1.6.2. Tree revitalization - Theory

General objective

To have a general knowledge how to improve health, growth and life expectancy of urban trees by reducing problems with soil and poor root vitality.

Specific objectives

A European Tree Technician working with tree revitalisation is expected to:

- Be able to identify and describe normal growth and architecture as well as diagnostic features describing poor vitality.
- Be able to identify the horizontal and vertical extension of the root zone
- Be able to analyse the soil condition and the vertical distribution of roots across the soil profile
- Have knowledge about requirements for good roots growth
- Have knowledge about techniques to improve the growth media of trees.
- Improve tree sites in accordance with technical regulations
- Carry out operations such as soil decompaction, soil aeration and soil replacement
-

Keywords

assess	Tree degeneration, “Root friendly” soil horizons, urban soil assessment, foliage density and colour, increment in stem and crown, flaws in the carbohydrate-balance
management	Projection of root zone on construction and demolition sites, air spade, air tilling, radial trenching, replacement of soil, root collar excavation, soil drainage, soil profile rebuilding, vertical mulching

See together with

This chapter assumes a thorough understanding of all other chapter 1 subchapters.

Essence of the topic

When the condition of a tree deteriorates, it’s up to the ETT to assess the possibilities and limitations for improvement of the tree’s growth media. When the options are still positive, revitalization methods can be used. There are many reasons why trees deteriorate (pests, diseases, climate change, decay ...), but one of highest share of urban trees deterioration is related to the soil and often soil compression. When revitalizing trees who are standing in bad soils, it’s essential to improve the soil. With improving we mean to get as many of the natural processes of the soil back up and running. It is rarely possible to get all three components of soil health (chemical, physical and biological) back at optimal work, but at least the root environment must be improved by a revitalisation. So, our goals are to improve soil processes and high longevity for roots, that will sustain tree vitality.

Introduction

Trees may have various acute defects like hollowness, stem forks, severed roots or rough pruning, but such problems are dealt with in other chapters. Tree revitalisation is specifically aiming at an improvement of tree vitality and tree increment and thus on a longer term the remaining life expectancy of the tree.

Tree revitalisation is a biological complicated matter and may be at the edge of the competences of many ETT's. A correct diagnosis is in particularly a complicated matter, that demands extensive knowledge and experience. Some ETT's may develop specialised skills within the subject, but all ETT's should be aware of the possibilities and the techniques of the subject. Support from specialists within urban soil management and tree biology will often be needed.

- Weakened trees may have many specific bad diagnostic features, which theoretically are dealt with in other chapters (biodiversity, tree assessment, pruning etc.), whereas a revitalisation basically is an improvement of the tree's fundamental life processes.
- Tree revitalisation aims basically at an improvement of the growth media of the tree in order to enhance the tree's water- and carbohydrate balance, which stimulate the tree's regenerative and protective processes.

Very many urban trees do not grow - they seem to remain static in size and shape. And gradually degenerate. The reasons very often relate to problems below ground. It is often related to limited root space (Urban 2008), but it is most often also related to poor soil conditions and poor root health. Suburban areas might still have some authentic, natural and undisturbed soils, but the soil in most European cities is not natural but fill materials. Old historic cities may have several meters of old building materials, debris and wastes, and random soil materials placed above the original historical soil surface. Quite often various qualities of "mull" soils (topsoils from forest or agriculture with organic material) have been used as fill material with the intension of improving growth conditions - often with poor result due to poor layering or compaction. Organic material needs a good gas exchange in the soil to have a positive effect on growth conditions. Urban soils are very often compressed with poor gas exchange (oxygen down, carbon dioxide up). Thus, "good mull" in deep horizons often do not do any good - quite often the opposite is the case. High content of organic matter below 30 cm depth often induce fermentation or anaerobic respiration by which phytotoxic substances are produced. Many urban soils contain old building materials, like iron, broken glass, brick, concrete and mortar. Brick material and coarse sand might be beneficial as these materials may improve stable structures, aeration and drainage. But bricks are commonly associated with mortar and cement, which provides the soil with an unbeneficial high pH value (pH > 8), which induces deficiency of manganese, iron and phosphorous. Urban soils commonly lack or have poor biological activity in the forms of natural soil flora and fauna. Thus, normal soil food webs and carbon cycling should not be expected in urban soils (but might be stimulated). Relevant mycorrhiza fungi are not to be expected either. However, to our experience, the most frequent problem in urban soils is the compression of the soil, leading to poor gas exchange and water logging. Other problems are related to water - either too little available water or too poor natural drainage causing anoxia (anaerobic condition). Compression often induces secondary problems with water (surface run off and poor drainage). Many urban trees can be revitalised / revived if proper soil actions are taken. In this way large, elderly trees may regain growth and vitality instead of felling them and replacing them with small nursery trees (that also quickly grown into stagnation). The economic, social and environmental benefits (not at least biodiversity issues) from revitalising elder trees instead of replacing them with small new trees are often very large.

Degenerating tree: Trees and traffic is a challenging combination. Trees often come out short. Root space and/or soil quality tend to be poor. Can the conditions be improved for the standing tree?

Soil analysis: As a minimum, a soil profile must be analysed, before initiating any soil improvements.

This profile shows 3 layers of soil fill. Large roots are only present in the upper 15 cm layer. Horizons 2 and 3 are lightly compressed. Spread clusters of fine roots are found in all three horizons. The deepest and 3. horizon has a high content of organic matter but also has a blue-grey colour. This colour indicates Fe^{+2} – the reduced (and phytotoxic) form of iron. This indicates lack of oxygen. Initiatives to improve the gas exchange to deep layers might improve the "root friendliness" of this layer.

What do we want to achieve? (the carbohydrate-balance)

A revitalisation basically aims at improving the carbohydrate-balance and thus the increment and defence mechanisms of the tree.

An improved carbohydrate-balance will improve increment in general, enhance twig and leaf mass, improve leaf colour, enhance root regeneration and above all: improve the maintenance of barriers for decay within the living woody body. Elder trees always have more or less hidden wounds in roots, stem and crown, where the woody body degenerates and dies back. A central purpose of a revitalisation actions is to slow down the spread of decay and degeneration. Or put in terms of urban forest managers: to enhance the remaining life span of the tree by several decades. Or in comparison with human medicine: It is ***not*** about fixing a broken leg; it is about improving the immune system and the general fitness, so that the patient will faster recover from a broken leg.

The carbohydrate balance is an accounting of input and output of carbohydrates ("sugar"). Input of sugar from photosynthesis and output of sugar from growth and maintenance respiration. The balance is improved either by enhancing photosynthetic productivity or by reducing inefficient sugar-consumption.

The production (input) of sugar in elder or stressed trees is commonly limited by a poor water supply to the crown (prolonged closure of stomata). This again is most commonly caused by poor root conditions. Therefore, an improvement of the growth media is often very effective to enhance root distribution, root longevity, photosynthesis and sugar reserves.

But poor root conditions also tend to speed up the "fine root turnover": Fine roots have a life span of 6-12 months ***in average*** (some live many years, others live only few weeks or days), meaning that the fine root population tend to become replaced at least once a year in a healthy tree with a good soil environment. It is anticipated that the turnover of fine roots is many times enhanced in urban trees with poor growth conditions.

In normal healthy deciduous forest trees with a "normal" viable carbohydrate balance, the produced sugar is consumed by the following sinks (a sink is a carbohydrate-consumer within the tree):

- 30% is used for development of new leaves (spring and summer)
- 30-40% is used for the current renewal of fine roots (fine root turnover all year around)
- 30-40% is used in branches, stem and woody roots for increment, wound protection and repair of rot barriers.

This carbohydrate budget is a rough average covering one year – a lot of balances (in and out) happens along the year with carbohydrates stored and used in various places at various times of year.

In urban trees with poor growth media, fine root turnover is likely to consume more than 60% of the total carbohydrate budget, which reduces the resources for growth and maintenance.

The purpose of the investigation is to identify the most critical factors and mechanisms that limits the carbohydrate-balance. This may either be flaws in carbohydrate-production (photosynthesis) or mechanisms that heavily consume carbohydrates.

A correct diagnosis is very important in order to evaluate the feasibility of a revitalisation project and in order to suggest proper measures. It may be necessary to associate a specialist to the project in order to ensure correct diagnosis.

Most often, we want to make a non-root-friendly soil into a root-friendly soil. The diagnosis (see chapter 2) clarifies whether this is possible and how to achieve a root-friendly soil environment. Techniques are explained in chapter 2.

Ideally, we want good conditions within all three components of soil vitality (physical, chemical, biological condition), but in real life we are often restricted by the site at hand. In particularly the biological component may be difficult to restore as the necessary ecosystem interactions (decomposition of leaves, interactions with low flora, migration of soil fauna etc) are absent. Success in application of mycorrhiza inoculates varies a lot – partly because of the many unknown interactivity of fungi with climate and soil components.

Often, we must be satisfied with an improvement of the physical components of soil ecology (porosity, drainage, gas exchange) whereas improvements of the chemical component of soils are often somewhat more complicated. Very low pH is the easiest chemical problem to deal with and laboratory analysis may reveal nutrient imbalances, which may also be counteracted by targeted fertilisation.

However, as soil compaction and poor gas exchange in deeper soil layers are the most common problems in urban soils, large improvements will often be possible by improved gas exchange in deep soil layers (O_2 down, CO_2 and poisonous gasses up). Furthermore, high availability of oxygen is likely also to have a beneficial spinoff to the chemical and the biological component of soils.

Problems with failing natural soil processes

In the soil chapter (1.2.1) we explained the natural soil processes as the foundations of soil health. As discussed, soil health for trees is a system consisting of a physical, chemical and biological component. Below, we describe what happens if these natural processes are failing by showing the common problems in urban soil. The focus here is to recognize these problems and knowing in what type of natural process(es) they influence.

- Urban soils are anthropogenic influenced. Very often, the soil is artificial “fill materials” of more or less beneficial kind. Furthermore, the layering of the fill materials is often not suitable.
- Poor gas exchange in the soil: low or abundant levels of O_2 and accumulation of CO_2 in the subsoil. Gas exchange and drainage can be evaluated by several parameters: A) odor/smell, B) colour (blue-grey colour is a sign of reduced iron, red or yellow colour is a sign oxidized iron). C) Absence of roots, where roots otherwise should be present, D) compression or cementation of soil. E) presence of earth worms should be evaluated conservatively (as they may eat their way through a compressed soil) but they create good macropores. The problem of poor gas exchange is commonly easy to solve, if this is the only problem.
- Compression of the soil (commonly leading to poor gas exchange, anoxia, poor natural drainage and lack of deep roots or roots being characterized by clustered presence of finer roots). Soil compaction can be measured in several ways. The “screwdriver test” is the simplest and quickest method. Test the soil by inserting a screwdriver into the soil (this works best if done 2 days after a rainfall during the growing season). If the screwdriver goes into the soil easily, the soil has minimal or no compaction. If the screwdriver can be pushed into the soil, but requires some pressure, the soil is moderately compacted. If the screwdriver cannot be driven into the soil by hand, the soil is severely compacted (Cappiella et al 2006). Please be aware of the strong bias from this method if the soil is dry. When assessing the soil profile, it is recommended to use the “screwdriver test” <u>horizontally</u> in every important soil horizon in order to reveal barriers to gas exchange and drainage. “Loosening” the soil with air pressure has become increasingly popular, and despite frequent positive effects in the short term, we do not really know very much about the intensity and vertical distribution of new

macropores after the loosening. Certainly, the soil is not loosened bulk wise – only scattered macropores are created. Also, on soils with high clay content simultaneous injection of a stable substrate into the macropores is crucial, as the pores otherwise are endangered to mud and close again after rain. The problem of compression can be dealt with in many ways.

- Lack or excess of humus. Soil fill often consist of pure mineral materials without organic material and an amendment can be reached by addition of compost or sphagnum, IF (AND ONLY IF) oxygen access is given in the enriched soil layer. Excess of humus in soil fill is but a common problem in deeper soil layers, because gas exchange is limited. This problem may be reduced by improved gas exchange.
- Unfortunate layering. If humus rich layers are buried under layers of gravel/sand, layers may be remixed by a backhoe treatment. Compression may also be reduced efficiently through a “soil profile rebuilding”.
- Lack or excess of water. The soil column may be completely dry due to slope of terrain and/or compressed topsoil. Or the soil is waterlogged due to poor drainage in the subsoil. Both problems may be solved by proper actions.
- Chemical unbalance or pollution: It is common to have pH above 8 in urban soils. Lowering the pH with sulphur is possible, but this demands a thorough analysis in the soil lab to find out the amount of sulphur. Also, it may take time for the soil to reach a new balance in the acid/Ca balance. For safety reasons, amendment with sulphur should only be carried out spot- or trench-wise, so that roots can find soil spaces with different pH-values. In the top soil addition of organic material (sphagnum) will also mitigate a high pH.

Give focus to these issues, when addressing the horizons of the soil profile. The main issue in the soil profile assessments is to clarify ***whether a soil horizon is “root friendly” or “root hostile” and reveal the causality of this judgement***. Therefore, it is important to carry out the soil profile analysis at a proper distance from a larger tree on the site (3-8 meter from the trunk), so that the vertical distribution of roots can guide you in the interpretation of “root friendliness” of the different horizons.

Self-test questions

1. How do urban soils differ from old growth forest soils?
2. Describe common problems with urban soils
3. Which soil factors are commonly limiting root vitality in urban soils?
4. At what distance from a tree do you analyse the soil profile in order to achieve knowledge about the vertical root distribution?
5. By assessing the soil horizons: what is the ultimate criterium for a suitable soil?
6. Beside soil compression, what other factors may cause tree roots to be absent in the upper 50 cm soil layer?

Case study

The picture shows a street tree from New Zealand. Please consider the problems and possible solutions.

Terminology

Condition	The actual status of physical stability
Vitality	The ability to live, grow and develop
Tree degeneration	Deterioration of the vitality (the carbohydrate-balance)

Reference list

Nielsen, C.C.N (2005): Alterungs- und Degenerationsmechanismen bei Wald- und Landschaftsbäumen. Proceeding Osnabrücker Baumpflegetage 6-7 Sept. 2004. pp 1- 12

Cappiella K, Schueler T, Tomlinson J, Wright T (2006): Urban Watershed Forestry Manual, Part 3: Urban Tree Planting Guide. USDA forest service. https://www.in.gov/dnr/forestry/files/fo-UrbanWatershedForestryPart_3.pdf

Kubisch P, Hertel D, Leuschner C (2016): Fine Root Productivity and Turnover of Ectomycorrhizal and Arbuscular Mycorrhizal Tree Species in a Temperate Broad-Leaved Mixed Forest. Forest. Front. Plant Sci. 7:1233. doi: 10.3389/fpls.2016.01233

Nielsen, C.C.N. (2007): Træers generelle ældelses- og degenerations-mekanismer. Diagnostisering og påvirkning af degenerationshastigheden. (General aging and degeneration mechanisms of trees. Diagnosing and influencing the rate of degeneration). Source: https://www.skovbykon.dk/images/stories/PDF_skovbykon/Notat_2_Degenerationsmodellen_generel.pdf

Nielsen, C.C.N. (2007): Degenerationsmekanismer i forskellige miljøer: Hvordan kan vi modvirke en hurtig ældelse og skabe gamle træer (Degeneration mechanisms in different environments. How can we counteract rapid aging and create old trees?). Source: https://www.skovbykon.dk/images/stories/PDF_skovbykon/Notat_3_Traeers_Aeldelse_forskellige_miljoeer_og_modvirkning.pdf

Essential reading

The text in this chapter summarises many years of scientific work and practical experience within different fields of science (whole tree physiology, biomass research, forest ecosystem research, root morphology and soil science). The present text is essentially new and similar is not found otherwise.

Additional reading list

UK	Urban, J (2008): Up by Roots. ISA	1