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Tree Root Systems

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Summary

The development and structure of tree root systems are described. They are wide spreading, extending radially in any direction for distances often in excess of the tree's height. Roots grow predominantly near the soil surface - over 90% of all roots, and virtually all the large structural supporting roots, are in the upper 60cm of soil. Soil disturbance within the rooting area should be avoided, as this can significantly affect tree stability and moisture uptake.

Introduction

1. This Note provides an overview of the development and structure of tree roots. Useful reviews can also be found in Perry (1982, 1989), Helliwell and Fordham (1992), Sutton (1969, 1991) and Dobson and Moffat (1993).

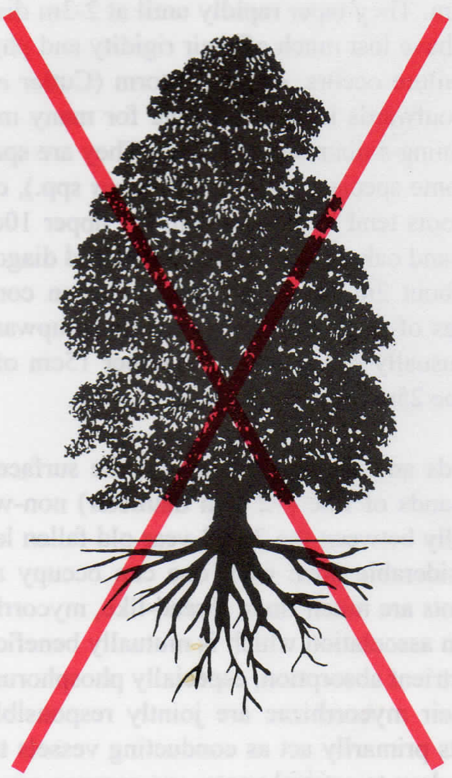

Figure 1. This is the commonly held idea of what a tree's root system is like. In fact it is quite wrong.

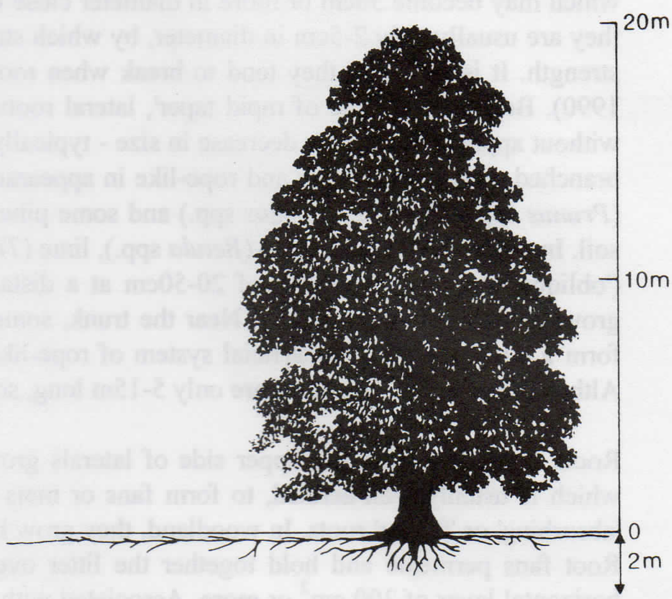

Figure 2. A tree's root system is typically fairly shallow (frequently no deeper than 2 m), but is widespreading, with the majority of roots found in the upper 60cm of soil.

2. Tree roots absorb water and nutrients from the soil, serve as a store for carbohydrates and form a structural system which supports the trunk and crown. The nature of this system is frequently misunderstood, probably because it is concealed below ground. A common misconception is that the root system is a 'reflection' of the trunk and branches (Figure 1). In fact, ***a tree's root system is surprisingly shallow, dominated by long, relatively small, lateral roots spreading out close to the soil surface*** (Figure 2) rather than by a deeply penetrating taproot. It is uncommon for trees to have roots deeper than about 2m, though exceptionally some small (a few mm in diameter) roots can extend to 5m or more. Most roots are found close to the soil surface, with 90% or more of all roots located in the upper 60cm. Whilst the typical depth of tree roots has been exaggerated, root spread has often been underestimated - they usually extend outwards well beyond the branch spread ('drip line').

Root system development

3. Initially a germinating seed has a single root, the radicle, or taproot, which grows vertically downwards provided soil conditions are suitable. Elongation is most rapid during the first 2 or 3 years but decreases with tree age and increasing soil depth. Horizontally growing side roots (laterals) form at an early stage and soon become largely responsible for structural support. Development of the taproot then declines with the result that only a small proportion of trees have a sizeable taproot at maturity. In fact, it is hard to distinguish a taproot at all in many mature trees, as injury to the juvenile taproot tip often occurs, for example, by the browsing of soil fauna, root rot, failure to penetrate hard or compact soil layers, or for nursery stock, by undercutting/transplanting. Species often thought of as 'taprooted', such as oak (*Quercus* spp.), pine (*Pinus* spp.) and fir (*Abies* spp.), appear to have a stronger inherent tendency to retain a distinct taproot, than species such as poplar (*Populus* spp.), willow (*Salix* spp.) and spruce (*Picea* spp.), but frequently the taproot does not persist even in these species. Intact taproots are usually largest just beneath the trunk and taper until they reach a depth of 0.5-1m, where they often divide into several smaller, but nevertheless downwardly growing, roots.

4. Lateral roots near the soil surface thicken over successive years, eventually becoming the large woody roots of the framework root system of a mature tree - there are usually between four and eleven such roots which may become 30cm or more in diameter close to the stem. They taper rapidly until at 2-3m distance they are usually only 2-5cm in diameter, by which stage they have lost much of their rigidity and physical strength. It is here that they tend to break when root plate failure occurs, e.g. in a storm (Cutler *et. al.*, 1990). Beyond the 'zone of rapid taper', lateral roots extend outwards in a broad zone for many meters, without appreciable further decrease in size - typically maintaining a diameter of 1-2cm. They are sparsely branched, perennial, woody and rope-like in appearance. In some species, e.g. ash (*Fraxinus* spp.), cherry (*Prunus* spp.), thorn (*Crataegus* spp.) and some pines these roots tend to grow within the upper 10cm of soil. In other species, e.g. birch (*Betula* spp.), lime (*Tilia* spp.) and oak, the lateral roots descend diagonally ('oblique laterals') to a depth of 20-50cm at a distance of about 2m from the trunk and then continue growing outwards horizontally. Near the trunk, some branches of these deeper laterals grow upwards to form a wide-spreading superficial system of rope-like roots, usually restricted to the upper 15cm of soil. Although most rope-like roots are only 5-15m long, some can be 25m or more in length.

5. Roots branching from the upper side of laterals grow upwards and divide profusely in the surface soil, which is usually well-aerated, to form fans or mats of thousands of fine (<2 mm diameter) non-woody 'absorbing' or 'feeder' roots. In woodland, they grow horizontally between the 2 to 3 year old fallen leaves. Root fans permeate and hold together the litter over a considerable area; each one can occupy a thin horizontal layer of 300 cm^2 or more. Associated with these roots are much finer, thread-like, mycorrhizae. Mycorrhizae are symbiotic fungi which grow on or in roots, an association which is mutually beneficial to both the tree and the fungus. They are extremely efficient at nutrient absorption, especially phosphorus, and many trees cannot survive without them. Fine roots and their mycorrhizae are jointly responsible for moisture and nutrient uptake, whilst the perennial woody roots primarily act as conducting vessels to and from the trunk. Fine roots have a life span ranging from a few days to several years - on average surviving for 1-2 years.

6. Roots branching from the lower side of the laterals are known as 'sinkers roots' and usually occur within a few metres of the stem. They are usually 1-2cm in diameter, grow downwards, and in contrast to the taproot or oblique laterals, divide at their extremities into fine, non-woody roots.

Root distribution

7. The variability of soil conditions and the presence of obstacles and barriers to root growth result in variable and unpredictable distribution within the general overview already presented. This is because ***root growth is opportunistic, occurring only where the soil environment can sustain it.*** Roots proliferate wherever they encounter favourable conditions, which is why the greatest root concentration is found close to the soil surface where the soil is loosest, and water, oxygen and nutrients are most readily available. Soil bulk density increases and aeration decreases with increasing soil depth and consequently root numbers and size decline sharply with depth (see paragraphs 11-13), thus below 1m it is rare to find many roots which are larger than a few mm in diameter.

Root depth

8. The deepest roots are usually found directly below, or near to, the trunk as tap, oblique lateral or sinker roots. Maximum root depth varies greatly, from only 10-20cm in waterlogged peaty soils to, exceptionally, tens of metres in loose, well-aerated soils or fissured rock. However, there is no such thing as an intrinsically 'deep rooted' or 'shallow rooted' tree species (Sutton, 1969). All trees can develop a deep root system (2-3m deep) if soil conditions allow. Apparent differences in rooting ability depend on the genetically determined capacity of roots to tolerate difficult soil conditions such as poor aeration and compaction. It is this propensity which results in the root systems of some trees being deeper than others under the same conditions.

9. Whilst genetic characteristics of a tree play some part in rooting pattern, soil conditions are of overriding importance. Thus, downward penetration of tree roots can be halted by excessive stoniness, ironpans, compact soil layers (especially compact clays), bedrock, poor aeration and high or perched water tables. Even taproots are unable to continue downwards when they reach such conditions - they either turn horizontally or die back. Where deep roots die, several replacement root tips can develop just behind the dead tissue and these in turn either become horizontal or die. Obstructions in the soil at shallow depths are common in the UK, and thus it is not surprising that a survey of the root plates of windthrown trees in southern England after the storms of 1987 and 1990 revealed that 44% of root plates were shallower than 1m, 95% were shallower than 2m and the deepest root plate was only 3m (Cutler *et. al.*, 1990). This pattern accords well with the large amount of data available from excavations of root systems which indicate that ***average root depths are typically in the range 1-2m.***

Root spread

10. Root spread is not confined to the area delineated by a downward projection from the branch tips as has often been supposed. Excavation has revealed that roots can grow for a considerable distance beyond the branch spread; typically extending outwards for a distance equivalent to at least the tree's height, and in some cases (particularly in infertile or compacted soils) up to 3 times tree height. Roots distant from the trunk are usually very close to the soil surface (Figure 2). Obstacles in the soil such as rocks, kerbs or building foundations provide a physical barrier to root extension (see Marshall *et. al.*, in preparation). Roots meeting such obstacles are typically deflected by them and once clear of the obstruction they often resume their original direction of growth.

Factors affecting root distribution

Soil bulk density

11. Root growth declines sharply with increasing density of soil; optimum growth being achieved at approximately 1.2 g cm^{-3} or less. In heavy clay soils, growth effectively ceases at a bulk density of about 1.6 g cm^{-3}, and in lighter sandy soils at about 1.7 g cm^{-3}. Compaction can be a natural feature on some sites, e.g. caused by glaciation, or it can be induced, e.g. by repeated passage of vehicles over the soil surface. Where soils have been compacted it is often difficult to establish trees because the roots fail to penetrate into the soil effectively. Trees growing in such soils develop a very shallow root system with a greater number of lateral roots in the relatively less dense surface soil (Dobson and Moffat, 1993). Roots reaching a compact subsurface horizon tend to deform or branch profusely and continue laterally above the plane of compaction. If these roots encounter a pathway through the compact layer, e.g. following a fissure or decayed root channel, they may resume downward growth. If soil beneath the obstruction is favourable then roots may proliferate, producing a two-tier root system. Established trees that experience sudden compaction of the soil (for example by movement of machinery on construction sites) frequently suffer root death, and crown dieback often occurs because of the inability of the tree to adapt quickly to the rapid change in soil conditions.

Soil aeration

12. In order for roots to survive, oxygen must be available in the soil immediately surrounding them. Oxygen supply to roots is governed by soil structure and texture; in loose or coarse textured soils the air gaps between the soil particles are relatively large and so atmospheric oxygen diffuses readily into the soil, and the waste product of respiration, carbon dioxide, can diffuse away. This process is inhibited in fine textured (clayey), waterlogged and compacted soils because pore spaces are small and may also be filled with water - gaseous diffusion is 10,000 times quicker in air than in water.

13. Poor soil aeration, especially that produced by prolonged waterlogging inhibits the growth of new roots, and can result in the death and decay of a large proportion of the existing root system. Trees standing in such conditions tend to be characterised by very shallow, plate-like root systems where roots are confined to the upper, more aerobic soil. The roots of dormant trees tolerate periods of poor aeration better than those of actively growing trees because their respiration rate is reduced and they need less oxygen.

Fertility

14. Fertile soil encourages the growth of shoots relative to roots and increases the branching of roots. Roots of established trees proliferate in areas of moist soil that are rich in nutrients, especially nitrogen and phosphorus. In general, soils with low fertility produce root systems characterised by long, slender, poorly branched surface roots, whereas sites with higher fertility produce root systems that are well branched and descend deeper into the soil (provided it is sufficiently loose and oxygen is available).

Tree roots and the water table

15. It is a common misconception that trees are heavily dependent upon the water table for moisture during dry summer months. In most parts of the UK the water table is situated deep in the soil, well beyond the reach of tree roots, and contributes nothing to meeting the water demand of trees. Trees, and other vegetation, are usually wholly dependent on recent rainfall and the water stored in the soil (Helliwell and Fordham, 1992). Moffat (1995) has demonstrated that the water requirement of trees in most parts of the UK and for most soil types, even during dry summers, is available in a soil depth of about 1.5 m. In the rare cases where roots are within reach of the water table, they quite often proliferate just above it, in the 'capillary fringe' but they are unable to grow into the saturated pores of the water table because of poor aeration. Helliwell (1993) gives further information about water tables and trees.

Practical implications

16. ***Tree roots may extend radially a distance equivalent to at least the height of the tree and are located primarily in the upper 60cm of soil.*** The main structural roots are usually found in the upper 30cm, and taper substantially within about 3m of the trunk. The vast majority of fine absorbing roots are even closer to the soil surface. Thus, ***any soil disturbance within the rooting zone will damage tree roots and should be avoided.*** Within the rooting area the following should especially be avoided:-

   - soil stripping and site grading
   - trenching, even a shallow (<150 mm) trench (see NJUG, 1995)
   - soil compaction by movement of vehicles or storage of materials
   - deposit of toxic or impermeable materials

   The nearer to the trunk that such operations occur, the greater the damage and loss of roots. This will increasingly reduce the ability of the tree to absorb sufficient water to sustain the foliage - dieback of the crown may result. ***If roots greater than 20cm are cut within 2-3m of the trunk, stability may be affected and the tree made dangerous.***

17. There is considerable misinformation about the damage that can be caused by tree roots. It is true that under some circumstances they may cause damage to built structures. However, direct damage is rare and usually only occurs when trees are situated less than 1-2m away from lightly loaded structures such as boundary and garage walls, paving slabs and kerbs (BS 5837: 1991). However, the direct pressure exerted by tree roots can be measured and is surprsingly small (MacLeod and Cram, in preparation). Indirect damage to structures may occur where tree roots contribute to the drying of shrinkable clay soils where foundations are inadequate to accomodate movements (see Biddle, 1992 for more detailed information). Guidelines exist for determining the appropriate depth of foundations for new houses on clay soils (NHBC, 1992).

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