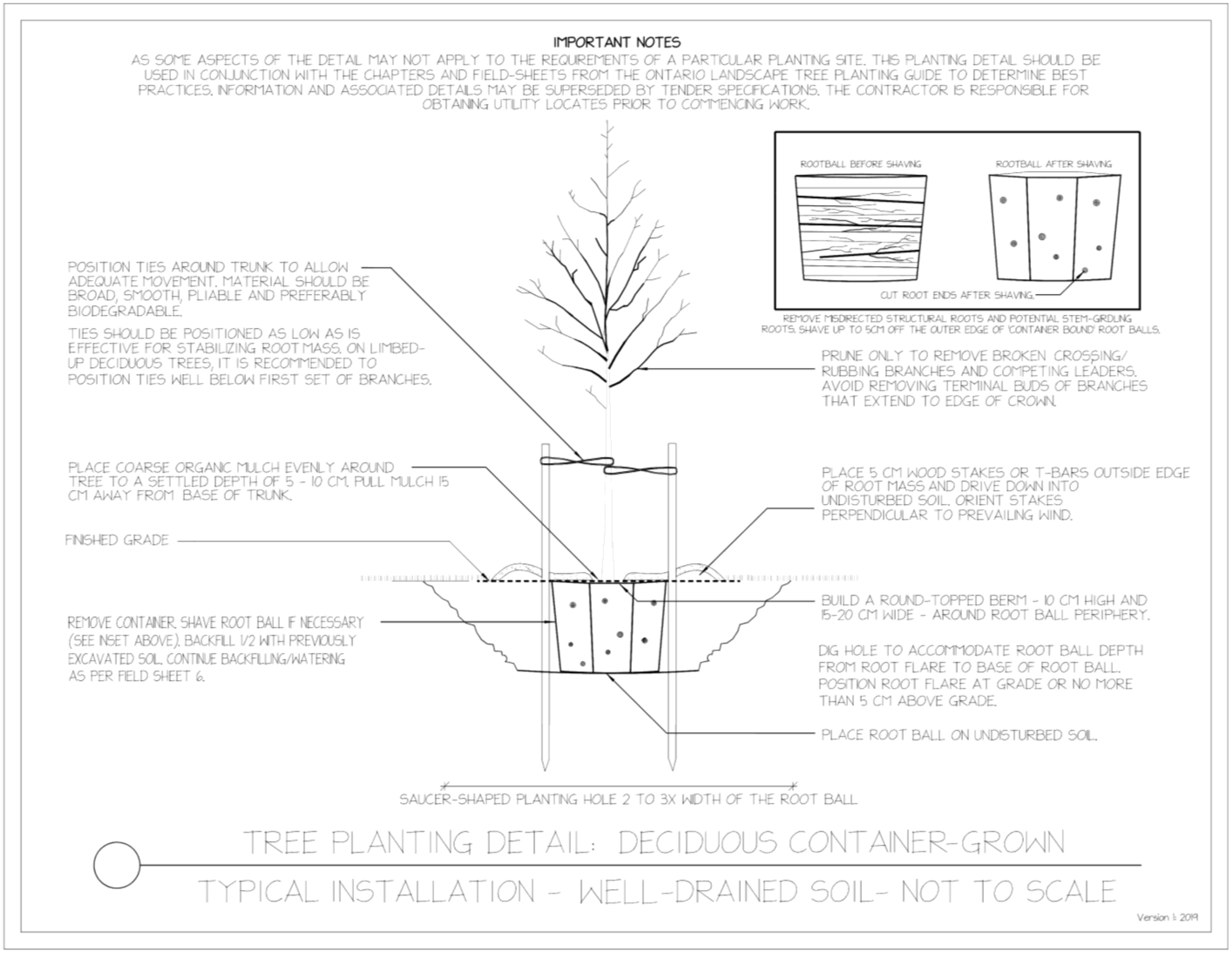
Deciduous Bare Root (Well-Drained Soil)



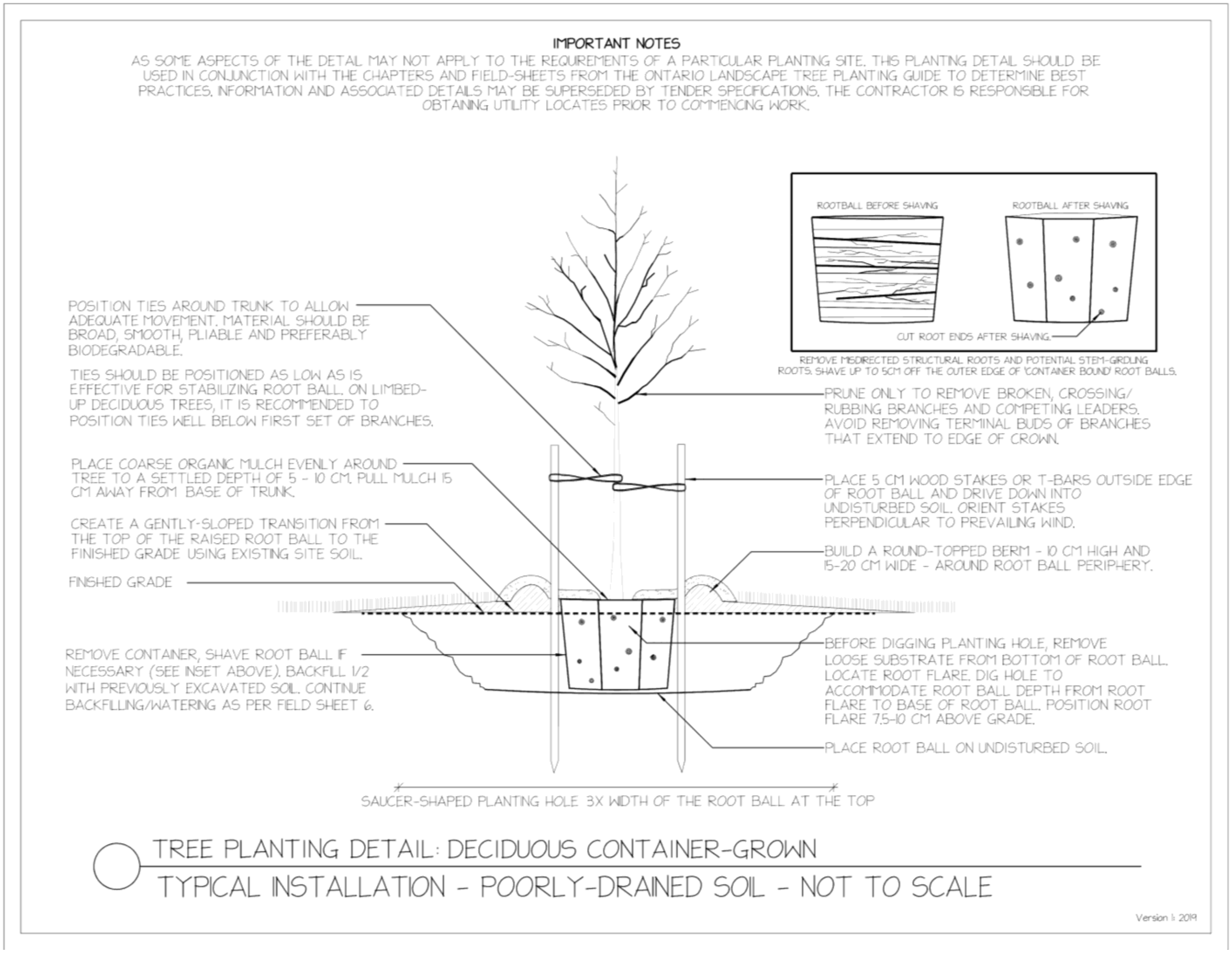
Deciduous Bare Root (Poorly-Drained Soil)



Deciduous Container-Grown (Well-Drained Soil)



Deciduous Container-Grown (Poorly-Drained Soil)



Glossary

Aggregates are groups of soil particles that are bound together between which spaces are created for air and water movement. Aggregates contribute to soil structure and form as a result of chemical and physical dynamics, as well as the biological activity of soil organisms. The process of aggregates forming is termed aggregation.

Aspect ratio is the diameter of the branch relative to the diameter of the trunk immediately above the union. Branches with small aspect ratios tend to have stronger attachments to the trunk than those with large aspect ratios.

Available water-holding capacity is the percentage of water stored between field capacity (shortly after soil is saturated from a rainfall) and permanent wilting point (the point at which soil water is generally no longer usable by plant roots). It is the amount of water that is potentially available for plant use.

Balled and Burlapped (B and B) are plants that are established in field soil, which are then harvested by digging so that the plant retains an undisturbed soil ball. The soil ball is bound in burlap and may be in a wire basket.

Bare root refers to plants harvested while dormant and where roots are exposed by removing the soil or growing medium.

Budding is a method of asexual propagation, where a bud is removed from one plant and is attached by grafting onto another plant.

Caliper is the above-ground diameter of a distinct part of a tree stem, measured in accordance with the Canadian Nursery Stock Standard. Measurement height begins at the ground level, soil line or root flare, as appropriate.

Chlorosis is a condition experienced by plants, causing a yellowing of the leaf tissue from a lack of chlorophyll due to a nutrient deficiency (often iron and/or manganese in high pH soils), disease or lack of light.

Co-dominant leaders refers to a group of two or more upright stems or trunks with similar diameters originating from more or less the centre of the tree.

Container-grown is a plant grown and marketed in a container.

Crown refers to the portion of the tree with foliage beginning at the lowest branch and including the main system of branches.

Cultivars are a variant of a species with unique characteristics, usually propagated asexually, with populations maintained through purposeful cultivation.

Electrical conductivity is the measure of the amount of salts in soil.

Essential nutrients are elements without which a plant is unable to complete its life cycle and cannot be replaced by another nutrient and is directly involved in plant metabolism.

Establishment is a period of reduced growth and vigour experienced by a tree after planting in the landscape.

Evapotranspiration is the process of evaporation from the soil, other surfaces and plant transpiration, which occurs when water is transferred to the atmosphere.

Friable refers to the crumbly texture of soil that promotes free drainage of water and root growth in the soil.

Girdling root refers to a root that grows around another root or stem, resulting in the constriction of vascular tissues of the plant. This can prevent or slow secondary growth, as well as water and photosynthate transportation.

Glazing refers to the process of creating smooth and impermeable sides and bottom of a planting hole as a result of the soil texture and digging equipment used (e.g. augers). Finer textured soils, like clays, become glazed much more readily than loamy and sandy soils.

Heading back is a pruning cut that removes a limb to a stub, bud or a lateral branch with a diameter less than one-third of the cut stem so that it does not compete with the leader.

Heeled-in refers to temporarily covering roots (e.g. with soil, gravel or mulch) before trees are permanently transplanted.

Humates are the dried and sieved form of solidified humic acids. Humic acids are derived from extractions of well-decomposed organic matter. Humic acids are organic polymers and possess very high cation exchange capacities.

Hydrogel or hydrophilic polymers can hold several hundred times their weight in water. When hydrogel is applied to tree roots, it can help prevent desiccation by releasing moisture to the roots when the surrounding soil begins to dry out.

Imprint is the structural malformation of a root system as a result of previous production practices. It most commonly attributed to solid-walled plastic containers.

Included bark refers to bark that is embedded within the union between a branch and the trunk or between two or more stems that prevents the formation of a normal bark ridge and can weaken the attachment.

Interfering branches are also referred to as crossover limbs and occur when one or more branches interfere, rub on, rest on or otherwise grow in the space of another well-positioned branch.

Leaf necrosis is the death of cells or tissues in leaves, commonly symptomatic of a disease or stress a plant is experiencing.

Leaf scorch refers to a scalding of tissues and can occur on leaves. It is a non-infectious, physiological condition that is an indicator of plant stress to environmental conditions. Leaf scorch can be identified by browning margins and tips and tissue death.

Macropores are the large (greater than 0.08 mm in diameter) primarily air-filled pore spaces among aggregates in soil which drain water freely.

Micropores are the relatively small spaces (less than 0.08 mm in diameter) usually within soil aggregates capable of retaining water and require suction to be made plant-available.

Mulch consists of material placed on the surface of soil surrounding plants. Organic mulch in particular has many benefits but should be applied at an appropriate depth and away from tree trunks to avoid moisture build-up.

Mycorrhizal fungi are a group of fungi which form symbiotic partnerships with root systems of vascular host plants, providing increased water and nutrients, as well as the potential for increased protection against some pathogens, in exchange for plant-produced sugars.

Organic amendment is any material of plant or animal origin that can be added to improve soil properties.

Porosity refers to how many pores (spaces) a soil has and is related to the space for roots to explore, space for air in soils and the amount of water a given volume of soil can hold.

Pot-in-pot system is a nursery production system that uses containers (production pots) placed inside permanent in-ground containers (the socket pot).

Radial trenching is a practice of digging channels of loosened soil, often mixed with organic amendment, to expand root-able area outside the planting hole.

Reduction cuts are pruning cuts that are made by removing a stem or branch back to just before its union with a living lateral branch of equal or smaller diameter.

Rhizosphere refers to a narrow region in the soil close to plant roots that is influenced by root exudates and associated soil microorganisms.

Root collar refers to the place on the plant where roots and stem or trunk meet, generally at the ground level or soil line.

Root defect refers to a structural malformation or misdirection of structural roots of a tree as a result of production and handling practices. Defects can occur on all trees regardless of production type.

Root flare (trunk flare) refers to the area of transition between the base of the stem or trunk and the root system where the stem or trunk broadens to form roots.

Root pathways are vertical drainage/aeration pathways or structures into which roots are channeled to grow, increasing the effective root zone beyond the planting pit.

Root shank is the transition zone between the natural root flare and the adventitious roots that have formed during field nursery production undercutting.

Soil biota refers to organisms (including microorganisms, soil animals and plants) that live the entire or part of their lives in the soil.

Soil blends are used in combination with structures that support hardscapes (e.g. suspended pavement) or modular load-bearing plastic structures and are designed to meet project requirements such as improved drainage.

Soil health refers to the capacity of the soil to function as an ecosystem supporting the myriad of organisms that live in the soil such that the ecosystem can sustain plants, animals and humans.

Soil organic matter is a carbon-rich component of soil including decomposing microbes, plant and animal residues. It is a combination of easily decomposable, less easily decomposable and more stable forms of organic matter called humus.

Soil structure refers to the arrangement of individual soil particles into groups or clumps (also called peds). These clumps can have different sizes and shapes, some appear as balls, blocks, columns or plates. Soil structure influences porosity and the movement of air, water and soil organisms.

Soil texture refers to the proportion of different sized mineral particles (sand, silt and clay) found within a soil. Sand is defined as particles between 0.05 and 2.0 mm, silt between 0.002 and 0.05 mm and clay < 0.002 mm in diameter.

Structural soil is composed of a mixture of graded gravel and soil (including both mineral and organic content) that resists compaction and provides pore space for root penetration.

Subsoil refers to the soil layer below the surface soil and is comprised predominately of mineral soils and leached materials.

Subsoiling refers to the practice of disturbing the subsurface layers of soil to reduce compaction and increase drainage.

Sunscald occurs when bark is warmed during a sunny day, usually in late winter and early spring, activating tissue to break dormancy. With the return of freezing temperatures, active tissue dies resulting in a canker followed sometimes by cracking and peeling. It occurs most commonly on the southwest side of young, thin-barked trees.

Swales are shallow low-lying, often wet, channels in the landscape. Man-made swales are often used to direct water, for instance, between houses in residential areas.

Thinning cut refers to pruning that is made to increase light penetration as well as air flow through the crown. Thinning cuts can include full branch removal or removing lateral branches from a limb.

Transpiration refers to the process – driven by evaporation – by which moisture moves upwards in plants from roots to the leaves, where it exits from stoma and is released to the atmosphere as vapour.

Transplant shock refers to a period of time after transplanting, ranging from months to several years, in which transplanted trees experience a number of different stresses.

Transplanting is the term used to describe the digging and replanting of field-grown nursery stock.

Trunk taper refers to a trunk diameter that is thicker at the base of a tree and decreases farther up the trunk.

Vertical mulching is a practice employed to aerate the soil and create localized areas of de-compaction. It involves using air cultivation, hydro-excavation or an earth augur into tree root zones and mixing loosened soil with an organic amendment.

Witch's broom refers to the stunted or abnormal development of multiple secondary shoots forming a bristly clump that resembles a broom.

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