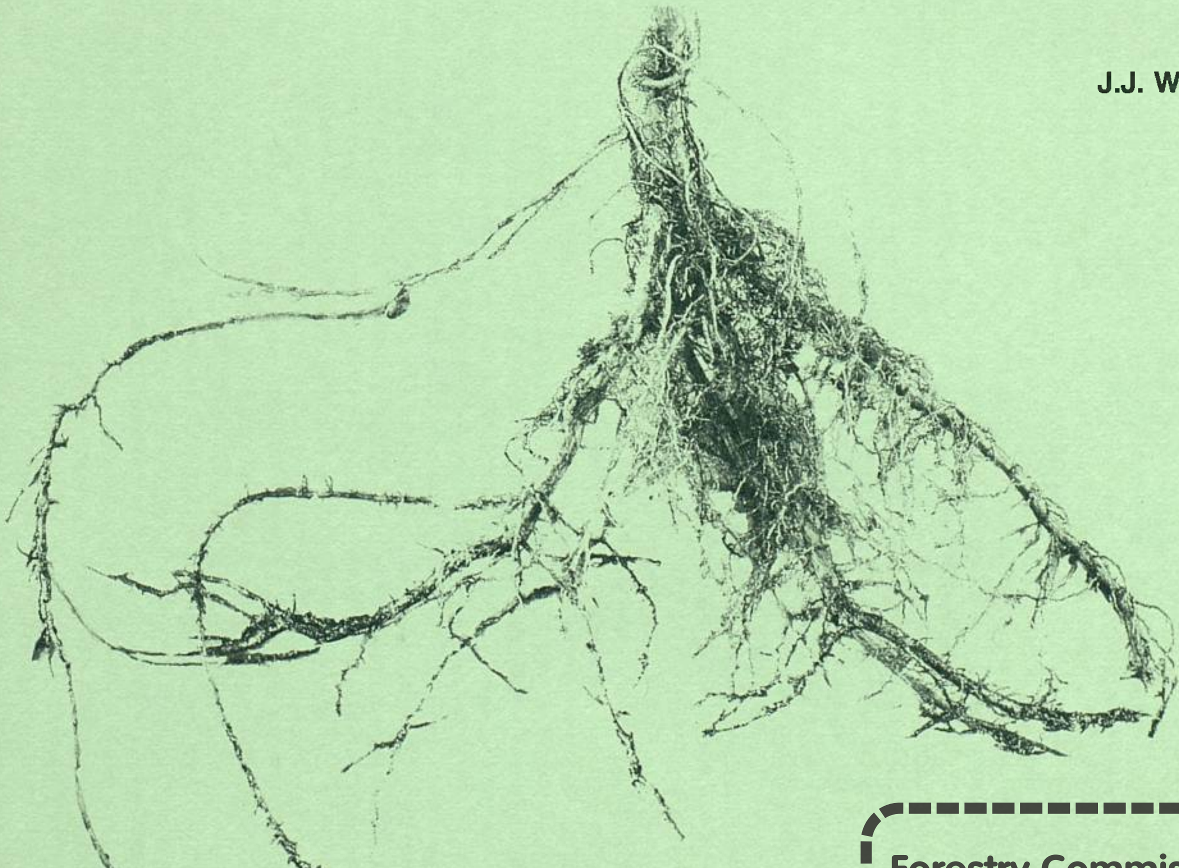
Forestry Commission

Occasional Paper 20

Nursery Stock Root Systems and Tree Establishment

A Literature Review

J.J. White



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OCCASIONAL PAPER 20

NURSERY STOCK ROOT SYSTEMS AND TREE ESTABLISHMENT

A LITERATURE REVIEW

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This review was contracted by The Committee on Plant Supply and Establishment (CPSE) whose constituent bodies are listed in the Preface

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FRONT COVER: Well-balanced root system of a 2-year-old oak transplant. (*38929*)

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The author is extremely grateful for this support and acknowledges the many people who so willingly assisted the work. The author particularly wishes to thank: Mr D. Patch – who initiated the work, for his enthusiastic support, advice and guidance, and for collating this report. Dr M. Coutts – for his help with the physiological aspects, and also his colleagues Mr P. Tabbush and Dr C. Walker; Mr J. White of Tilhill Nurseries and Mr B. Humphries, formerly of Hilliers Nurseries – for their invaluable assistance in nursery practice; and lastly the staff of the Forestry Commission Library.

Preface

Landscapers, foresters and all who use trees and shrubs, usually only meet nurserymen when plants are being bought and sold and such business encounters rarely encourage the interchange of information, experience and ideas. For this reason the Joint Liaison Committee on Plant Supply was established to provide a forum for both the large scale users of plants and for the growers. However, as areas of concern have emerged the Committee has evolved to include tree establishment in its remit and is now known as the Committee on Plant Supply and Establishment (CPSE). Representation on the Committee has varied over the years but at the time of writing member organisations are:

Arboricultural Association
Association of County Councils
British Association of Landscape Industries
Horticultural Trades' Association
Institute of Leisure and Amenity Management
Forestry Commission
National Farmers' Union
Landscape Institute
New Towns Landscape Working Party

Early achievements of the Committee included production of lists of plants, trees and shrubs and herbaceous plants suitable for regular use in amenity planting schemes. In an effort to ensure that plants were adequately specified and tenders for supply of nursery stock were comparable, a recommended Form of Tender for Plant Supply has been developed, and recently revised for the use of major plant purchasers.

The Committee also produced a booklet *Plant handling* which gives a code of practice for the care of plants from the time they are lifted until they become established. Adoption of these recommendations should be an essential feature of any contract for the supply of trees and shrubs so that among other things, desiccation of roots should be minimised and plants should be alive and viable at the time of planting. (This booklet is reproduced here as Appendix III).

In about 1982 the Committee became concerned at the inadequacy of specifications concerning plant roots in, for example, British Standard 3936 *Nursery stock. Part 1: Specification for trees and shrubs.* It was thought possible that the characteristics of a root system capable of withstanding planting shock and becoming established could be better defined. However, a brief review of the subject highlighted an apparent paucity of knowledge and suggested that research might be needed. As a result it was agreed that an initial literature review should be undertaken with the object of indicating what was known and where deficiencies in knowledge existed and research justified. As neither finance nor manpower could be found within existing research organisations for this initial work it was agreed that the necessary finance be raised from the organisations represented on the Committee. This was provided by:

Arboricultural Association
Horticultural Trades' Association
Landscape Institute
National Farmers' Union.

A botanist with post-graduate experience was recruited on a short-term contract in 1984. The initial work and preparation of the report was undertaken under the guidance of staff at the Forestry Commission's Research Station at Alice Holt Lodge. The Forestry Commission has acknowledged the importance of this review by agreeing to publish and distribute the report. Many thanks are due to the Forestry Commission and to organisations listed above for their support of this project.

Looking to the future it is hoped that research can be initiated to answer some of the questions posed.

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November 1986

NURSERY STOCK ROOT SYSTEMS AND TREE ESTABLISHMENT - a literature review

Jenifer J. White†

Introduction

John Evelyn (1678) recognised that trees were being cut down more rapidly than natural regeneration, which was often browsed by animals, could replace them. As a result he suggested that trees should be grown intensively in nurseries and transplanted to their growing-on positions. Today we rely on nursery-grown trees for both forestry and landscape use. Unfortunately on many amenity sites a large proportion of newly planted trees fail to establish and die within weeks while the ones that survive often do not grow vigorously.

Many factors are undoubtedly responsible for these failures and current research is investigating the causes and developing ways to alleviate the problem. For example the Department of the Environment is funding the Forestry Commission to investigate tree establishment problems and results have shown the importance of better plant handling during transport and the need for weed-free areas around newly planted trees. Other research is examining soil physics problems on reclamation and development sites, the importance of protection and microclimate around individual trees, and effects of staking. However there appears to be little published research into either determination of the optimum root system required for a tree to survive transplanting or into the characteristics which govern plant quality necessary for good establishment.

In the nursery, transplanting and undercutting are practised to produce field grown trees and shrubs with a root system conforming to British Standard 3936 *Nursery stock*, that is "well-balanced in relation to the plant and . . . conducive to successful transplantation". Optimum growth is also encouraged to meet the overall height and stem diameter requirements of this standard.

The British Standards Institution produces two types of publications:

1. recommendations and

2. specifications.

The recommendations are intended to be advisory or for guidance. Quotation of a 'specification' number in a contract calls for compliance and the courts may take into account the details of the specification in determining whether or not someone has been negligent or in breach of contract. Ideally, specifications should, therefore, include only criteria which can be assessed and enforced. In the case of BS 3936 there is a need to develop specifications which can be quantified for a root system which can tolerate short periods out of the soil during which some desiccation may occur, but which can regenerate rapidly after planting to fulfil the moisture and nutrient needs of the tree.

This Occasional Paper is a literature review which was undertaken in 1984 to establish what is known about tree root systems, their size in relation to the shoot and the nutrient/moisture status needed for good root regeneration after planting. The specific objectives of the review were:

1. to prepare a report summarising the available information and highlighting deficiencies in knowledge;

2. to identify research needs in tree and shrub production and handling;

3. to make amendments to the specification for roots in the Plant Supply Tender Document (Joint Liaison Committee on Plant Supply 1982) and BS 3936 (1966, 1978 and 1980).

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Interpretation of the literature is hampered by a lack of consistency in the criteria used, combined with a lack of supporting evidence for statements made. In addition the terminology is often undefined leaving the reader to guess the meaning. For example, when used in terms of roots 'fibrous' and 'fine' have different meanings to plantsmen and scientists. Unfortunately, as a literature review, this report can only adhere to the terms used in the literature cited.

Most of the reports of research work on nursery stock relate to forestry and especially coniferous transplants. Although such works may be of interest and indicative of likely results it is considered unwise to extrapolate the results to broadleaved trees without any form of verification. Furthermore there may be differences between the genera of broadleaved trees.

The Paper concludes with a list of subjects which appear to warrant both research and development.

Measuring planting stock quality

There is a need to be able to measure quantitatively the quality of trees and shrubs produced by the nursery trade. Planting stock quality was defined by Willen and Sutton (1980) as "the degree to which that stock realises the objectives of management (to the end of rotation or achievement of specified sought benefits) at minimum cost. Quality is fitness for purpose." The objectives of management are critical in determining quality, i.e. size and form, they must be realistic and take account of site factors, cultural practices (including site preparation and establishment methods) and species characteristics (Willen and Sutton, 1980). But this overlooks the biological 'fitness' of a plant, which may include conditioning in the nursery to aid survival in the environment of the planting site.

The size of the root system, that is percentage of total root system retained on the tree after lifting from the nursery bed, is an important factor in nursery stock quality (Day *et. al.*, 1976). Physical characters such as lengths and diameters are the most commonly used measurements as they are easy to make, and correlate with performance (Nambiar, 1980). According to Lyr and Hoffman (1967) root length reliably relates to the plant's physiological quality. Root colour has also been used as an indicator of root condition but it is not reliable (Mullin and Svaton, 1972; Sutton, 1979). Root weight represents the net gain from phytosynthesis but it must be measured as oven dry weight and therefore necessitates destructive sampling. Root weight as a measurement can be misleading because the tap root may account for nearly 50% of the dry weight but only 3–6% of the root length (Mullin and Svaton, 1972). Lyr and Hoffman's (1967) root analyses showed that 86–89% of the total root length is fine root (less than 1 mm in diameter). On average fine roots of Sitka spruce (*Picea sitchensis*) made the largest contribution to root biomass and had larger radial growth than thick roots (Deans, 1981).

Armson and Sadreika (1974) used root and shoot volume, or root area index and shoot diameter, as indicators of the morphological quality of roots and shoots, while Racey (1985) compared root area index, volume and dry weight. The root:shoot ratio appears to have a limited value in assessing plant quality, since it is difficult to define what the optimum should be. The ratios of dry weights or lengths apparently are not reliable indicators (Mullin and Christl, 1981 and 1982; Racey, *et al.*, 1983; Sutton, 1979). Ratios are difficult to interpret or use in an objective manner, but they may be useful in the identification of damaged or deformed root systems (Mullin and Christl, 1981 and 1982). Mullin and Svaton (1972) found that only shoot length and diameter in white spruce (*Picea glauca*) seedlings were well interrelated with survival and growth 10 years after planting. For transplanting into landscaping schemes it is surmised that stock having a root:shoot length ratio equal to, or greater than one (≥ 1), would be advantageous; however, Mullin and Christl (1981 and 1982) found that the larger the conifer transplant the better the field performance in research plantings, and, since taller trees have smaller root:shoot ratios, small root:shoot ratios may not necessarily be detrimental. It may be that research has concentrated on unsuitable components for determining root:shoot ratios. Perhaps ratios such as root spread to shoot height would be better if lateral root spread rather than depth is more desirable or some aspect of proportion of root types may have some relevance. These morphological measurements have been combined to produce an index of seedling (forest conifers) quality. Dickson *et al.* (1960b) (cited in Armson and Sadreika, 1979) suggested for white spruce:

$$\text{Quality Index} = \frac{\text{seedling dry wt (g)}}{\dfrac{\text{height (cm)}}{\text{shoot diameter (mm)}} + \dfrac{\text{shoot weight (g)}}{\text{root weight (g)}}}$$

Alternatively growth can be expressed as seedling indices:

$$\text{Seedling Index} = \frac{\text{Height (cm)}}{\text{Root Area Index (cm}^2\text{)}} \times \text{diameter}^2\ (\text{mm}^2)$$

(Armson and Sadreika, 1979).

All these reports refer to physical criteria and relate them to survival after planting - none attempt to evaluate the physiological condition of the plants with the different physical ratios.

It cannot be assumed that planting stock in a visually good physical condition will also be in good physiological condition (Day *et al.*, 1976). The physiological status of the plant determines its ability to produce roots after planting and its subsequent survival and, hence, success in establishment. Glerum and Lavender (1980) discuss the various techniques available for assessing physiological quality such as foliar and soil nutrient analyses which indicate the nutrient status and possible deficiencies of the stock. Such analyses are, however, generally too slow for corrective fertiliser programmes to be applied in the same growing season.

Seedling survival is directly related to root growth capacity, frequently measured as RGP (root growth potential) (Burdett, 1979; Bushey, 1947; Day *et al.*, 1976). Deans (1981) showed relative root growth rates in Sitka spruce (*Picea sitchensis*) to be inversely related to root diameter. The root growth capacity can be measured by either a displacement technique to detect root volume changes, or a semi-quantitative method where, under standard conditions, the number of newly elongated roots is recorded (Burdett, 1979). Laboratory measurements such as photosynthetic rate, seedling lipid content, and membrane integrity may be useful but probably not for practical determination of present or future nursery practice. In cold storage the viability of stock could be assessed by carbohydrate analyses (McCracken, 1978; Ritchie, 1982), but this technique requires more research and calibration.

There are possibilities of using electrical impedance as a physiological measure. Glerum (1980) studied the annual trends of electrical impedance in coniferous nursery stock, and inferred that, to some degree, it measures dormancy and frost hardiness. However, there are practical problems with the method as electrical impedance is influenced by a number of physical factors, such as tissue type assessed, size of plant, temperature and moisture content, each of which must be taken into consideration. It is not understood what is actually measured: whether it is ionic or electrical activity, or whether the activity is due to moisture content, water potential or water saturation deficit, all of which are physiologically distinct (Coutts and Tabbush, personal communication). Webb and von Althen's (1980) work suggests that shoot xylem water potential is a promising rapid measure of physiological quality. This is based on the root growth capacity of six hardwood species being significantly correlated to shoot xylem water potential at time of removal from cold storage. However, Coutts' (1981a) results show that moisture content and water potential, as measures of planting stock quality before planting, are unlikely to be reliable.

Conclusions

A 'standard' root system is purely theoretical, as roots develop in response to soil conditions. A generalised measurement of physical characteristics may not therefore provide a measure of plant quality.

Apart from recent developments using root growth potential (RGP), the ability of a tree to survive lifting in the nursery, transport and replanting and then to flourish is the only gauge of physiological condition currently available. This is unsatisfactory because it is time consuming and if, for assessment purposes, a sample of plants is forced in a protected environment, the trees are effectively destroyed for landscape use. Where small numbers of large nursery stock are involved these techniques would be unacceptable because of cost and space required.

Although theoretically it should be possible to measure the physiological quality of a tree - especially moisture content and carbohydrate status - a practical and accurate test has not yet been developed.

Current specifications

A "root system well balanced in relation to the plant" as specified in the British Standard for trees and shrubs (BS 3936:Part 1:1980) is difficult to quantify, and because of its subjectivity it cannot be used to decide a dispute about plant quality. The standard has been augmented with various apparently subjective guidelines for root ball sizes. The Department of Transport (1977) and Hebblethwaite (1974) recommend that when moving smaller semi-mature trees "the diameter of the prepared root ball should be at least twelve times the stem diameter measured at a height of one metre above ground level. This can be reduced to nine times the stem diameter as the tree height increases." The suggestion is that young trees need a relatively larger root:shoot ratio to survive than large trees. The Civic Trust Practice Notes (undated) include that for semi-mature trees "the diameter of the prepared root ball should be ten times the diameter of the stem at three feet above the ground, the depth will seldom be less than one foot or more than three feet." The East Sussex Conservation Grants Scheme (1982) stipulates for bare root nursery stock that "for all trees taller than 1.8 m the minimum acceptable radius of viable root (well spaced on more than one quadrant of the stem) shall be 10% of the overall height of the tree." Stanley and Toogood (1981) suggest guidelines for the depth of root balls of unspecified sizes of conifers as:

1. root balls with diameters of less than 500 mm, the depth should not be less than 75% of the diameter;
2. root balls with diameters of 500–750 mm, the depth should not be less than 67% of the diameter;
3. root balls with diameters of 750–1500 mm, the depth should not be less than 60% of the diameter.

In the British Standard specificiation for roses the root systems are defined dimensionally (BS 3936:Part 2:1978). For bush and shrub roses the root system, grown in open ground, must "include at least three major roots of minimum length 20 cm, arising within 7.5 cm of the union and having lateral and sublateral root growth" (see Appendix I). These minimum dimensions are based on a sample of rose bushes specially lifted and taken by the representative nurserymen to the BSI Committee (Mattock, personal communication). The 20 cm quoted, which is very similar to the depth of a spade, is what nurserymen can produce.

The *American Standard for nursery stock* (Anon., 1973) (see Appendix II) details minimum root spreads for shoot heights and calipers for bare root stock. The Standard details both the minimum root ball diameter for shoot heights and calipers, and ball diameter:depth ratios. The research that these dimensions are based on is not known (Brush, personal communication). It seems that the sizes quoted probably reflect what a nurseryman can feasibly produce rather than research based criteria for optimum stock quality. However, the *American Standard for nursery stock* 'has received no criticism on the root spread since it was added in 1959' (Brush, personal communication).

Except for root:shoot ratios there is little available literature defining the size or quality of the root system in quantitative terms. In conifers the root:shoot dry weight ratio decreases from the first year progressively and is almost always less than one (Jones, 1968). In broadleaved seedlings the ratio usually decreases to a minimum of less than one (Jones, 1968). The high shoot proportion in conifers is partly due to leaves being included in the shoot weight. Stoeckeler and Jones (1957) specify minimum calipers at ground level and top lengths, to tip of terminal bud for conifers, for nursery, and field planting based on general experience and experiments. A 200 mm (8 inches) root length for transplants was regarded as acceptable for final field planting stock. Root:shoot weight ratios of greater than 1:3 were considered very good, whereas ratios less than 1:5 were considered top heavy. Yet references for container stock have root:shoot ratios of 1:7 (Rogers and Head, 1969) suggesting that a container grown plant is likely to be either unbalanced or more able to withstand transplanting shock.

Generalising for broadleaved transplants, although little information was available, Stoeckeler and Jones (1957) suggested the plants should have "a minimum stem caliper of 6/64 inch at ground line to give good field survival for 2-0 stock and 10/64 inch for 3-0 stock". Evans (1984) recommends that "for plants between 25 and 50 cm tall root collar diameter should be at least 5 mm and preferably in the range 6–8 mm."

Stout (1968) summarised ratios of root spread:shoot height found in the literature. The lateral radial spread of a root system of a mature undisturbed tree is greater than that of the crown, and crown spread is often less than the tree height, which is less than root length (Stout, 1968).

Conclusions

The well balanced root system required in specifications has not been defined quantitatively. Furthermore it seems that root system dimensions quantified in some specifications are based on subjective comparisons and not the result of objective experiments.

Root growth

There is no standard root system. Roots form a dynamic structure, and root architecture reflects hereditary factors - species, variety, clone, etc., and environmental ones - soil moisture and nutrient patterns, availability of oxygen, and soil temperature; the latter factors are controlled by soil physical properties, moisture status and to a lesser extent by gravity. The production of new roots depends not only on the soil conditions, but also the genetic characteristics of a particular species or individual, the nursery practice during the production cycle (especially in the season prior to lifting), and the conditions under which stock is stored and transported between nursery and final planting (Danier *et al.*, 1979). All these factors are likely to affect the ability of a tree to regenerate roots.

Prager and Lumis (1983) correlated survival and growth of trees after planting with the inherent root growth capacity of the tree at planting time (also Burdett, 1979). As Day *et al.* (1976) point out, root regeneration capacity, both potential and actual, is probably more important in terms of survival, than the initial size of the system lifted from the nursery. Bushey (1947) related the variation in survival among species to differences in the loss of fibrous roots during lifting and planting, and in the capacity to regenerate new roots. The actual root growth potential (RGP) appears to be influenced by the timing of lifting, storage regime and chilling requirements, and endogenous factors such as hormones (Prager and Lumis, 1983). Recent work by Tabbush (1986, 1987b) has also shown the sensitivity of RGP to rough plant handling and seasonal factors.

The growth of roots is periodic, which obviously has important implications for the timing of successful planting (Kozlowski, 1971). Spring planted trees regenerate more new rootlets than those planted in the autumn (Bushey, 1947). The length of time the root grows is dependent on the species, but generally it continues longer than shoot growth, ending in October/November, and starting again in March to June. Temperature is often a limiting factor to root growth (Hoffman, 1974). The limiting range of soil temperature appears to be 2–7°C. The problem is distinguishing between the physiological and ecological optima. A physiological optimum temperature would be around a maximum of 20°C, but the ecological optimum is likely to be much lower, and the actual soil temperatures are probably lower than either optimum (Lyr and Hoffman, 1967). Bowen (1970) demonstrated that increasing soil temperature to 15–20°C resulted in increased primary root length but there was also a marked increase in the number and length of lateral roots of *Pinus radiata*. However, with *Robinia* lateral root formation was inhibited at 19°C, and at higher temperatures, 33°C, the length growth of the main root was inhibited favouring side root development (Kozlowski, 1971). Low soil temperatures slow the plant's metabolism so that transport of carbohydrates, essential for root growth, is restricted. In winter, as well as low soil temperature, there is hormonal inhibition of root growth in deciduous trees (Hoffman, 1974).

Good aeration of the soil is essential for root growth and nutrient uptake (Shoulders and Ralston, 1975; Sutton, 1969; Trought and Drew, 1980). The compact layers of soil beneath the surface can influence the shape of a root system by deflecting individual roots (Büsgen and Münch, 1929). Lyr and Hoffman (1967) found that trees with a high root:shoot ratio seemed to have a greater ability to penetrate hard soil layers.

Root growth is affected by soil moisture conditions. It is well known that plentiful supplies of water and nutrients to a plant's roots will result in a smaller proportion of root growth in relation to shoot growth. Also the larger the supply of carbohydrates the smaller the proportion that is used for root increment (Jones, 1968). Koller (1977) and Bibelreither (1966) both demonstrated that on dry nutrient-poor soils lateral root extension was greater than in trees on richer, moister soils. Stress in upper regions of root systems due to a dry soil layer can reduce growth. Equivalent water stress to lower roots is even more detrimental, especially as it is from these roots that most new roots originate (Larson, 1980). An external water shortage causes internal xylem water stress. Significant stem dieback also occurs at only moderate (-4 to -6 bars) soil moisture stress (Larson, 1980). Nurserymen irrigate to avoid moisture stress in their growing stock, but if an application is inadequate to make good the soil moisture deficit, it encourages superficial root development. Waterlogging leading to anaerobic conditions inhibits or, if permanent, prevents root growth and such a zone, e.g. a water table, will, like hard rock or indurated layers, act as a barrier.

Application of fertiliser encourages strengthened development of side roots at the expense of the main root growth (Kozlowski, 1971). There is preferential allocation of photosynthate to the roots when the plants are under mineral nutritional stress, but nutritional deficiency will reduce the mean diameter of lateral roots (Nambiar, 1980) and they will be poorly branched and long ('seeking' roots) (Kozlowski, 1971). The individual nutrients may have direct effects on the root system's shape and quality. High nitrogen levels will reduce the root:shoot ratio (Atterson, 1964). Phosphorus influences the root system configuration in wheat (Nambiar, 1980), and is important in tree root development (Patch *et al.*, 1984). Because phosphorus moves slowly downwards in the soil, surface application can stimulate superficial rooting (Kozlowski, 1971). Drought resistance is thought to be improved by increased nitrogen and phosphorus availability (Furuta *et al.*, 1972; and Larsen, 1981).

Physiologically, RGP appears to be closely linked to bud dormancy (Ritchie and Dunlap, 1980). Increased root regeneration coincides with loss of physiological dormancy in sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*) seedlings (Webb, 1977). The control mechanism is not really understood but involves a combination of promoters and inhibitors (Lavender and Hermann, 1970). There is conflicting evidence for the origin of root growth stimulus. Lee and Hackett (1976) proposed that rooting is stimulated by growth regulators from physiologically active buds, and by sufficient available carbohydrate. New root production seems to require current assimilates rather than stored carbohydrates (Ritchie and Dunlap, 1980). Shoots and roots compete within the plant for carbohydrates and their distribution is essentially determined by the relative levels of metabolic activity of the shoots and roots (Brouwer 1977; Webb, 1976). Brouwer (1963) found that removal of part of the shoot or root resulted in the redistribution of metabolites between the two parts until the original root:shoot ratio was restored (Brouwer, 1963), implying that loss of roots may result in shoot dieback and conversely shoot pruning may lead to root dieback. However, in experiments with northern red oak (*Quercus rubra*), Farmer (1975) showed that stimulation of root activity originated in the stem of both active and dormant plants; and Lavender and Hermann (1970) demonstrated that active buds did not stimulate root growth. From the literature there seems to be little attempt by researchers to correlate the activity and growth of root and shoot meristems. Studies on the physiology of the whole plant during both the dormant period and the subsequent period of active growth appear to be lacking.

There is also conflicting evidence for the role of individual hormones. In Farmer's (1975) experiments auxins applied to decapitated plants stimulated root regeneration while inhibiting shoot growth. Prager and Lumis (1983) state that auxins act directly on root initiation, and that the other homones – cytokinins, gibberellins, ethylene and abscisic acid act through control of shoot growth. Maki and Marshall (1945) showed that although IBA (indole-butyric acid) created a substantial increase in root development this was at the cost of reduced survival. However, endogenously applied auxin, or gibberellic acid did not stimulate root growth in Lavender and Hermann's (1970) work. It is likely that root growth is affected through the role of gibberellins in dormancy release. Ethylene and cytokinins are thought to influence root growth directly through their other functions. The root tip appears to be the source of a powerful inhibitor of lateral root emergence (Wrightman and Thimann, 1980); this inhibitor is possibly abscisic acid (Ritchie and Dunlap, 1980). The root tip is also the source of a substance that moves basipetally (descending from the apex to base, and interacts with the acropetally (ascending) moving growth regulators, to regulate the zone for lateral primordia initiation (Wrightman and Thimann, 1980). It is thought that auxins mobilise the sugars or increase carbohydrate metabolism in roots (Prager and Lumis, 1983). Hay and Woods (1975) postulate that accumulated carbohydrates are channelled into the lateral roots between photoperiods. The well developed roots that result may be advantageous during establishment in the field. Removal of the root tip, as in root pruning, causes a rapid, but temporary, increase in the number of lateral primordia. Selby and Seaby (1982) suggest that as auxin treatments stimulated lateral root production such hormones could be used in the nursery to increase the stability of transplanted seedlings.

Ritchie and Dunlap (1980) comprehensively review the nature of the root growth stimulus. They conclude that the action of auxins in root growth is not clear but it probably works through effects on other hormones. The concentration of auxin is important. High levels promote initiation of lateral root primordia whereas low levels stimulate root elongation. In conifers gibberellins have no direct effect on root growth but may be indirectly involved through control of carbohydrate distribution. In broadleaves the effect of gibberellins on root growth is dependent on the species.

Root regeneration characters are highly heritable (Nambiar *et al.*, 1982) and there are possibilities of exploiting such effects on root morphology and physiology to improve establishment and survival (Nambiar *et al.*, 1982; Räsänen, 1980).

Conclusions

In summary it must be emphasised that there is no standard root system or pattern of growth. The way a root system develops is dependent on many soil factors, the species of plant and within a species from one plant to another. Certainly root growth is periodic and the potential for root growth is influenced by date of lifting and storage, and the soil conditions at the planting site. Nursery practices such as adding fertilisers and irrigating stock encourage a type of root system that may not be conducive to survival when planted out in landscape schemes. The trees are grown in the ideal nursery environment and then transplanted to hostile planting sites.

The physiology of tree root growth is complex and the role of individual and combined hormones are not yet understood. Root growth is linked with the breaking of bud dormancy, the stimulation being hormonally controlled. Auxin appears to be an important hormone influencing growth by controlling carbohydrate metabolism. The root is part of a whole plant and will respond to hormones controlling shoot growth as well.

Mycorrhizas

The root systems of most woody plants are greatly modified by the presence of mycorrhizas (Kramer and Kozlowski, 1960).

The mycorrhizal association, especially for deciduous trees, is an obligate symbiosis; the mycorrhiza provides an extension to the root system for the uptake of nutrients and water absorption. Mycorrhizas probably increase the root:shoot ratio by providing additional absorbing organs and effectively increasing root surface area. (Lyr and Hoffmann, 1967). In tree establishment it is usually assumed that the associations will develop but research shows that specific inoculation can sometimes improve survival and establishment following planting (Mexal, 1980).

Kormanik *et al.* (1982) showed that the presence of mycorrhizas significantly increased root weight, and that differences among the tree species were reflected in the numbers of structures produced by the fungi. Levy and Krikun (1980) postulate that the mycorrhizal association affects plant-water relations through the root and shoot hormonal balance because of changes in stomatal regulation rather than by reducing root resistance.

Before mycorrhizal inoculation can be used commercially an appreciation of the importance of the symbionts in relieving transplanting shock is required. High levels of fertiliser decrease the extent of advantageous mycorrhizal associations with the roots. Practical consideration must be made of inoculum production and integration of inoculation with other nursery practices.

Conclusions

The mycorrhiza can extend the root system of a plant and improve the potential for water uptake. A possible commercial application could be to inoculate planting stock with mycorrhizal fungi to aid establishment, especially on virgin soils and man-made sites.

Nursery practices

When a tree is planted out its survival will depend on its physiological condition, its genotypic ability to adapt and the environmental conditions on site (Burdett, 1983). Nursery practices should aim to produce the best stock. Lower plant densities in the nursery lead to improved root growth (Timmis and Tanaka, 1976), and the results were better than from root pruning (Aldhous, 1972; Atterson, 1964). Lower stocking densities result in increased dry weight, root area index, root collar diameter, and height (McClain, 1977). However, the main practices designed to improve plant quality for planting out are undercutting and transplanting.

Undercutting

Undercutting (root pruning) is primarily a method of producing nursery stock, without transplanting, fit for planting out in the field. This is achieved by stimulating the growth of new roots, secondary laterals, by cutting existing roots during the growing season with a blade moved horizontally under the nursery bed at a regulated depth (Aldhous, 1972). It is generally accepted that the roots of seedlings are undercut at a depth of 8–10 cm when they have reached a depth of 20–25 cm in the soil (Aldhous, 1972). With mechanised undercutting any lateral roots growing across the rows and sinker roots will be pruned. Wrenching is a method of undercutting which also lifts the plant slightly by using an angled blade. The result is to produce a shorter, fibrous root system that is considered desirable, and conducive to survival and establishment in landscape planting (Kozlowski and Davies, 1975).

Nambiar (1980) demonstrated that undercut seedlings (*Pinus radiata*) had a larger proportion of roots (primary laterals) capable of regeneration, and regenerated more new roots after transplanting than seedlings that had not been undercut. He reasons that this is probably due to the plants' ability to avoid water stress during the post-planting period (Nambiar, 1980). However, the increased root branching generated by undercutting was shown to have no beneficial effects on subsequent survival and growth in black walnut (*Juglans nigra*) seedlings (Williams, 1972). Williams (1972) advocates that it is not necessary, or desirable, to increase root fibrosity by cultural practices (i.e. natural root development should be allowed) other than to restrict the roots, which if left undisturbed for 4–5 years would be very extensive.

In temperate climates there is usually a seasonal pattern to root growth. The periodicity of root growth is dependent on shoot activity and soil conditions (Daniel *et al.*, 1979), primarily moisture and temperature. Generally roots are dormant during midwinter. Root dormancy begins after shoots are already dormant about October (Lyr and Hoffmann, 1967). Root growth is initiated again by the breaking of bud dormancy. The periodicity of root growth is controlled by hormones. The pattern of growth and dormancy is dependent on the species and age (Daniel *et al.*, 1979). Generally, maximum root growth, in terms of number and length, is in the early summer (Lyr and Hoffman, 1967). Growth may also stop in midsummer because of drought or high temperatures.

As new root formation occurs primarily on fibrous roots it is important that the fibrous roots are not lost through poor lifting or handling (see p. 11 root growth). The root system must be lifted from a depth greater than the undercutting level for the root pruning operation to be effective. The timing of undercutting is therefore important if the results are to be effective. Generally the earlier in the growing season undercutting was done the greater the root regeneration stimulated (Eis and Long, 1973). Stanley and Toogood (1981) recommend the practice of undercutting in the autumn so that the new growth occurs in the spring. However, it seems that the nurseryman often undercuts late in the season using the method as a 'salvage' operation. This practice eases late lifting if the stock can be sold but checks shoot growth in the following growing season if the plants have to be held over until the next growing season. Frequent root pruning increases root branching but also decreases the total root mass (Hamilton *et al.*, 1981). Therefore undercutting inevitably results in a reduction of carbohydrate reserves, and late season undercutting could be detrimental to the next season's growth. Rook (1971) found that undercutting and wrenching caused a major change in the proportion of carbohydrates translocated to the roots of *Pinus radiata*, and that the intense frequency of wrenching experimented with did not affect survival in the next season. It is the timing of undercutting that appears to be critical, and Eis and Long (1973) have suggested that root pruning has a hormonal effect. Ritchie and Dunlap (1980) discuss the physiological mechanisms initiated by undercutting. It may reduce inhibitory growth substances in the roots, and frequent undercutting may alter the ratio of inhibitors and promoters. By increasing the plant's metabolism as a result of root pruning, the root can gain more carbohydrates, and therefore potentially grow more (Rook, 1971). Root pruning increases auxin activity coupled with lateral root growth (Carlson and Larson, 1977).

Although Nambiar (1980) suggests the root system produced by undercutting enables the plant to avoid soil water stress in that there is a larger area for water absorption, it may also be true that the root system being composed of finer roots is more prone to desiccation. Insley (1982) showed that the finest roots have the highest moisture content, and dry out most rapidly. The top of the tap root, the axis of the root system, had the lowest moisture content within the roots and dried most slowly. Initially in the growing season before the fine roots have regrown the suberised roots absorb the water required (Kramer and Bullock, 1966; Patch *et al.*, 1984). Brown, suberised roots are less sensitive to injury by desiccation and other factors than white actively growing roots (Coutts, 1981 b and c).

Root pruning can be used to improve stock quality by manipulating the root:shoot ratio. Shoot expansion is checked by root pruning but growth in weight and diameter of the aerial portion is much less affected, so the undercut plant is heavier and stouter than an untreated plant. Growth of the root, in length and perhaps weight (Hamilton *et al.*, 1981), is encouraged so producing a plant with a higher root:shoot ratio (Jones, 1968). Similarly, although not widely used, shoot pruning can be used to influence the root:shoot ratio. Shoot pruning can be disadvantageous as the tree's means of food production needed for future growth is reduced (Page, 1973). The desirable root:shoot ratio is not known but it is likely to be different for different species. The root:shoot value may vary with chronological age, especially during the early years of a tree's life (Jones, 1968), with stage of morphological development, and with environmental conditions. In seedlings of broadleaved trees the root:shoot ratio is greater than in the conifers *Pinus* and *Picea*, and usually increases for 2 or 3 years (Jones, 1968).

As Hamilton *et al.* (1981), Insley (1982), Jones (1968) and Nambiar (1980) point out practices during nursery production may be harmful in that they lead to a low root:shoot ratio. These practices include frequent applications of root inhibiting herbicides, frequent watering and fertilisation, frequent root pruning, harvesting techniques (Mullin and Christl, 1981 and 1982), and container-plant production. It appears that the optimum plant would have a high root:shoot ratio based on a major network of coarse roots, providing a large food store and resistance to desiccation damage (Insley, 1982).

In the nursery, trees are graded on phenotypic characteristics but these do not reflect a tree's ability to adapt to site conditions or the physiological conditions of the plants. Culling, which is the commonly used method of quality control, should reduce stock heterogeneity but it cannot transform poor stock.

Transplanting

Transplanting is the operation of moving seedlings from the bed in which they were sown to another one specifically to prevent taproot development and break fine roots in order to stimulate a fibrous, compact root system. Traditionally, transplanting is carried out at the end of the first year, and may be repeated in later years depending on rate of growth and size of plant sought (Aldhous, 1972). Much of the physiology of undercutting applies equally to transplanting.

Conclusions

Undercutting and transplanting have an important role in nursery management and production. Both practices are designed : (1) to produce a compact root system of fibrous roots which is easy to lift; and/or (2) to control the root:shoot ratio. Transplanting is done when trees are dormant but the timing of undercutting is critical to ensure root growth is stimulated. The earlier in the growing season undercutting is carried out the more the root growth. Planting stock should be lifted at a lower depth than the undercutting level. The fibrous roots produced by undercutting may be more prone to desiccation when planted out. Good root systems tend to be enhanced by growing stock at lower densities. Undercutting and transplanting can increase the root:shoot ratio but other nursery practices such as luxuriant fertiliser or irrigation regimes may lower the root:shoot ratio.

Root drying

Exposing plant roots to drying conditions, even for only 1 to 3 hours, causes a significant reduction in survival and growth following planting, an effect which can still be detected 5 years later (Mullin, 1974b). Insley (1982) also found that exposure after lifting considerably reduces survival, and recommends that the whole system for lifting and handling stock should aim to minimise water loss from the roots. Performance after planting is dependent on whether water loss due to exposure is predominantly from the shoot or root (Mullin, 1974b). The relative rate of water loss from root or shoot, under controlled conditions, is dependent on the root:shoot surface area ratio. In birch (*Betula* spp.) seedlings the moisture content (per cent oven dry weight) of the root is higher than in the shoots, so after lifting, most water is lost from the generally fine root system rather than the shoots (Insley, 1982). Plants in a condition of active growth sustain more damage as a result of planting out than those in a dormant condition (Mullin, 1963). The damaging effects of moisture stress during planting are dependent on the physiological condition of the plant, especially its level of dormancy and moisture status (Insley, 1982), also the size of the roots and shoot (Parvianinen, 1981), and the species (Brix, 1979). Exposure reduces subsequent water uptake, and root growth (Kramer, 1950; Brix, 1960). This was assumed to be due to the reduced water permeability of living cells in the roots and was demonstrated by Ramos and Kaufmann (1979). Winzum (1963, quoted in Tinus, 1974) demonstrated that as a plant becomes dormant its internal moisture status is lowered, and moisture stress can induce dormancy as shown by Zaerr and Lavender (1980). Lifting and planting out and any associated moisture stress should be least damaging, therefore, when the plant is completely dormant.

The suberised layers which form in dormant roots may protect the root apex from desiccation. Coutts (1981b) suggests that "the tips of active roots may be particularly prone to desiccation because of the absence of functional xylem in the subapical zone of elongation, which is believed to produce a resistance to water movement (Kramer, 1969). Therefore water lost by evaporation from the apex may not be replaced so readily from stores in the remainder of the plant as it is in the fully differentiated subapical portion. In dormant roots the differentiated xylem extends closer to the apical meristem (Wilcox, 1954), and this feature could also render the apex more tolerant to drying conditions."

Christersson (1976) postulates that calcium has a negative influence on drought hardiness of plants, whereas potassium has a positive drought hardiness correlation.

The loss of water through the shoot by transpiration is controlled by the closing and opening of the stomata. Work by Coutts (1981b) has demonstrated that the stomata on Sitka spruce (*Picea sitchensis*) closed at a lower moisture stress than previously quoted in the literature. When the root system was damaged the stomata began to close before any reduction in leaf water potential was detected (Coutts, 1981b). The mechanism is not understood, but it is believed to result from roots producing and releasing a substance which controls stomatal closure (Coutts, 1980).

Desiccation is not the only form of stress in the root system during transplanting or planting out. Mechanical damage (lifting and handling) and damage caused by temperature extremes are important. In fact, Coutts (1981a) suggests that desiccation appears to be aggravating the effects of mechanical damage. The three types of damage are believed to be cumulative and interactive in their effects (Tabbush, 1986). In the literature the emphasis concentrates on desiccation, its effects and control, as it is easier to research than other forms of damage (Tabbush, personal communication). The poor root growth response in dry soils is probably the result of a mechanical effect as well as water stress, nevertheless, root moisture content remains a useful index of plant condition (Tabbush, 1987).

Navratil (1976) considers post-lifting (pre-storage) dehydration of stock can be self-adjusted within plants by cold storing in boxes with moisture retentive material, and/or following thorough watering in the nursery beds before lifting. Similarly, Mullin (1974b) found rewetting of tree roots (prior to planting) to be effective in assisting survival of plants where some degree of exposure was involved. Certainly the appearance of the roots may be improved by rewetting but as Insley (1982) emphasised rewetting would be expected to remove water stress but not necessarily the critical dehydration strain. Tabbush (1987) reported that rewetting after a period of desiccation could raise root moisture content of spruce and Douglas fir, but this alone did not affect survival or growth. The effects of rewetting roots needs further research.

Survivial and growth of newly planted trees should be improved by decreasing transpiration between lifting and planting, and increasing water absorption after planting (Kozlowski and Davies, 1975). In aiming to deliver physiologically vigorous stock the nurseryman must package plants to minimise moisture loss and many also use anti-transpirants, root dips and defoliants (see p. 18). After lifting, all exposed bare-root plants will continue to dry out, until an equilibrium is reached with the surrounding air. Storage should be in an atmosphere with a high relative humidity. Closed polythene bags are effective protection against plant moisture loss (Aldhous, 1959 and 1960; Mullin, 1974a), but the whole plant should be enclosed (Insley, 1982), as water can move fairly freely between root and shoot (Coutts, 1981c). The Joint Liaison Committee on Plant Supply's Code of Practice for Plant Handling (1980) (see Appendix III) directions for packaging follow the findings of Aldhous. Plants packed in polythene bags must not have surface wet foliage otherwise mould might develop. The plants should be loosely bundled and the number in the bundle should be as detailed in the specification for packaging and transporting nursery stock in *Plant handling* (Committee for Plant Supply and Establishment, 1985 - see Appendix III). The packed plants must always be kept out of direct sunlight and away from heat to reduce possibilities of heat damage and water stress (Coutts, personal communication). Careful handling and packaging should not be regarded as a means of prolonging the period of time between lifting and planting, but only as a means of improving stock physiological quality over the minimum possible time plants are out of the soil. Moreover, recent work by Tabbush (1986) shows that simple mechanical damage, such as caused by dropping bags of plants or piling them on top of each other leads to much fine root breakage and greatly reduced survival and growth when planted.

Conclusions

Water stress has less effect if the roots are in a dormant condition. Therefore, the timing of lifting and transporting is important. The plants must be packed in polythene bags to reduce water stress during handling or stored in an atmosphere of high humidity.

Cold storage

Ideally, plants should be lifted in a dormant state, packaged and immediately delivered to the planting site, however, in practice, plants may have to be stored.

Each species varies in its reaction to cold storage (Aldhous, 1964). Guidelines need to be developed for each species for the duration of successful storage, temperature, humidity, and date of lifting (Navratil, 1976). At present the nurseryman only has the guidelines developed for conifers in cold store (Aldhous, 1972), which may or may not be suitable for storing broadleaved species. These guidelines are based on a review of the knowledge on cold storage of forest plants which was completed in 1971 (Brown, 1973).

There are three types of damage that are likely to occur to stock during cold storage: temperature, mechanical and disease (Cleary and Tinus, 1980). Experiments on seven temperate zone hardwood species by Webb and von Althen (1980) showed that storage temperature and packaging methods can markedly affect the physiological quality of the planting stock. Similarly, although different conifer species show different effects, temperature during and length of storage directly affect survival. Storage temperatures should not be lower than necessary. Sub-zero and freezing temperatures reduce the rate of respiration in the plants, and disease incidence, but induce high moisture stress (Cleary and Tinus, 1980; Morby and Ryker, 1979) and lower root growth capacity (Webb and von Althen, 1980). Survival and growth are thought to be related to the extent and length of moisture stress. The optimum storage temperature appears to be $1^{\circ}C \pm 1^{\circ}$ (Cleary and Tinus, 1980; Webb and von Althen, 1980). Root growth capacity and overall growth potential of cold stored stock at these temperatures were comparable with those of normal spring lifted plants. Increases in storage temperature lead to depleted carbohydrate reserves in the plants (Navratil, 1976; Ritchie, 1982). A temperature rise to 2°C doubled dry weight losses, and higher temperatures, 2.5–4°C, caused a 6.5–17% loss in dry weight (Navratil, 1976). The relative humidity of the atmosphere around stock in cold stores should be at least 85% if desiccation exposure damage is to be eliminated (Mullin, 1971).

No information was found about the optimum lifting dates for broadleaved species prior to cold storage. However, it is critical that the shoots are in a physiologically dormant state, and that bud break has not been initiated if plants are to be stored more than 30 days (Cleary and Tinus, 1980). A test is needed for both nurseryman and purchaser to measure the level of plant dormancy, i.e. a measure of the buds' readiness to break and flush (Cleary and Tinus, 1980), as it affects the long-term survival in storage. Hopkins (1975) reports on studies in Holland for optimal lifting dates for conifers to be cold stored. Recommendations were made that lifting Douglas fir should be restricted to between mid-January and early February; other conifer species could be lifted from December onwards.

The length of storage affects the quality of the stock. With increasing duration of storage the plants' carbohydrate reserves are depleted (McCracken, 1978). Storage may reduce frost hardiness and drought resistance through its effects on sugar concentrations (Ritchie, 1982). Long-term storage will delay flushing when the stock is planted, and in turn reduce height growth (Pollard, 1973). During cold storage, handling of the plants should be avoided to minimise mechanical damage.

The effects of cold storage on the plants' physiological condition is not fully known. Cold storage of pines reduced the rate of carbon dioxide uptake after planting despite the water potential being normal for active exchange, and the effect compounded with increased period of storage (McCracken, 1978). McCracken's results suggest that there is a disorganisation of chloroplasts during cold storage, thereby disrupting photosynthesis and lowering the water potential following planting.

The response of trees (250–300 cm tall) to applied auxins (IBA) and ethylene seemed to be influenced by cold storage (Prager and Lumis, 1983), but it may be that it is something to do with the physiological condition of the plant at time of lifting (Alvarez and Linderman, 1983). Cold storage effects interact with bud dormancy hence possible changes in endogenous plant growth substances and carbohydrate reserves (Prager and Lumis, 1983).

Webb (1977) demonstrated that the number of hours chilling was interrelated with the break of bud dormancy and root regeneration. Experimenting with sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*) seedlings Webb (1977) found that bud dormancy was broken after 2500–3000 hours of chilling at 5°C, and maximum root regeneration occurred after 3500 hours of chilling. Cold storage of autumn lifted hardwood species could be a technique for producing seedlings in a physiological condition conducive to rapid growth in the spring (Prager and Lumis, 1983; Webb, 1977). Similar advantageous effects have been recorded for conifers. Aldhous (1964) showed that cold stored seedling spruces grew more and survived better than stock lifted later in the season.

Conclusions

Cold storage is a practical way of keeping healthy stock after lifting out of the ground. For some species it may even be advantageous but standard storage regimes for each species, and especially broadleaves, have not been worked out. Temperature, relative humidity, lifting date and duration of storage are all important factors in sustaining stock quality during storage. For broadleaved trees it is essential that the plants are dormant.

Antitranspirants, root dips and other chemicals

Antitranspirants have not been widely used in the UK, and as Insley (1982) points out adequate planning of planting when ground conditions are conducive, i.e. correct water content, frost free and workable, should make the use of such products unnecessary. Many examples have been cited in the literature of the beneficial use of antitranspirants. Davies and Kozlowski (1975) and Davies *et al.* (1972 and 1978) have experimented with different antitranspirants, at various dosages to different species in the field, glasshouse and in environmentally controlled growth chambers. Davies *et al.* (1974) and Davenport *et al.* (1971) report that antitranspirants reduced transpiration of transplanted ornamentals, and improved water balance in transplanted citrus trees. The effects of antitranspirants depend largely on environmental factors and the species (Davies and Kozlowski, 1974). As there is great variation in the leaf structure of different species and their water loss it might be that antitranspirants should be used for some species and not others.

There are two main types of antitranspirants: (1) impermeable layers, which include waxes, wax-oil emulsions, high molecular weight alcohols, silicones, plastics, latexes and resins; and (2) metabolic inhibitors which prevent stomatal activity, such as succinic acids, phenylmercuric acetate, hydroxysulfonates, the herbicides karsil and atrazine, sodium azide and phenylhydrazones of carbon cyanide (Kozlowski and Davies, 1975). The use of either type of antitranspirant does not guarantee good survival if the planting material is not handled carefully (Lee and Kozlowski, 1974) and the soil conditions of the planting site are not appropriate for root growth. There are often toxicity problems with high concentrations of antitranspirants, especially the metabolic types, reducing photosynthesis, altering the plants' metabolism, and degradation of the plants' vigour (Lee and Kozlowski, 1974). Toxicity problems are particularly apparent at high temperatures (Kozlowski and Davies, 1975). In deciding on the use of antitranspirants the grower must consider the long-term toxicity as well as the immediate transpiration effects. Kozlowski and Davies (1975) report that although antitranspirants reduce water loss in pines (*Pinus* spp.) by as much as 90%, photosynthesis was greatly reduced for a long time. They suggested that the nurseryman experiments with particular antitranspirants on a sample of the species to be planted out before treating plants on a large scale. Davies and Kozlowski (1975) showed that abscisic acid acts as a non-toxic metabolic inhibitor and could be of commercial use. It is difficult to lay down detailed guidelines for the use of antitranspirants because of the many interacting variables such as product, rate of application, species, morphological age, physiological status, and environmental conditions. Reviewing the literature Kozlowski and Davies (1975) stress the "unsatisfactory status of research on antitranspirants . . . short-time observations of antitranspirant not followed up. Many reports on antitranspirants do not provide any indication of the effects of the compounds on physiological processes such as photosynthesis. Antitranspirants are reported as being X% effective in reducing transpiration with no reference made to the species studied or to prevailing environmental conditions."

Some antitranspirants are recommended for incorporation into the soil where, it is claimed, they have reduced evaporation of soil moisture (Robertson and Greenway, 1973). These antitranspirants are absorbed by the plants and translocated to the leaves forming a water-impermeable film around mesophyll cells in the interior of the leaf. Kozlowski and Davies (1975) do not recommend this form of application as it can cause harmful effects to the foliage such as chlorosis and smaller size, and can reduce seed germination. However, such use of antitranspirants is attractive so there should be further research.

Root dips, such as clay slurry and especially sodium alginate, are being more widely used in the nursery trade to reduce moisture loss between lifting and planting. Dipping is only advantageous if the bare roots are exposed, and it must be emphasised that it only delays the desiccation process (Insley, 1982). Bacon *et al.* (1977) and Flemer (1967) demonstrated that clay slurry or sodium alginate root dips increased plant survival and height growth. However, work by Lohbeck (1978) found that alginate dipped roots, and antitranspirant treated shoots, reduced the physiological quality and growth rate of the plants. Different species respond differently, and for some there may be no beneficial gain (Sims, 1967). Kozlowski and Davies (1975) experimented with succinic acid as a root dip as it increases root permeability to increase water absorption after planting but the roots were damaged.

Chemical defoliants have been experimented with to induce a leafless and dormant condition in trees. These chemicals only accelerate natural processes. This technique could be useful to the nurseryman as a means of extending the lifting season into early autumn, and allowing for the planning of lifting and planting operations (Insley, 1981, 1982). Examples of chemical defoliants are potassium iodide, ethephon (2-chloroethylphosphonic acid) and DEF (tributyl trithio phosphate). Application of defoliants requires careful timing and accurate concentrations otherwise physiological damage, in the form of bud death and shoot dieback, will occur. Insley (1981) records species variation to the effects of such chemicals. No information was found about the effect of chemical defoliants on the vigour and growth of trees in the growing season following application.

Conclusions

Root dips and antitranspirants and other chemicals may be a useful means of controlling water loss. However, properly planned lifting and planting out during appropriate conditions should make chemicals, especially root dips and antitranspirants, unnecessary.

Container stock

Raising stock in one place then planting out at another is an unnatural practice and some root damage or deformation must always occur during the operation. As a result container-plant production is perceived to have apparant advantages for both grower and purchaser compared with open nursery (bare root) production and is therefore gaining favour. Harris (1983) suggests container stock production reduces labour costs because of the greater plant uniformity, allows for mechanisation and greater production per unit area (Khatamian and Agnew, 1984).

It is argued that by using containers the plants are maintained for optimum growth as the water and nutrient regimes can be controlled and temperature manipulated. Container production manipulates the root:shoot ratio to lower values, such as 1:7 (Rogers and Head, 1969) but often plants produced in containers are tender and have weak stems and are unlikely to be suitable for the exposed conditions and mineral soils of landscape and development sites. When planted out such plants are initially susceptible to frost heave and may be unstable, especially as top growth develops. Compared with bare rooted plants, however, there should be less moisture and root loss during final planting with container stock (Tinus, 1974). If water stress does occur in container stock, root to soil contact will be lost because of root shrinkage, creating even more water stress. Added to this is the problem created by sharp differences between container soil (growing medium) and that of the planting site. Development of roots from the root ball into the surrounding soil is frequently impaired where the one is friable and rich and the other somewhat impervious, compacted, clayey or nutrionally poor.

When grown in containers tap-rooted and rapidly growing plants are particularly susceptible to root spiralling and root deformation (Harris, 1968). Unless corrected, circling roots will enlarge into girdling roots, which can result in death, ground-level breaking of trunks, poor wind stability and poor growth in landscape plantings. Harris *et al.* (1971) note that such root problems seem to be caused by the propagation practices at the liner stage. Eccher (1975) demonstrated that removing malformed roots had a beneficial effect on the plants' growth and stability, but it should be noted that the type of root removed is important.

In their experiments Harris *et al.* (1971) showed that root pruning and care in nursery seedling transplanting more than doubled the number of plants with root systems free from root kinking and circling except those with roots which were circling only. Root spiralling has been shown to be relieved by growing trees in square, bottomless containers on raised wire-mesh benches which causes air pruning of the roots (Davis and Whitcomb, 1975). Also, spiralling problems in the Kentucky coffee tree (*Gymnocladus dioicus*) have been solved by placing a layer of silver nitrate in the soil which effectively prunes the roots (Pellett *et al.*, 1980). In a simple method of adding rigid plexiglass inserts in semi-rigid plastic containers, Khatamian and Agnew (1984) reduced root circling.

Insley (1982) questioned the value of container stock compared with bare root stock. Although it is difficult to produce comparable plants he showed that the container plants had no benefit in survival or growth, compared with well-handled bare root stock, after two growing seasons. A similar result was found by Mason and Biggin (1988) who concluded that well-handled transplants were the most appropriate plant type for use in upland Britain, but that containers may be of greatest benefit in production of seedlings of 'sensitive' species or of high genetic quality.

Conclusions

This brief and incomplete review of containers suggests that, theoretically, container production should produce quality stock as the plants can be grown under optimum conditions. However, in practice, many problems arise, such as inadequate potting on, resulting in unstable plants because of deformed and spiralling roots, problems with root ball:planting site interface, bulky transport, etc. Such plants may produce management problems when used in the landscape.

Discussion

The concept of growing trees in a nursery for planting out to the final position is centuries old; John Evelyn (1678) writes about it at length. Nursery practices have evolved slowly since those early days, but the biological reasons for some of the traditional operations appear to have become clouded until today their execution may be less than ideally implemented in the interests of commerce. As a result the true value of the work may not be reflected in the trees offered for sale. Nursery practices are unlikely to kill a tree which is growing in the nursery, but when that tree is used in the landscape the ability of a tree to develop roots may become the limiting factor for tree growth especially if site conditions are inhospitable.

Root growth is dependent on nursery practices especially in the growing season prior to sale. As root growth is periodic it is important that nursery operations are timed to coincide with the quiescent and actively growing phases as appropriate. For example undercutting is a means of manipulating the root:shoot ratio but the same results can be achieved by a lower density of plants in the bed and without root damage. The disadvantage of wider spacing would be a spreading root system which would be difficult to lift, package and transport without causing damage to the roots. When undercutting is desired, it should be done in late spring so that regeneration of the roots can occur. Autumn undercutting can result in wounded roots being exposed for unnecessarily long periods until callus develops in the spring.

Furthermore, autumn undercutting could remove parts of the major roots so reducing the carbohydrate reserve needed for root regeneration in the spring after planting. Once plants have been undercut it is essential that all subsequent operations should be done outside the width of the undercut so that root regrowth is not damaged or lost.

Nursery practices such as fertiliser application and irrigation are understandably geared to producing a plant of a particular size in a minimum of time. In fact such operations produce trees with a low root:shoot ratio. Little is known about the regimes needed to create both a balanced plant and a carbohydrate reserve which can be best mobilised to regenerate roots when the tree is planted. The nurserymen's techniques of increasing plant growth by fertiliser applications and irrigation on sheltered lowland sites can produce soft shoots which are unable to withstand the harsher climatic conditions of landscape planting sites. Modification of late summer fertiliser prescriptions, e.g. increasing potassium and reducing nitrogen levels, and withholding water may condition trees to produce tougher material more able to survive in the final planting position. The need to minimise losses of plants may explain the establishment of holding nurseries by local authorities which allow the trees to grow in favourable conditions for one year before they are finally positioned into the field. Investigations into nursery nutrition and its effect on plant establishment in the field would appear valuable. Similarly a greater understanding of the role of hormones in root growth and plant establishment generally is needed. Such knowledge might allow use of externally applied hormones to enhance growth as in the practice of rooting cuttings.

The work of Insley (1979b, 1980a, and 1980b) has shown the adverse effects that even short periods of exposure of the roots to drying conditions can have on tree survival. Roots must be protected from drying throughout the time they are out of the ground. Possibly the ideal method of protection is cold storage which allows very careful control of the conditions around the plants. While it is known that plants must be dormant before being cold stored, the only regimes of conditions (temperature and relative humidity) that have been worked out are for conifers (Aldhous, 1964). It is possible that broadleaved trees require storage temperatures markedly different from the $1°C \pm 1°$ usually used for conifers. Furthermore the ability of broadleaved trees to resume growth in the spring may depend on fluctuating temperatures or there may be an optimum low temperature which triggers the hormonal movement necessary to stimulate growth. Furthermore, since plants cannot be cold stored in all nurseries, during transport and prior to planting, further investigation of packaging appears justified.

The alternative to adequate packaging and storage might be antitranspirants, root dips and defoliants; but these techniques appear to have problems which require investigation. For example a root dip that prevents water leaving a root and going into the atmosphere may have a similar effect on the uptake of soil water into the roots. Antitranspirants applied to the shoots and buds may reduce water loss from the plants so that there is no suction force to draw water through the plant from the roots. This may be of little consequence in a transplant but with larger trees such a lack of suction could be damaging.

Cleary and Tinus (1980) suggest that "nurseries create quality during growing and conditioning of stock". What is quality? All too frequently tree buyers assess quality on purely visual characteristics of height, stem diameter and possibly even number of branches. This is only one aspect of quality and, as has been learned in forestry, visual assessment is no indicator of the physiological status of trees or their ability to grow after planting. The physiological criteria that appear to be necessary for tree establishment are an adequate moisture content, a concentration of carbohydrates in a plant which can be moved to the growth points and an ability to regenerate roots. At present these attributes cannot be measured other than by performance in the field after planting and, sadly, it is clear that quite often dead or nearly dead trees are planted. More rapid and precise techniques of assessment are needed so that both growers and purchasers of trees can assess health and plant physiological quality and, if necessary, undertake practices designed to overcome the deficiences. For example if it were shown by instrumentation that a plant had suffered desiccation it might be possible, within limits, to rehydrate the root system by soaking the plant in water before planting. However, the efficacy of such treatment is not known and there would always be the temptation to try and resuscitate abused and dying plants.

Sophisticated tests of physiological condition and subjective assessments of a tree's quality are of little value within the existing specifications (e.g. BS 3936). This is because there is no information on the range of performances achieved by trees of different root:shoot ratios. Furthermore the relationship of total height to stem diameter, form of root system and number of branches needs determining. This information is not easily collected from empirical experiments because of the range of potential species available for landscape planting and the variety of soil and climatic conditions encountered throughout Britain, however, people involved in specifying and planting trees should be able to collect such data from their area. Supplementary data of performance over a number of years should also be readily collectable. Once collected, data should then be made available to researchers, who can investigate anomalies. Only when such detailed information has been collected from a wide range of site type and location can worthwhile specifications for visual quality, physiological quality and handling of trees be written and have any value. When the information and specifications are available the nurseryman can be expected to modify his practices to produce the desired plant. Even if such plants are more expensive their reliability in landscape use should make tree planting more predictable and their improved growth should result in better value for money.

Conclusions and recommendations

This review of the literature on tree roots highlights deficiencies in our knowledge and suggests where further work is needed.

1. A morphological and physiological definition of a root system conducive to survival and growth for each species at various sizes should be developed.
2. There is a need for a reliable means to measure stock quality, particularly physiological condition; it must be easy enough to do in the field and preferably be non-destructive.
3. A better understanding of root physiology is required especially with regard to the relationship between the root and shoot.
4. Control of root growth (length, diameter and branching) merits further investigation.
5. Differences in root growth between and within genera need to be investigated.
6. If there is genetic variation in root regeneration between individuals then there are possibilities for genetic selection of stock.
7. Use of containers.

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APPENDIX I
British Standard specification for nursery stock; BS 3936 : Part 2 : 1978 Roses.

Root systems

Plants shall have a well developed root system. The root system of a plant grown in open ground shall include at least three major roots of minimum length 20 cm, arising within 7.5 cm of the union and having lateral and sublateral root growth. For standard or half-standard roses, minimum root length for the major roots is 25 cm.

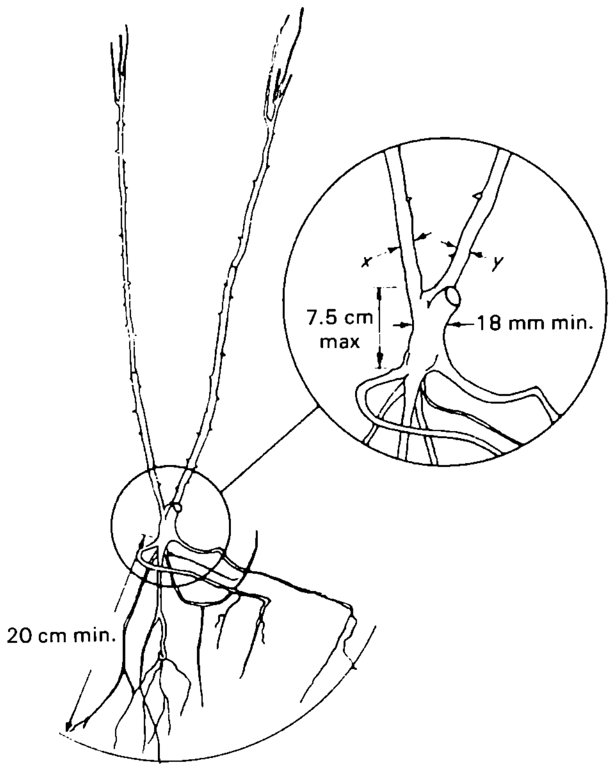

Figure 1. Bush or shrub rose

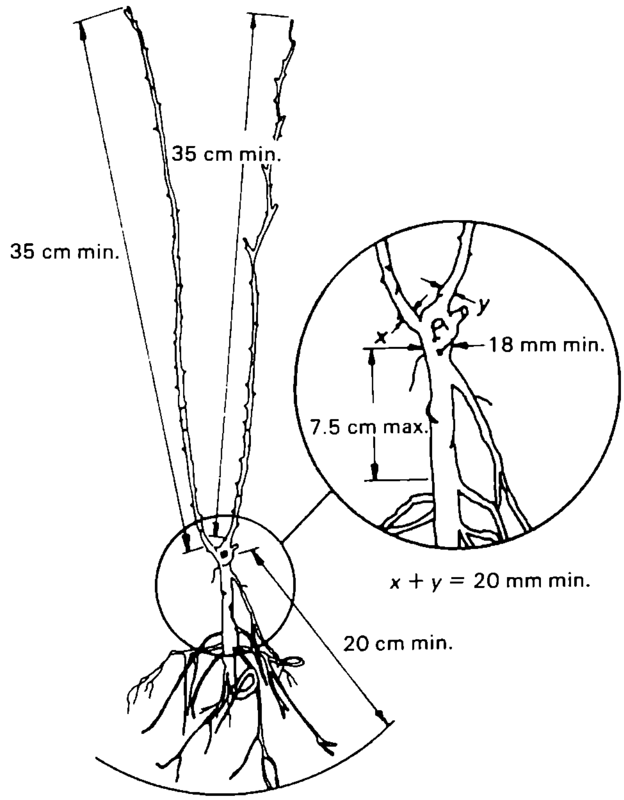

Figure 2. Climbing, rambler or pillar rose

These diagrams are only intended to clarify the minimum dimensional requirements.

Acknowledgement

Extracts from BS 3936 : Part 2 : 1978 are reproduced with the permission of BSI. Complete copies can be obtained from BSI Sales, Linford Wood, Milton Keynes, MK14 6LE.

APPENDIX II
American Standard for nursery stock

Bare root specifications

Nursery grown – spread of roots

All bare root trees shall have a well branched root system characteristic of the species. The following table represents the approved minimum root spread for nursery grown shade trees.

Caliper	*Average height range*	*Minimum root spread*
½ to ¾ in.	5 to 6 ft.	12 in.
¾ to 1 in	6 to 8 ft.	16 in.
1 to 1¼ in.	8 to 10 ft.	18 in.
1¼ to 1½ in.	8 to 10 ft.	20 in.
1½ to 1¾ in.	10 to 12 ft.	22 in.
1¾ to 2 in.	10 to 12 ft.	24 in.
2 to 2½ in.	12 to 14 ft.	28 in.
2½ to 3 in.	12 to 14 ft.	32 in.
3 to 3½ in.	14 to 16 ft.	38 in.

APPENDIX III
Plant handling

Published by: The Committee for Plant Supply and Establishment (CPSE) and approved by its constituent bodies:

Arboricultural Association
Association of County Councils
Association of District Councils
British Association of Landscape Industries
Horticultural Trades' Association
Institute of Chartered Foresters
Institute of Leisure & Amenity Management
Landscape Institute
National Farmers' Union

Obtainable from:
The Horticultural Trades' Association, 19 High Street, Theale, Reading, Berks. RG7 5AH. Tel: (0734) 303132

This booklet is for reference, not just at the desk or drawing board when drafting specifications, but also in the field and on site – thus its handy pocket size. It should be of much use for staff training. Employers are encouraged to ensure relevant staff have copies.

FOREWORD

The booklet *Plant handling* (reproduced in its entirety in this Appendix) seeks to assist all who purchase, supply, and endeavour to re-establish plants to achieve successful results. It is in three interlocking parts: the landscape architect, plant purchaser and user are directly concerned with all three; the nurseryman with the first two; and the landscape contractor with the third.

SPECIFICATION FOR PACKAGING AND TRANSPORTING NURSERY STOCK

Sets out requirements which can – and it is recommended should – be checked by the purchaser on delivery. It is in a suitable form, apart from the introductory paragraph, for the purchaser to include in full as an integral part of any invitation to tender and contract to supply plants.

RECOMMENDATIONS FOR PLANT HANDLING FROM LIFTING UNTIL DELIVERY TO SITE

Gives guidance to the nurseryman on requirements where the purchaser has to rely on the nurseryman. In any invitation to tender and contract to supply plants, the purchaser is advised to stipulate that the nurseryman adheres to "CPSE recommendations for plant handling from lifting until delivery to site".

RECOMMENDATIONS FOR PLANT HANDLING FROM DELIVERY TO SITE TO SUCCESSFUL ESTABLISHMENT

Explains the requirements for successful establishment to landscape architect, plant purchaser, user, and landscape contractor. Those responsible for preparing, planting, and maintenance contracts, are encouraged to ensure each requirement is adequately specified in any invitation to tender and contract to undertake such works. Many of the paragraphs are in a form suitable for direct inclusion, but for some –in particular '7.4 Providing moisture' – a decision on the most cost effective solution is essential.

July 1985

SPECIFICATION FOR PACKAGING AND TRANSPORTING NURSERY STOCK

1.0 *Introduction*

Good handling and packaging between the nursery bed and final planting are essential if damage to plants is to be minimised. This specification should be incorporated as an integral part of any invitation to tender for and contract to supply trees and shrubs.

For plants less than 45 cm tall, the packaging quoted is essential while for plants over 45 cm tall and below 14 cm girth the requirements are the minimum that should be expected. With high unit value plants the purchaser may wish to specify additional packaging – but this may increase the cost of the plants.

On receipt of a delivery, the purchaser should check that each requirement of this specification has been complied with by the supplier.

2.0 *Bundling*

2.1 General

Bundles of bare rooted plants shall consist of graded plants of one species with all shoots facing the same direction. Bundles shall contain equal numbers of plants. Any part bundles shall be clearly marked. A bundle shall be such a size that one person can handle it on receipt, unless the supplier has ascertained, in advance and in writing from the purchaser, that mechanical handling will be available at the place and time of delivery. Bundles shall be tied securely with string, twine, plastic strip or other supple material which will not, by its nature or tension, cause damage to the plants.

2.2 Bare-root trees

Do not exceed the following maximum quantities in each bundle. The quantity shall be reduced where larger heads or roots may be subject to damage:

Feathered trees	1.8 – 2.4 m height	up to 15 per bundle
Standard trees	4 – 6 cm stem girth	up to 10 per bundle
	6 – 8 cm stem girth	up to 6 per bundle
	8 – 10 cm stem girth	up to 3 per bundle
	10 – 12 cm stem girth	up to 2 per bundle
	12 – 14 cm stem girth and above.	not normally bundled

2.3 Root-balled and container-grown plants

These plants shall not be bundled.

3.0 *Labelling*

3.1 General

Each individual or plant bundle, bag or lot of one species of plants shall be labelled by the supplier with a securely attached durable primary label.

The *plant name, size* and *quantity* in the bundle or bag, and the *total quantity* in the consignment shall be clearly and durably displayed on the label together with the *supplier's name.* A reasonable proportion of a large consignment of distinct plants shall bear a durably written secondary label easily related to the primary label.

3.2 Forestry species, subject to EEC Regulations

Forestry species specified under the EEC Forest Reproductive Material Regulations (1977) shall be labelled in accordance with those Regulations.

4.0 *Packaging*

4.1 Bare-root plants up to 45 cm tall

Bare-root plants up to 45 cm tall shall be entirely enclosed in plastic film bags (250 gauge minimum, 65 μm) securely tied at the top. Plants shall be loosely bundled within the bag, which shall be of an adequate size. All shoots must face in the same direction so that roots and shoots are not in contact. Thorny or very bushy plants may have only their roots enclosed in a plastic film bag of suitable thickness which shall be securely tied around their stems. Although it is always desirable to enclose plants in polythene when supplied for large scale planting, exceptions may be allowed by the purchaser, but the supplier must clarify the specification required by the purchaser prior to submitting a tender.

4.2 Bare-root plants 45–60 cm tall

The roots of bundles of plants shall be enclosed in a plastic film bag of suitable thickness which shall be securely tied around the stems.

4.3 Bare-root plants 60 cm tall and above, excluding trees in excess of 14 cm girth.

Plants may be supplied bare-root but at all times roots shall be kept moist and protected from drying out and layers of plants in transit must be sheeted over.

4.4 Bare-root trees 14–20 cm girth

To be supplied without soil adhering to the roots unless otherwise specified, but with the roots packed with a pre-wetted moisture-retentive granular or fibrous material, enclosed in either a moisture-retentive material such as plastic film (500 gauge minimum), or in a porous material such as hessian, and firmly secured.

4.5 Root-balled plants

Root balls shall be moist, supported by an elastic band or string or stronger material where the root ball so requires to prevent collapse, and protected against drying out by wrapping firmly with moisture-retentive porous material such as sacking.

Packing shall be firmly secured over the top of the root ball. Where wire netting is used to support the root ball, any moisture-retentive material such as sacking shall be wrapped outside the wire netting.

4.6 Container-grown plants

Container-grown plants will not normally receive additional packaging, but degradable pots shall be enclosed in polythene film (250 gauge, 65 μm minimum) and firmly secured.

4.7 Variations in packaging

Variations from the above packaging may be appropriate in certain circumstances. The purchaser shall state such revised specification in the tender conditions for the purchase and supply of plants, or the requirements shall be otherwise agreed in writing between the purchaser and supplier prior to submission of tenders.

5.0 *Transport*

5.1 Open lorries

All plants shall be loaded, stacked and unloaded in such a way that breakage of crushing by the weight of plants above, or the security ropes will not occur. The consignment shall be completely and firmly covered with opaque sheeting in such a way that there is the minimum draught under the sheet from the direction of travel. Plants in polythene bags shall be sheeted so that they are shaded from direct sunlight.

5.2 Closed lorries or containers

All plant material shall be loaded in such a way that breakage or crushing by the weight of plants above is avoided during loading, transit and unloading.

5.3 Transit by third parties (e.g. post, rail, road, etc.)

Where transport is entrusted to others, not under the control of the supplier or the purchaser, consignments shall be clearly addressed, manageable units, securely crated or packaged to withstand mechanical damage.

RECOMMENDATIONS FOR PLANT HANDLING - FROM LIFTING UNTIL DELIVERY TO SITE

1.0 *Introduction*

1.1 Objective

Once out of the ground, roots of plants are highly susceptible to damage. Adherence to these recommendations should ensure roots of plants are exposed to the risk of damage for the minimum time, so following re-planting there should be maximum plant survival. Nursery operations should be carried out by appropriately skilled operatives under the control of competent management and with adequate supervision.

1.2 Scope

These recommendations apply to the handling of trees, shrubs, climbers, roses, conifers, forestry seedlings, hedging plants, fruit trees and bushes, herbaceous perennials and alpines.

1.3 Damage

Damage to roots can be caused by drying-out (even in still, apparently moist air), heating up, freezing, water-logging and physical breakage.

1.4 Length of time at risk

Ensure the period between lifting and placing plants under storage, and the period between storage and despatch are kept to a minimum.

Unless in cold storage, ensure the plants are in temporary storage for the minimum of time appropriate to the method of temporary storage.

Despatch bare-root plants in sufficient time to allow the purchaser to plant dormant stock.

2.0 *Time of lifting*

2.1 Deciduous bare-root and root-balled plants

Lift when the ground is moist and the plants are dormant – normally between October and March (earlier or later lifting may be possible where local conditions or seasons permit). Pay particular attention to protecting roots when lifting in a drying wind or in sun. Avoid lifting during severe ground frost or when the ground is frozen. Ensure roots balls are adequately supported to prevent collapse.

2.2 Evergreen bare-root and root-balled plants

Lift between September and April provided the ground is moist. Avoid lifting during severe ground frost or when the ground is frozen. Pay particular attention to protecting roots when lifting in a drying wind or in sun. Ensure root balls are adequately supported to prevent collapse. (*Note:* evergreen plants, other than forestry transplants, older than 3 years should be root-balled).

2.3 Deciduous and evergreen container-grown plants

Move at any season, except during periods of extreme cold, provided the root systems are well established in the containers and the plants are fully hardened off.

3.0 *Bundling and bagging*

3.1 So as to minimise the risk of heating up, only bundle when foliage surface is dry, and consider the type and condition of the plants when deciding the number per bundle, or how many to put into a bag.

3.2 Tie in lateral branches securely if otherwise they may be damaged during transit. Do not bundle container-grown or root-balled plants.

4.0 *Transporting plants within the nursery*

4.1 Be as speedy as possible getting plants into temporary storage, as they are at particular risk during this period.

4.2 Protect bare roots at all times. On open vehicles securely sheet over roots in such a way that there is the minimum draught under the sheet.

4.3 Root-balled and container-grown plants may be transported without additional protection, provided the plants are not exposed to extremes of temperature.

5.0 *Short-term storage before despatch*

Plants may be stored for the minimum of time appropriate to the method of temporary storage, provided the following requirements are adhered to strictly.

5.1 Bare-root plants

5.1.1 *Outside*
Keep the plants in a moist, cool, sheltered and shaded location. Surround the roots with a freely-draining moisture-retentive material moistened periodically as the condition of the material requires. Ensure good contact between the material and the roots. Protect against damage by rodents.

5.1.2 *Indoors*
Relatively short periods of exposure, even in an unheated packing shed, can result in serious drying out, especially of roots, and thus plant losses. For plants kept in such a location for up to 24 hours, water the roots frequently. For longer periods, surround the roots with a freely-draining, moisture-retentive material and moisten as frequently as the conditions require. Ensure good contact between the material and the roots. Protect against damage by rodents.

5.1.3 In polythene bags
Protect the bags from direct sunlight at all times. Do not stack bags for any length of time. Where delays of more than a few days occur, cut the bags open and store the bags upright in a cool, shady position or shed, or place in a cold store.

5.1.4 In cold storage
In direct cold store wrap the plants entirely in polythene. In jacket or humidified cold stores, no additional protection is necessary.

5.2 Root-balled plants

For short periods of storage, keep permeable wrappings moist by watering. Protect polythene wrappings from direct sunlight. For longer periods of storage, place plants with root balls with permeable wrappings on a well-drained surface and cover with a freely-draining, moisture-retentive material, moistened regularly as the condition of the material requires. Ensure good contact between the material and the root-ball. Protect against damage by rodents.

5.3 Container-grown plants

Stand containers upright on well drained, weed-free ground. During the period April to October, water sufficiently to prevent the compost drying out. Support tall plants to prevent them blowing over. Give temporary protection to species susceptible to frost damage.

6.0 *Loading for despatch*

Unless otherwise instructed by the purchaser, adhere to the specifications on bundling, labelling, packaging, and transport, set out in *The general conditions, specifications and schedule of quantity for the supply and delivery of plants*, published by the Committee on Plant Supply and Establishment.

RECOMMENDATIONS FOR PLANT HANDLING – FROM DELIVERY TO SITE TO SUCCESSFUL ESTABLISHMENT

1.0 *Introduction*

1.1 Transplanting and re-establishment involve a plant in considerable stress and if they are to be successful they must be planned to satisfy the basic biological requirements of the plant. This *Code of practice* has been prepared as a guide to plant handling and management by the user to ensure successful establishment. To achieve this, the planting must be followed by a period of planned aftercare, covering at least two growing seasons.

The Code assumes that the nurseryman supplying the stock has adhered to the 'Recommendations for plant handling from lifting until delivery', and that the purchaser has specified, and the nurseryman has adhered to, the 'Specification for packaging and transporting nursery stock'. It also assumes that the species are correctly chosen for the geographical location and site conditions. It sets out the requirement that should be followed and specified in detail according to the situation on each particular site.

1.2 External pressures

Blanket or standard specifications are unlikely to be satisfactory but even when the work is properly specified, there are many outside pressures that provide strong incentives to set aside or compromise the biological and other principles and factors.

These include:

(1) The relatively short lifting and planting season.
(2) The logistics of lifting and supplying large numbers of different species.
(3) The financial pressure to complete projects as a whole, or within a financial year.
(4) The unpredictable and often unsuitable weather conditions which may effectively reduce the planting season to a mere 15 weeks.

1.3 Counter measures

In order to counter these pressures, it is essential that:

(1) The planting specifications are prepared in detail to suit the requirements of the site.
(2) The planting is planned, and plants are ordered, in sizes normally available, as far as possible in advance of the planting season.
(3) The planting is only carried out by appropriately skilled operatives under the control of competent management and with adequate supervision.
(4) After care is properly specified in advance and the finance secured as part of the overall planting and establishment cost.
(5) Adequate facilities are available for the receipt and storage of plants, including a conveniently situated water supply.

2.0 *Planting season*

2.1 Bare-root or root-balled plants

Traditionally the planting season is during the dormant period which is normally from October to the end of March, but early planting, before the end of the year, is more successful than planting from January onwards. Late plantings are particularly vulnerable to Spring droughts and should be avoided unless watering can be carried out. Evergreens establish more readily if planted in early Autumn or late Spring.

2.2 Container-grown plants

Plants may be planted throughout the year in appropriate weather conditions provided they are regularly watered.

3.0 *Receipt and unloading*

3.1 When placing an order, the purchaser shall give the nurseryman notice of any restrictions of access to the delivery site, and notify him whether mechanical lifting aids are available for off-loading.

3.2 The nurseryman shall give adequate notice of the date and time of delivery, and the purchaser shall ensure that adequate numbers of nursery staff with mechanical lifting aids where previously notified, are available to assist the off-loading without delay.

3.3 During unloading damage in handling shall be avoided.

3.4 The purchaser shall inspect and check the plants as quickly as possible after unloading to ensure each requirement has been complied with by the supplier.

3.5 The plants shall then be moved to temporary storage.

4.0 *Temporary storage*

4.1 Short-term

Where the air temperature is under 5°C plants may be stored in their packaging, under cover and away from sunlight, for a maximum of 7 days after receipt from the nurseryman.

4.2 Longer than 7 days

(1) Bare-root plants and root-wrapped plants in non-porous material
Plants root-wrapped in non-porous material shall be unwrapped. Bare root plants and plants root-wrapped in porous material, which have to be stored for longer periods should be heeled-in or plunged. The roots of all plants shall be moist and placed so that all are in contact with the plunge medium.

In order to achieve this, a free moving medium is required, such as a 50/50 mixture of coarse sand and peat, or sawdust, and care must be taken to ensure no degradation or heating up of the material occurs. Bundled plants may require cutting open and spreading out so that intimate contact between the roots and the plunging medium is achieved. The plunging site shall be well drained and sheltered, and stout rails will be needed to support standard trees and other large stock. An adequate supply of water points is essential.

If necessary, plants may remain heeled-in from November to March, but the period shall be as short as possible. Beyond this period, plants shall be planted out or containerised.

(2) Root-balled plants in porous material
Root-balled plants in a porous material shall be supported upright with the ball immersed in a deep layer of moist straw, hay, sand, peat, pulverised bark, sawdust, suitable soil or other suitable material. Watering may be essential to prevent the ball drying out.

(3) Container-grown plants
Containers shall be stood upright on well-drained, weed-free ground. Sufficient watering will be required for container grown stock during the period April to October to prevent the compost drying out. Tall plants will require support to prevent them blowing over. Species susceptible to frost damage shall be given temporary protection.

(4) Removal from temporary storage
Container grown stock and root-balled plants shall be watered before transportation to the planting site. The roots of bare-root stock shall be moist before removal from the heeling-in or plunge medium and the roots protected to prevent drying-out. Plants shall be re-labelled as necessary.

5.0 *Ground preparation*

5.1 The planting medium shall have the following properties:

(1) a texture that will retain and release moisture and nutrients to the plant;

(2) a crumb structure that will promote root growth, and drainage to prevent waterlogging in the root zone.

5.2 The following are essential if these properties are to be achieved:

(1) Where planting is proposed on imported soil or made up ground, a soil structure needs to be established before planting takes place. This may involve deep soil cultivation and draining, followed by grassing or herbaceous cover, and the delay of planting for at least one growing season.

(2) The structure of heavy clay soils may need to be improved so that they become more free-draining and friable, while light sandy soils will need to have their water retaining capacity increased.

(3) Ground preparation is best carried out in advance of the planting season, when the weather is more reliable; less soil structure damage is likely to be caused. This will allow more time for the planting operations.

(4) Ground preparation shall be carried out over an area at least 3 times the diameter of the root spread, and 1½ times the depth of the roots, of the stock to be planted.

6.0 *Planting*

6.1 Soil conditions for planting

At the time of planting, the soil shall be moist and friable and not frozen, excessively dry, or waterlogged.

6.2 Planting requirements

The hole excavated shall be of sufficient size to accommodate the spread roots and the stock shall be planted at the same depth as it was grown in the nursery. If the face of the plant hole becomes smeared during digging, particularly on heavy clay soils, the smearing shall be broken up before planting.

6.3 Stabilising support and protection

Some plants may need a support to hold them secure at ground level. Stakes shall be inserted before planting. Plants shall be held secure against the stake by the use of a proprietary tie, or similar method, ensuring that the stem shall not chafe against the stake. Guards may be needed to protect trees against physical damage by vandals, horses, cattle or other agencies.

6.4 Treatment of plants immediately prior to planting

All containers and wrapping, unless fully bio-degradable, shall be removed at the latest point before planting. Root-balled plants shall be placed in the planting pit before the hessian or other protective material is removed to avoid disturbance of the root ball. Wire netting shall be left on the root ball provided that there is no other material between the wire netting and the root ball. Damaged or torn roots and stems shall be cut back cleanly with a knife or secateurs and, particularly with container-grown plants, any coiled roots shall be spread out or cut to prevent future stability problems.

6.5 Backfilling

During backfilling around the plant, the soil shall be lightly firmed to ensure intimate contact with the roots, but with large material, successive layers of soil will need to be firmed as backfilling proceeds. The layers of soil shall be firmed separately so that the plant is securely held but penetration of moisture is not restricted. No snow shall be included with the backfill material.

6.6 Pruning

After planting, damaged, dead, diseased or crossing branches shall be removed by pruning. Opinions differ on whether the size of the head of a standard tree should be reduced after planting, but if it is decided to do so, do not prune the central leader.

7.0 *Aftercare*

7.1 Firming after frost or wind

If the roots of newly planted plants are loosened, they shall be re-firmed as soon as practicable. This is readily achieved with the heel, to exclude air pockets from around the roots.

7.2 Weed control

Weeds and grass compete for moisture and nutrients and shall be eliminated until the plants are well established, usually at least 2 years. Cutting or mowing weeds does not prevent this competition. Pre-planting site preparation may give a weed-free start. A minimum of a 1 metre diameter weed-free area shall be maintained around each transplant by herbicide applications or mulches. Large weed-free areas are appropriate for larger plants.

7.3 Conserving moisture

Mulching may be used to conserve soil moisture. Mulches achieve this by helping to control weeds which rapidly transpire moisture, and by reducing evaporation from the soil. Mulches may consist of either sheet or granular materials such as ultra-violet stabilised polythene or roofing felt, or pea gravel or ground bark. Mulches shall only be applied when the soil is moist. Regular hoeing in dry weather will produce a dust mulch.

7.4 Providing moisture

Though local climate and soil types will vary the requirements, as a guide it is recommended that during the growing season newly planted trees and shrubs shall be irrigated following any 4-week period without appreciable rainfall. (This may not apply to forestry planting.)

For reasonable growth, irrigation shall be applied at fortnightly intervals to moisten the soil so as the full rooting depth of soil is saturated. This may require at least 20 litres per watering for a heavy standard and at least 10 litres per watering for a small transplant. These quantities may be halved for survival only. Over-watering is wasteful, may not encourage root growth and will leach nutrients away. Soil with a low water holding capacity shall be irrigated more frequently, but with smaller quantities of water.

7.5 Protection

Plants may be damaged by voles, mice, hares, rabbits, deer and farm stock, etc., and suitable protection shall be considered at the planning stage. Regular inspections, say once a month, are essential so that appropriate action may be taken. Local circumstances will dictate whether it is best to fence a large area, use individual guards, or use poison for rodents. Maliciously damaged plants shall be replaced as soon as possible.

7.6 Stake maintenance

Stakes and ties must be maintained to prevent damage to trees. Stakes shall be inspected regularly to ensure they remain secure and ties shall be adjusted at least once a year. As soon as they are no longer necessary, supports shall be removed to encourage the trees to develop naturally.

APPENDIX IV

Summary table

Life cycle stage	*Factors affecting post-planting establishment*
Nursery growth	Undercutting, fertilisation, irrigation planting density
Lifting	Depth of lifting, timing, physiological condition
Storage	Temperature/relative humidity, pattern of storage, timing, physiological condition
Packaging and transporting	Type of packaging, timing, mechanical damage, desiccation
Planting	Soil conditions, timing, water handling, planting techniques

Note: Response varies enormously between species and size of transplants.