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The Influence of Soils and Species on Tree Root Depth

INFORMATION NOTE

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NOVEMBER 2005

SUMMARY

There are numerous publications on the root plate dimensions of windthrown trees, but few relate the root depth and spread to the soil types in which the trees were growing. It is well known that different soil types and their properties are an important factor in determining the rooting habit of a tree. This Information Note reviews the available published information and aims to fill in some gaps to produce a guide of plausible rooting depth ranges for a selection of species on soils with different characteristics. By providing information on the likely extent of tree roots, this Note aims to be useful to anyone with an interest in subterranean utilities, objects or features.

INTRODUCTION

The ever-increasing quantity of utilities located below ground has highlighted the need for a greater awareness of tree root distributions and the likelihood of these utilities being affected by subsequent root growth. Similarly, landscape designers, planners and land managers are often interested in the potential distribution of tree roots when considering the preservation of features such as buried archaeological evidence, watercourses, foundations and pavements. In addition, civil engineers need to take into account the potential extent of tree roots when placing mineral caps and soils over landfill and similar reconstructed landscapes.

Figure 1

A beech tree uprooted by the October 1987 storm showing root plate.

PUBLISHED DATA

While published data are plentiful, studies of mature tree root systems that have not been uprooted are few. Due to logistical problems, excavations have been restricted to a limited number of species and soil types (Sutton, 1991).

Most of the data collected on root dimensions are therefore derived from mechanically lifted root plates (e.g. Forest Research tree pulling database) or windthrown trees, such as those in south-east England that were uprooted by the storm of October 1987 (Figure 1).

The published data from the windthrown tree surveys (Cutler *et al.*, 1990; Gasson and Cutler, 1990; Gibbs and Greig, 1990) give the soil types encountered and the number of trees recorded on each. However, no analyses of the influence of soil type were made when the root plate dimensions were recorded, and subsequent analysis from the published data is not possible.

Other methods of root study have involved trenching, soil coring and detailed excavations, for which soil information is usually given. However, the soil variability, the numerous soil classification systems and descriptive terms used further complicate direct comparison of the results. Where published root data have been found with soil description, the values have been added to the tree pulling data to produce a Forest Research root plate database that has subsequently been used in the production of the rooting guide (Table 1, page 6).

ROOT FUNCTION AND GROWTH

Larger roots contribute to the tree's stability (Coutts *et al.*, 1999), provide a network of transport vessels for water, nutrients (Coutts, 1987), other metabolic compounds, and act as a food storage organ during periods of dormancy. However, to take up water and nutrients efficiently (and increase structural support), it is necessary for root systems to establish an intimate interface with the surrounding soil (Coutts, 1987). This is achieved by the production of many fine roots and root hairs that significantly increase the surface area at the root and soil interface.

ROOT DISTRIBUTION

Root distribution can be extensive but many factors including the type of soil, tree species, age, health, environmental stresses, planting density and silvicultural management all impact upon the final root structure.

A common misconception regarding tree root structure is that the volume and distribution of roots is thought to reflect that of the trunk and branches (see Figure 2a; Dobson, 1995). A more accurate representation of tree roots is shown in Figure 2b. Typically, trees have relatively shallow but widespread root systems (Dobson and Moffat, 1993; Dobson, 1995). It is uncommon for roots to penetrate to a depth greater than 2 m, with 80–90% found within the top 60 cm of the soil profile. As mentioned, many factors can influence the rooting habit of a tree; this Note focuses on the influence of species and soil properties.

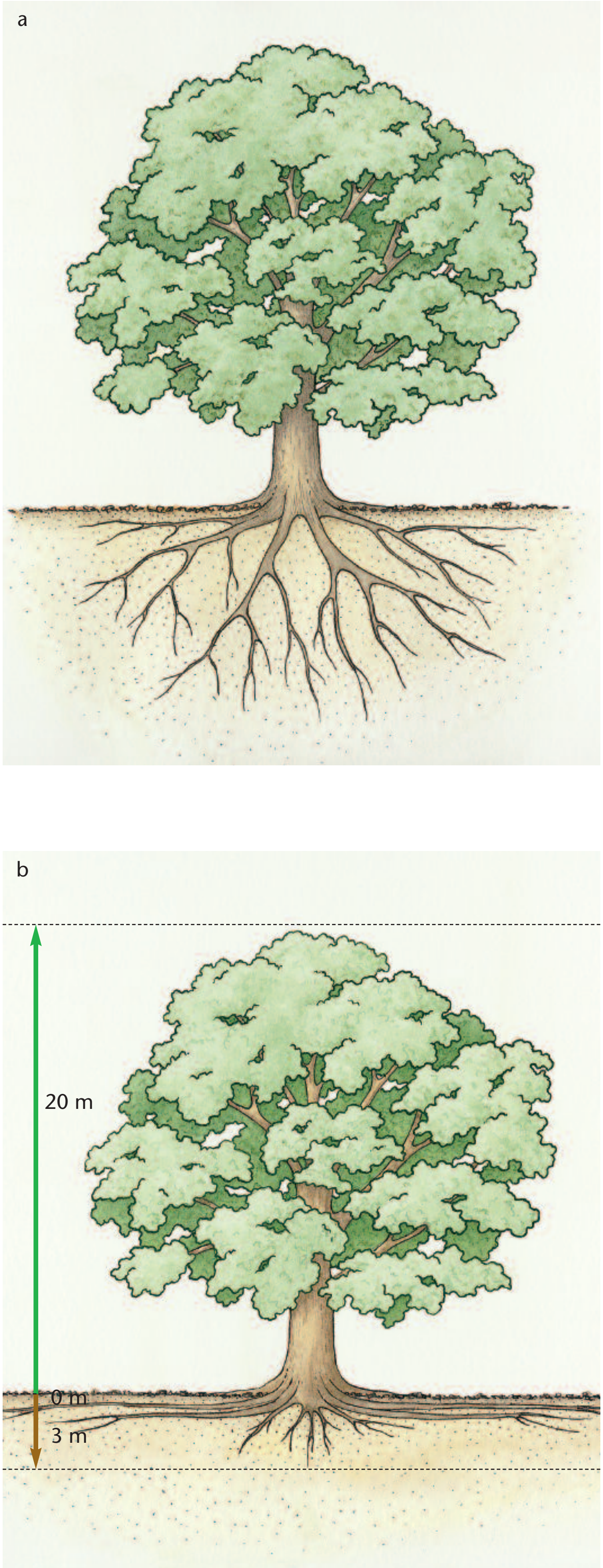
Species characteristics

The development of the tree root architecture is influenced by both the tree species (Toumey, 1929) and a range of soil conditions. Nonetheless, the initial root systems of all seedlings develop along a single axis, the taproot, from which lateral roots grow to form an extensively branched system (Coutts, 1989; Centre for Ecology and Hydrology, 2005). However, in most species the dominance of the taproot diminishes very early in the development, and is replaced by secondary roots (Sutton, 1980).

For example, of the 4511 windthrown trees surveyed after the October 1987 storm by the Royal Botanical Gardens at Kew (Cutler *et al.*, 1990), only 2.4 % were found to have taproots. A few species, e.g oak, pine and fir

Figure 2

The commonly held idea of a tree's root system (a) and a more realistic representation (b).



(Büsgen *et al*., 1929), have shown taproots that persist into adulthood of the tree and these were largest immediately beneath the tree trunk with diameters that decreased sharply (Perry, 1982).

Büsgen *et al*. (1929) identified three principal types of root system shape that were attributed to species characteristics. However, as considerable variability is encountered even within a single species, only broad generalisations can be made about the shape of the root system.

- **Taproot systems**: where a strong main root descends vertically from the underside of the trunk. Examples include English oak, Scots pine and silver fir.
- **Heart root systems**: where both large and smaller roots descend diagonally from the trunk. Examples include birch, beech, larch, lime and Norway maple.
- **Surface root systems**: where large, horizontal, lateral roots extend just below the soil surface, from which small roots branch down vertically. Examples include ash, aspen, Norway spruce and white pine.

The systems outlined here are useful to describe rooting characteristics, however Dobson and Moffat (1993) warned against such rigid classification. The characters of the three forms are often not retained by a species and many exceptions occur (Bibelriether, 1966). Additionally, this classification gives no indication of the possible rooting depth. For example, a surface root system may have branching vertical roots which descend as deep or deeper than those of a heart root or taproot (Stout, 1956).

Where trees are to be planted on or near sensitive subsoil areas, the choice of species will be an important issue, but will be restricted by the environment of the site in question.

Soil properties

While there are species-specific rooting characteristics, significant influences on rooting habit are silvicultural and environmental, i.e. silvicultural practice and soil conditions. Dobson and Moffat (1993) classified these environmental constraints into four groups:

- **Mechanical resistance.** Roots are unable to grow far into soil horizons that are of high bulk density. These include layers of bedrock, excessively stony soils or fine sands, ironpans and many clays that may become compacted.
- **Aeration.** All tree roots need oxygen to respire, but some flood-tolerant species have strategies to help them cope with reduced levels. For most, when the oxygen falls below 10–15 % in a soil, root growth is inhibited and it stops completely at 3–5%. Such conditions occur when airspaces in the soil are replaced by more soil (compaction), water or gases such as carbon dioxide, hydrogen sulphide or methane.
- **Fertility**. Infertile soils produce root systems with long, poorly branched surface roots, whereas fertile ones produce more vigorous well-branched roots that may descend deeper into the soil. While roots are unable to actively grow towards a source of nutrients, they will proliferate when in contact with areas that are especially rich in nitrogen and phosphorus. For undisturbed soils, this tends to be the upper organic-rich soil horizons.
- **Moisture**. Waterlogged soils result in poor gas exchange which depletes the soil of oxygen and leads to anaerobic conditions and subsequent root death. Soils with permanently high water tables typically cause trees to develop very shallow, widespread rooting systems. Drought conditions also cause some trees to produce a shallow root system to maximise rainfall interception near the soil surface. If there is a deeper subsurface supply of water, roots may well exploit it, providing that the soil conditions are suitable at that depth for root penetration and respiration.

The mineral and organic composition of a soil will determine the relative quantity of water that can be held within it. Soils with a large clay content are renowned for their ability to shrink and crack whereas the structure of free draining sands and gravels will be comparatively unaffected by prolonged drying. Figure 3 shows the relative fractions of particles that comprise the main soil textural classes (Biddle, 1998). When water is removed from between soil particles by roots or a falling water table, a vacuum is created. This may result in the shrinkage of some clay soils, but is usually associated with an increase in the air content between the particles.

Such differences in particle size, air and water content play a significant role in determining the soil's susceptibility to root penetration. Soils with a moisture-retaining clay content can reduce the need for roots to extend far in search of water. Conversely, a loose, well-drained soil may promote a more extensive and potentially deeper root system.

Figure 3

Phase diagram showing typical particulate composition and air and water content at field capacity for mineral soil texture classes. Adapted from Biddle (1998).

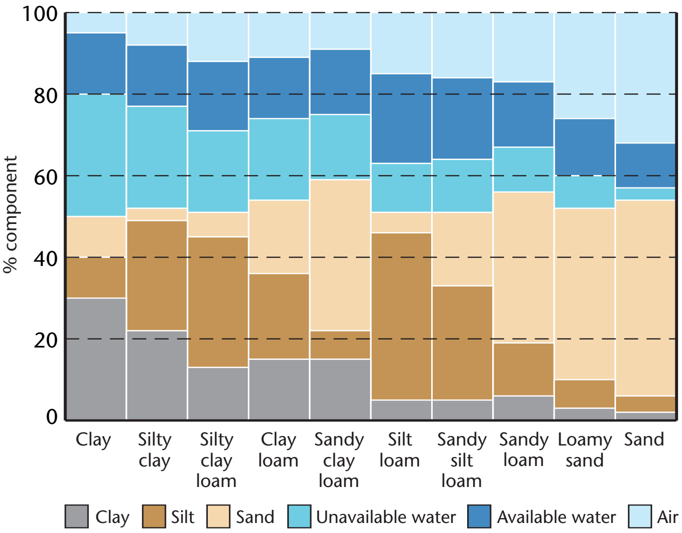


Figure 4

(a) Example of a beech root plate when grown over chalk (depth 1.1 m).
(b) Diameter (2.7 m) of the beech plate seen in (a).

ROOT DEPTH

Tree roots do not occur in significant quantities at substantial depths (e.g. > 2 m) in the soil profile. However, there are cases where isolated roots have been found at depths much greater than this in deep and loose soils (Gilman, 1990), but typically between 90 and 99 % of a tree's total root length occurs in the upper 1 m of soil. A large dataset on root plate dimensions of windthrown trees following the October 1987 storm (Gasson and Cutler, 1990) showed that no trees had roots deeper than 3 m and only 5 % had rooting depths greater than 2 m.

The soil properties described in the previous section are most variable vertically and thus have the greatest impact on rooting depth. An example is shown in Figure 4, where the shallow chalk bedrock has restricted greater rooting depth. The nutrients and moisture content influence the need for roots to descend to greater depths, while physical properties and aeration may restrict the ability to grow deeper.

LATERAL ROOT SPREAD

During windthrow, many of a tree's lateral roots will snap. The diameter of the root plate in Figure 4b is therefore not a true measure of the total lateral spread. However, root studies in forests and orchards involving excavations and soil coring have shown that the lateral growth of some tree roots can extend well beyond the canopy perimeter (Stout, 1956; Hodgkins and Nichols, 1977). Gilman (1990) found considerable variation between species in the extent of lateral root growth but many have been recorded with a radius >10 m or >20 m (Stone and Kalisz, 1991).

The ratio of root spread to crown radius was measured in several species in the eastern United States by Gilman (1990) after excavation of lateral roots. Average root spread exceeded crown radius by a factor of 1.7 in green ash (*Fraxinus pennsylvanica*) and >3 in poplar (*Populus* sp.) and red maple (*Acer rubrum*). Coile (1937) suggested that the maximum extent of the tree roots is reached before the canopy has completed expanding, and thus the ratio of root may change as trees become older.

Asymmetrical root systems are not uncommon and may result from variations in the soil environment or topographical features such as slopes. Factors influencing root asymmetry have been discussed by Coutts *et al.* (1999).

GUIDE TO ROOT DEPTHS

Table 1 shows plausible root depth ranges for a selection of species on different soil conditions. This table only addresses depth, as studies into the full lateral extent of roots are scarce. The greatest root depths found in the Forest Research database were used in the production of Table 1. Most tree roots should therefore be shallower than the value shown. However, due to the many site-specific variables that may influence the depths, they should only be used as a guide. Where possible, all values have been taken from published scientific literature or Forestry Commission data, but estimates have been made for many soil/species combinations. These are based upon the published rooting values for the species and the likely effects of conditions, and are indicated by an exclamation mark. Only species found with at least one recorded depth and soil description are included.

There are many types of soil classification system; common examples include that of Avery (1980) and the Forestry Commission (Kennedy, 2002). However, as this Note may be used as a guide in an urban, agricultural or archaeological context and potentially includes many anthropogenic soils that are less representative in such classification systems, the soils have been grouped largely by their physical and hydrological properties. These groupings may not accurately satisfy all soils encountered, but the physical and hydrological features should enable some comparisons.

1. Loose, deep well-drained soils

Some sands with large pore spaces are most likely to promote greater root depths as they are well aerated and may provide less resistance to root penetration. Examples include Littoral soils.

2. Shallow soils over rock

These are also well drained, but bedrock occurs at less than 1 m. If the rock is chalk or a similar soft rock, some local root penetration may occur. Rendzinas and Rankers are common examples of this class.

3. Intermediate loamy soils

These retain more moisture than groups 1 and 2, but still allow considerable root development. Examples include Brown Earths that can vary greatly in their constituents and water content.

4. Impervious subsoils

Soils with a large particle size that are restricted by an impervious layer. These soils may be seasonally waterlogged. Podzols, with a cemented iron pan formed within 1 m of the soil surface, are the main soil type in this class.

5. Soils with moisture retaining upper horizons

These soils are seasonally waterlogged in the top 40 cm due to poor slowly permeable surface horizons. In such soils, there may be little need for deep root development. Surface-water gleys are the most important type of soil in this class.

6. Soils with wet lower horizons

Examples such as Ground-water gleys occur within or over permeable materials that allow periodic waterlogging by a fluctuating water table. These waterlogged horizons may determine the root depth.

7. Organic rich soils

These include peat soils of varying type and origin. A distinction has been made between those that are drained (7a), and those that are predominantly waterlogged (7b).

CONCLUSION

There are many site, climatic, silvicultural and biological factors that will influence tree rooting habit, only some of which have been covered in this Information Note. However, the rooting environment (soil, geology and hydrology) has arguably the largest constraints. Published data of root dimensions for mature trees that include observations on this rooting environment are limited, and those found to date have been incorporated into Table 1. However, it must be stressed that these ranges are only examples and site-specific variables may result in depths different to those shown. Finally, it should be emphasised that for all tree species, the vast majority of roots will occur in the uppermost metre of soil.

Table 1 Probable rooting depth ranges for selected tree species. For details of soil groups 1–7 see page 5. Soil suitability data adapted from Mitchell and Jobling (1984) and Pyatt *et al.* (2001).

Species		Soil groups							
Scientific name	**Common name**	**1**	**2**	**3**	**4**	**5**	**6**	**7a**	**7b**
Abies grandis	Grand fir[a]	**	!		!				*
Abies procera	Noble fir[a]	**	!	!	!	!	!	*	*
Acer campestre	Field maple	**	**		**	!	!	**	***
Acer pseudoplatanus	Sycamore	*	**		!	!	!	!	**
Alnus glutinosa	Alder[a]	**	!		!		!	!	!
Betula pubescens	Downy birch[a]	*	!		!	!	!	!	!
Carpinus betulus	Hornbeam[a]	*	!		!			!	***
Castanea sativa	Sweet chestnut[a]	*	!		**	**	**	!	***
Fagus sylvatica	Beech	**	!		!	!	!	**	***
Fraxinus excelsior	Ash	*	**		**	*	*	!	***
Juglans regia	Walnut[a]	*	!		**		!	**	***
Larix decidua	European larch		!		!	**	**	!	**
Larix kaempferi	Japanese larch[a]	**	!	!		!	!	!	*
Malus sylvestris	Apple[a]		!		!		!	!	*
Picea abies	Norway spruce	*	!		!		!	!	*
Picea sitchensis	Sitka spruce[a]	*							
Pinus contorta	Lodgepole pine[a]		!				!		
Pinus nigra var. *maritima*	Corsican pine		!				!	!	***
Pinus sylvestris	Scots pine[a]				*	***	***	!	***
Populus alba	White poplar[a]	**	**		!		!	**	**
Populus tremula	Aspen[a]	*	!					!	*
Prunus avium	Wild cherry	**	**		!	!	!	!	*
Pseudotsuga menziesii	Douglas fir[a]	*	**		*	*	*	!	***
Quercus robur	Pedunculate oak[a]	*			!			!	***
Salix alba	White willow[a]	**	!	!	!	!		!	!
Thuja plicata	Western red cedar	*	**	!	!			!	*
Tilia cordata	Small leaved lime	!	!		!	!	!	!	***
Tsuga heterophylla	Western hemlock[a]	*	**		!		!	!	***

[a] Unlikely if soils are calcareous.
*** Conditions not recommended for growth.
** Not ideal and growth may be impeded (will vary from site to site).
* Not ideal for growth but some values published.
! Values are conjectural (all others values are from database).

Probable rooting depth range for mature trees

<0.5 m | <1.5 m | <2.5 m | <4.0 m | <1.0 m | <2.0 m | <3.0 m

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ISSN 1460-3802
ISBN 0 85538 679 7