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Factors Influencing the Establishment of Amenity Trees

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TIMOTHY JAMES WALMSLEY

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The Problem

PREFACE

I obtained my first degree (B.Sc. Hons.Botany) from the University of Manchester in 1984. This was followed by two years research in the Department of Environmental Biology at the University of Manchester, on air pollution effects on woodland and grassland plant species in the Southern Pennines, from which I gained an M.Sc. in 1988.

The work described in this thesis was carried out in the Department of Environmental and Evolutionary Biology under the supervision of Professor A.D. Bradshaw F.R.S.

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Abstract

The scale of the problem of establishment failure of amenity trees, particularly in the urban environment, has recently been recognised. This research project examined factors that could influence the growth of amenity trees during the establishment period. From this a clear picture of the part played by root and soil factors, and their interaction, on the success or failure of amenity tree establishment became apparent.

Initially an experiment was conducted to assess the sensitivity of root growth to disturbance. Newly planted trees were subjected to a combination of drought and defoliation and subsequent root development monitored, until visible signs of water stress were observed. The investigation showed that root growth of the newly planted tree is highly sensitive, not only to drought but also to shoot disturbance.

The investigation went on to demonstrate the importance of the size of the root system that is moved with the tree from the nursery. It was shown by neutron probe measurement of soil water in the rooting zone, that the size of the root system determines the amount of soil water available to the tree. As a result, newly planted trees can be expected to experience water stress very readily. The use of a cross-linked polyacrylamide soil polymer, to increase the available water capacity of the soil was shown to overcome this and to increase markedly root development and reduce the shoot:root ratio.

Shoot pruning was examined as a method of reducing leaf area and thus alleviating the effects of drought stress. Dormant shoot pruning was shown to have no effect on root development or on the water relations of the tree, whilst summer pruning significantly reduced root growth.

In a series of experiments on the effects of applying 1) different combinations of nutrients ii) two commercial slow release fertilisers iii) nutrients at different times of the year and iv) nutrients in combination with irrigation and pruning, a general lack of effect of nutrient addition on tree growth was observed.

Finally the effects of weeds on the growth and water relations of trees were investigated, as were the effects of different methods of weed control. Weeds were shown to compete very strongly for water. Nutrient addition in the presence of weeds detrimentally affected tree growth, by increasing the weeds competitive power for obtaining water. Herbicide application was shown to be superior to either a bark or black polythene mulch.

It was concluded that the principle effect that transplanting has on tree growth, is by affecting the water relations of the tree. Various methods of improving tree establishment, by altering not only planting practices but also subsequent management procedures are discussed.

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Chapter 1

Introduction

Failure at Establishment

In recent years attention has come to be focused on the problem of establishment failure of amenity trees, particularly in the urban environment. Published reports indicate the scale of the problem. Gilbertson & Bradshaw (1985) concluded that 'dead, dying and moribund trees are an all too common occurrence in the urban areas of Britain' with over 10% of surveyed trees dead. In the London borough of Lambeth, Lohmann (1988) found that the proportion of dead or dying trees amounted to 11% in the whole borough, with extremes passing the 20% level in certain parts of the borough. More alarming statistics appear from the City of Boston in the USA where the average survival rate for pavement trees is about ten years. The City of Washington D.C. replaces 6000 of its 100 000 trees each year, or its total canopy once in 18 years (Foster & Blaine, 1978). Insley (1982) reported that the failure rate of new motorway plantings was usually over 30%. Capel (1980) conducted a survey into the fate of three common species of newly planted trees in the City of Liverpool. Not only was a vast range of growth performance noted, but more alarming was the fact that only 60% of the trees survived. Gilbertson (1987) pursuing the investigation into establishment failure in Liverpool, monitored, for 3 years, 1000 trees from planting. The results indicate that close to 23% of these trees were dead by the end of this period.

Indeed the problems are not related solely to the urban environment. Sykes and Briggs (1986) in a study of rural amenity tree planting schemes found a median survival of 77%. Of those trees surviving 12% were moderately healthy whilst 13% were unhealthy. Insley (1982) reports that the Forestry Commission during 1979/80, used 8 million plants to replace establishment losses. Peters (1987) reports that it was estimated that after the 'Plant a Tree in '73' campaign, 50% of the trees were dead after the first growing season rising to a level of 70% after 5 years.

It has been suggested that a conservative estimate of the urban tree population of Britain must be at least 100 million trees. Thoday (1983) suggests the extent of annual amenity tree planting in the United Kingdom to be 15 million whips and 2 million standards. A recent value of £121 million has been placed on the annual farm gate value of field and container grown hardy nursery stock to the wholesale market (Review Group on Arboriculture,1988). Recent suggestions that establishment failure can lead to the loss of 20% of trees, as previously discussed, means a loss of £24 million of stock alone (wholesale value). This does not take into account transport or labour costs, which if included would inflate this value enormously.

Possible Causes of Establishment Failure

The question therefore arises as to why this level of failure occurs. There is no doubt that transplantation is a totally unnatural procedure, causing the trees to undergo a massive physiological shock when removed from the soil. This is often termed 'planting shock' (Coutts,1981) which is apparent as reduced shoot vigour or 'planting check'. Watson, Himelick and Smiley (1986) have reported that a period of 4 or more years of stress and reduced vigour follow transplanting, even for relatively small trees. Stoneham & Thoday (1985) have identified four stages during the transplanting process where factors can influence survival; at lifting, during transportation, during the replanting process and subsequent aftercare.

The majority of trees planted in the United Kingdom are planted bare root i.e. without any soil adhering to the root system, rather than planted with soil adhering to the roots (ball rooted) or as containerised stock. In the USA the situation differs in so much as bare root planting is limited to deciduous shrubs and tree up to 5cm in diameter, planted in the early spring or autumn. Balling and burlapping (soil ball) is practised for all evergreens and trees over 5cm in diameter, that are moved either during the dormant or growing season (Himelick,1981). For the different types of stock, transplanting causes differences in physiology and morphology. The bare-rooted tree experiences most moisture and root loss in the process of transplantation (Tinus, 1974).

The importance of preserving the roots of trees during transplanting was noted even as long ago as 1678, when John Evelyn wrote in his treatise:

> 'Theophratus in his Third book de Causis,c.7. gives us great caution in planting, to preserve the roots, and especially the earth adhereing to the smallest fibrills, which should by no means be shaken off......... Not at all considering, that those tender hairs are the very mouths, and vehicles which suck in the nutriment, and transfuse it into all the parts of the tree, and that these once perishing, the thicker and larger roots, hard and less spungy, signifie little but to establish the tree.'

Aldhous (1972) has distinguished three types of damage that can affect bare-rooted transplants during handling; physical, heating and drying. Physical damage includes loss of a large part of the root system. Accepted transplanting practices often mean that only 5% of the original root system is moved along with the tree (Watson & Himelick, 1982). Gilman (1988) found that between 91-95% of the root systems of *Gleditisia triancanthos, Populus generosa* and *Fraxinus pennsylvatica* were outside the harvestable root ball.

The removal of such a large portion of the root system predisposes the transplanted tree to internal water deficits. The physiological responses of the shoot cannot sufficiently reduce transpiration to compensate for the loss of absorbing roots (Witherspoon & Lumis, 1986). Physical damage also includes damage caused by rough handling. Tabbush (1986) noted that the effect of dropping bags of trees, to simulate rough handling, was a reduction in root growth potential and survival, and the induction of water stress.

Heat generated by respiration of bacteria and micro-organisms on the plant surface has been identified as a problem (Aldhous,1972). Thus if the plants are packed to tightly whilst in storage, the heat cannot escape, the plants warm, respiration increases and a vicious circle begins until plants may be killed.

Sutton (1969) states that even with the most careful handling, desiccation may reduce the root system, the problem being exacerbated as the wounding of root bark increases loss of moisture. Insley (1980) reports that up to 10% of trees supplied by commercial nurseries for roadside plantings had lost more than 50% of the water that they contained at lifting. Damage to lifted plants by exposure is usually manifested by reduced survival or reduced growth rate (Kendle, Gilbertson & Bradshaw, 1988). This is often as a result of reduced transpiration following replanting and reduced gas exchange due to the closure of stomata. It is also reported that root regeneration capacity was reduced following exposure and drying. Mortality induced by exposure varies, with the degree of exposure (Ritchie & Dunlap,1980; Coutts,1981; Coutts,1982; Tabbush,1987).

Sands (1984) believes that with normal storing and transplanting practices, the prolonged water stress that is observed to occur, is not caused by root loss or damage, nor by desiccation on storage, but rather because of poor root to soil contact on transplanting, when air gaps form at the root-soil interface. This would cause a relatively large resistance to water flow in the soil-plant continuum, as water can only cross an air gap in the vapour phase, which is considerably less efficient than movement of liquid water. The transplanted seedling would recover from such stress only in direct proportion to the rate at which new roots generated from the transplanted root system. These new roots would grow through the soil and have a good root-soil contact, compared with the old transplanted root system.

The ability of newly planted trees to generate new root growth soon after planting is of vital importance to the subsequent survival (Howe,1979). Apart from providing, once established, anchorage necessary to support the tree, the newly formed roots also provide the absorbing surface necessary for the uptake of water and nutrients. According to Atkinson & Wilson (1980) an established, five year old *Malus domestica* will exploit a soil volume of approximately $7m^3$ whereas Gilbertson, Kendle & Bradshaw (1987) suggest that a newly planted standard tree of the same age may have roots that only tap $0.1m^3$, providing only 8 days water supply at the most. Hence the conclusion of Kozlowski & Davies (1975) that the most important cause of death of transplanted trees is desiccation. This restricted root volume appears to be even more serious when predictions made by Watson (1985) that a 10cm dbh tree would replace its original root system in 5 years, are considered.

According to Ritchie & Dunlap (1980) it has been difficult to establish a clear cause-effect relationship between root growth potential and seedling survival after planting. However a number of authors have highlighted the existence of a functional relationship between the root and shoot systems (eg. Hunt,1975; Thornley,1975). Davidson (1969) suggested this relationship could be expressed by:

$$\text{root mass} \times \text{rate (absorption)} \propto \text{leaf mass} \times \text{rate (photosynthesis)}$$

Gilbertson (1987) ranked the causes of death of the trees examined in the survey of Liverpool's tree population. Over 65% were associated with the poor properties of urban soils, the remaining 35% of deaths a result of vandalism or poor maintenance. Water and nutrient stress were the factors that were ranked first and resulted in the death of 56% of the trees, of which over 50% were associated with substantial weed growth, which is believed to have led to severe competition for both water and nutrients. Vandalism was ranked second accounting for 18% of tree deaths and poor maintenance of tree guards and tree ties accounted for 12% and 5% respectively, of tree deaths. Soil compaction caused by trampling and mechanical damage was ranked fourth being associated with 9% of tree deaths.

There are however, many other factors that can lead to premature tree death in urban areas. Trees that are weakened by other stresses, are often predisposed to infection by plant pathogens or attack by organisms of secondary action (Houston,1985; Impens,1987). These secondary organisms include a wide variety of saprophytic fungi and insects that can kill fine roots, buds and fine twigs, or bark and cambium of branches, stems and roots. Herbicides if improperly used can destroy not only the unwanted vegetation but also the tree itself. The effect of herbicides is often to cause epinasty or chlorosis of foliage, and in some parts of Germany the use of herbicides is no longer allowed (De la Chevallerie,1986). Natural gas leakage is known to occur and, although not itself toxic, it displaces the oxygen content of the soil and prevents normal root respiration and can destroy the tree within a matter of weeks. Certain soil bacteria can oxidise methane into carbon dioxide and water, in this way extracting from the soil atmosphere 2 molecules of oxygen per molecule of oxidised methane whilst discharging carbon dioxide (Adams & Ellis, 1960).

Air pollution has been a serious problem in the past. Sulphur dioxide was once very important, so much so that it was impossible to grow conifers in cities and in the early part of the century even the 'notoriously hardy' *Rhododendron ponticum* only survived one or two seasons (Pettigrew,1928). Now however SO_2 levels have declined dramatically so that they no longer appear to cause a problem (Review Group on Acid Rain,1987; Walmsley,1988). Concurrent with the decline in SO_2 there has been a dramatic increase in NOx levels which may interact with SO_2 and other pollutants (Bell,1982). Also there is always the possibility of local air pollution problems related to a specific industrial source (Vick & Handley,1977). Toxicity produced by salt from de-icing is rapidly becoming a serious problem for street trees. A considerable amount of work has been carried out and reviewed by Bernatzky (1978) and Sucoff (1976).

There is no doubt that many trees planted in urban areas are located in soils which are less than desirable for plant growth. Bockheim (1974) has suggested a definition for an urban soil being 'a soil material having a non agricultural, manmade surface layer more than 50cm thick, that has been produced by mixing, filling or by contamination of land surface in urban or suburban areas'. Indeed, Patterson, Murray & Short (1980) have projected that about 80% of urban plant problems which develop can be initially traced to and/or caused by a poor soil environment.

Urban areas have an unusual hydrological cycle. Precipitation falls on surfaces which are predominately paved, so run off rather than infiltration occurs. This run off is channelled away from the sites where soil recharge could occur via a network of gutters and sewers. In this manner ground water and sub-surface runoff are also intercepted, further reducing the available store of soil water.

In addition, bare urban soil exhibits a pronounced tendency to form a crust on or within several centimetres of the surface (Craul 1985). The phenomenon is caused by several factors. The most obvious one is foot and wheel traffic destroying vegetative cover and compacting the surface soil, the binding of roots is absent as is the surface protection provided by organic litter. A horizontal orientation of particles occurs, creating one and sometimes two distinct microlayers within the surface two centimetres (Ruark *et al.*,1983). Water infiltration and gaseous diffusion are reduced. Therefore a tree placed in a pit surrounded by concrete or asphalt and underlain by compacted soil is supplied with very little natural precipitation in summer, followed by too much water in the dormant season, and too little oxygen throughout the year, setting up the extremes in stressful conditions for plants, which few can tolerate (Kozlowski, 1985).

According to Dutton & Bradshaw (1982) brickwaste and exposed subsoils are the most frequently occurring potential growth media that the urban environment offers. There is no doubt that the dominant nutrient in short supply in the urban soils is nitrogen (Bradshaw,1981; Marxen-Drewes,1983). This is for the simple reason that nitrogen is accumulated in soils by biological processes occurring in the surface layers, so that subsoils, wastes and equivalent materials have little or none (Bradshaw, Walmsley & Hunt,1989).

Aims of the Thesis

It can therefore be seen that there appears to be two basic elements universally required for plant growth, namely water and nutrients, that could be limiting to the newly planted tree in the urban environment. Therefore the question arises as to what management practices could be employed to reduce the water and nutrient stresses placed upon the tree. The basic need however is clearly understood and is to aid the tree to restore as quickly as possible the shoot:root ratio that was found before transplanting.

Reducing the loss of root at lifting, thereby increasing the volume of soil the tree can exploit, appears to be the simplest method of easing water stress. Increasing the water supply within the rooting zone is another method by which stress may be reduced, where soil water is the limiting factor. This can be easily achieved with the use of soil ameliorants such as water retentive polymers or by irrigation. Shoot pruning on planting has often been advocated as a means of reducing transplanting shock and promoting successful plant establishment (Kozlowski & Davies,1975; Harris,1983). Pruning instantly restores the shoot:root ratio and is believed by many workers to be a means of reducing the transpirational water losses from the newly planted tree (eg. Chandler & Cornell,1952; Harris,1975).

Much research has been carried out to determine the effects of nutrient addition on tree growth, however the majority of this work has involved examining the trees response in terms of shoot growth. Little research has been published on the effects of fertiliser addition on root growth. There are however, indications that root growth may be enhanced by nitrogen addition, for example, Kendle (1988) found that with increasing levels of nitrogen application, the shoot:root ratios of *Betula pendula* and *Acer pseudoplatanus* were reduced. However, the investigation was carried out on china clay waste, which has been demonstrated to have a particularly low nitrogen content (Ward, Marrs & Bradshaw,1981). Van de Werken (1981) reports that neither soil nitrogen levels before transplanting nor those immediately after transplanting affect survival or rate of growth of trees in the first 3 years after planting. Similar responses were observed by Capel (1980) who suggests a possible period of delay before any accumulated vigour of fertilised trees is expressed as a significant growth response. Whitcombe (1979) again reports that benefits from fertiliser will not be noticeable until the second or third growing season but at least nitrogen should be applied to most urban soils.

Much of the research that will be discussed in this dissertation will have resulted from an interest in forestry or fruit production rather than from an amenity point of view. Although there is a central theme, the three disciplines differ radically in their outlook on the tree. To the forester, the primary objective is the growing of trees for timber production, for the fruit grower, the production of fruit, whereas to the arboriculturist the prime objective is presenting the tree for the provision of amenity (Review Group on Arboriculture,1988). This therefore dictates that although the tree and its biology provide a common link, research may need to be applied in very different ways.

The following investigation has attempted to evaluate some procedures which might encourage the reduction of transplant stress of bare rooted amenity trees. All the operations that have been investigated are designed to reduce the shoot:root ratio and could be carried out during the planting procedure. Initially, however, the sensitivity of root growth of the newly planted tree has been examined (chapter 3). This relationship was disturbed by defoliationand drought and the root response was examined using root observation boxes.

Increasing the water supply to the newly planted tree was examined from two different aspects in Chapter 4, firstly by increasing the volume of soil that the tree can exploit by transplanting trees with larger root systems, and secondly by investigating the ameliorative effectiveness of a water retentive soil polyacrylamide gel. The effect on the water relations of the tree following pruning and the responses of a number of species to dormant shoot pruning have been examined (chapter 5). Using pruning as a means to reduce crown area in order to remove the necessity to stake a newly planted tree has also been investigated.

The effects of addition of nutrients on the root growth of newly planted trees including three different methods of nutrient addition have been examined in chapter 6. The effectiveness of weed control on the water relations and subsequent growth of the transplanted tree, in relation to the use of three weed control measures is discussed in chapter 7.

From this it was hoped to test the hypothesis, that the high failure rate and poor growth of amenity trees is a direct consequence of the process of transplantation, and that a clear picture of the part played by root and soil factors, and their interaction, on the success or failure of amenity tree establishment would become clearer.

Chapter 2

The Species, Plant Handling and the Experimental Site

2.1 Definition

Before describing the species used in the following investigations, it is pertinent to consider an acceptable definition of a tree:

> A tree is not a botanical class of plants, it is a mode of growth. Trees are distinguished from the herbaceous vegetation by the formation of secondary wood; and from shrubs in having one dominant trunk and a height greater than 5 metres.

However, it is recognised that trees grown out of their normal geographic range or ecological niche, can acquire a shrubby or semi-dwarf habitat, because their genetic potential is limited by the new environment. For example, *Picea glauca* which makes a valuable timber tree in New Hampshire, USA, may well become a shrub at the timber line in Northern Canada (Zimmermann & Brown,1971). However, the essential character of a tree is that it is (a) woody and (b) large and normally single stemmed.

2.2 The species

In the following investigations five deciduous tree species have been employed. The following descriptions have been adapted from Clapham, Tutin & Warburg (1981) and Anon (1985a).

Acer platanoides L. (Norway Maple)

First introduced from Scandinavia in about 1860, it is now common and widespread in the British Isles, growing equally well on chalk or acid sands. The bark is grey and smooth or with low ridges. The twigs are dull green or tinged with red. The buds are ovoid, those at the tips often with a red tinge. The leaves are 10-15 cm long, with 5-7 pointed, toothed lobes, the basal pair smaller and more narrowly triangular than the rest; bright green and glabrous above, paler beneath with white hairs in the axils of the veins; the petiole is up to 20cm long. The flowers are in upright clusters of 30-40, strong greenish-yellow, opening before the leaves, and persisting until the leaves are fully open.

Acer pseudoplatanus L. (Sycamore or Sycamore Maple)

Introduced in the fifteenth or sixteenth century, this large tree, up to 30m, is now very common throughout the British Isles preferring deep, moist, well drained rich soils. The bark is grey and smooth for a long time before finally scaling. The leaves are 5 lobed to about half way, cordate at the base, dark green above, pale and glaucous beneath. The lobes are ovate, acute, coarsely and irregularly toothed. The yellow inflorescences are terminal with 60-100 flowers on a short leafy branch.

Fraxinus excelsior L. (Common Ash or European Ash)

A tree common throughout the British Isles on calcareous soils, particularly on the wetter parts. A tall tree up to 40 m high with an opened, domed crown. The bark is smooth but becomes fissured on old branches. The tree has large black terminal buds with imparipinnate leaves with 7-13 lanceolate to serrate leaflets. The flowers appear before the leaves as purplish panicles.

Platanus x hispanica Muenchh (London Plane)

The origins are obscure, considered by many to be a hybrid between *P.occidentalis* and *P.orientalis* which were introduced into the British Isles in the early 17th century. This species is also known as *P.x acerifolia*. It is normally vegetatively propagated and probably consists of only a few clones. The trunk is very tall with the bark being dark grey or brown, regularly flaking to reveal large yellowish or pale patches beneath. Young shoots are green with whitish hairs, becoming darker with age. The leaves are up to 24 cm long, usually 5 lobed, usually rounded palmate but immensely variable, shiny and smooth except for the woolly veins above, paler below. The sinuses are generally shallow but very variable, cutting one third to half the length of the blade. The lobes are triangular with up to 5 forward pointing teeth on each side. The catkins are 2-8cm long; the male flowers are borne on 2-6 yellowish globose heads, female flowers are borne on 2-5 crimson globose heads.

Tilia cordata Miller (Small-leaved Lime)

A tall, irregularly domed tree with a dense crown. The leaves are 3-9cm long more or less round, abruptly narrowed into a tapering point, heart shaped at the base, the margin with fine dark teeth,dark shiny green and smooth above, pale beneath with reddish brown tufts in the axils of the veins. The flowers are translucent white,4-15 carried together in an obliquely erect cyme. The bark is grey, very smooth on young trees, becoming dark grey or brown with large cracks and flakes on old trees. This is a native tree, commonly occurring on base rich soils.

These species were chosen, as according to Gilbertson & Bradshaw (1985) they represent the most common newly planted species in northern England, *Platanus x hispanica* dominating the urban tree population with over 50% of the survey trees comprising of this species. The *Acer* family represent over 20% and *F.excelsior* 5% of the surveyed trees. *Tilia cordata* was chosen as although it represented less than 1% of the newly planted urban tree population in the north of England (Gilbertson & Bradshaw, 1985), it is widely planted in streets, parks and gardens (Anon,1985a) and in Liverpool represents over 5% of the urban tree population (Gilbertson & Bradshaw,1985).

All the species used, have been recommended as suitable for urban sites. Dutton & Bradshaw (1982) have commented upon the suitability of four of the five species. *Platanus x hispanica* being 'attractive and extremely hardy in a wide variety of urban situations', *F.excelsior* is described as doing well 'on exposed sites and in stony ground'. Both *A.platanoides* and *A.pseudoplatanus* are described as being 'very hardy, establishing easily either as a whip or standard and coping well with ground cover competition'. Emery (1986) lists *T.cordata* as one of the trees most suitable for urban conditions especially on well drained loam.

2.3 Stock size

In the following investigations trees of various sizes have been used ranging from seedlings to standards based on the British Standard 3936 specifications, given in Table 2.3.1, (Anon,1980). It would have been preferable to have used standard trees throughout but the cost and labour requirements would have been prohibitive.

This heterogeneity in size of the experimental material has important implications, as there are many morphological and physiological changes which can occur in the transition from juvenility to sexual maturity. These can include such differences as leaf shape and phyllotaxy, growth habit, bark appearance, production of spines and thorns and the retention of leaves by the lower and inner portion of tree crowns (Zimmermann & Brown,1971).

Caution also has to be taken when making generalisations concerning physiological mechanisms because of differences in species response. For example, Richardson (1958) found root growth of *Acer saccharinum* seedlings completely inhibited after autumn leaf fall until a chilling requirements of the buds had been met. In contrast Wilcox (1962) in studying root dormancy in *Libocedrus decurrens* found neither a dependent relationship between shoot and root growth or evidence for a chilling requirement of the buds. This is especially true when seedlings instead of older trees are used as experimental material. Seedlings are more responsive to the environment because of the close proximity of roots to shoots and the rather immediate effect of one upon the other (Zimmemann & Brown,1971).

Table 2.3.1 **BS 3936 Specification for Tree Nursery Stock**

Taken from Anon (1980)

Dimensions of standard trees

Designation	Circumference of stem measured 1 m from ground level	Min. overall height from ground level	Approximate max. height from ground level	Clear stem height from ground level to lowest branch
	cm	m	m	m
Short standard	Not specified	Not specified	Not specified	1.00 to 1.20
Half standard	Not specified	1.80	2.10	1.20 to 1.50
Light standard	6 to 8	2.50	2.75	1.50 to 1.80
Standard	8 to 10	2.75	3.00	1.80 min.
Tall standard	8 to 10	3.00	3.50	1.80 min.
Selected standard	10 to 12	3.00	3.50	1.80 min.

NOTE. Minimum overall heights do not apply to weeping trees.

11. Trees, other than conifers

11.1 Standards. All standards shall be supplied in one or more of the following forms of root system; bare root, root-balled or container-grown (pot-grown). Column 2 of appendix A indicates the species which shall be supplied root-balled or container-grown. All standards shall have been previously transplanted at least once during their life.

All standards shall have reasonably straight stems. Bottom-worked trees may have no more than a slight bend at the union. Temporary feathering shall have been removed flush with the stem.

The head shall be well developed for its type and evenly balanced, with no main branch crossing the crown. Standards shall have a central leader, but the species marked 'BHS' in column 1 of appendix A may alternatively be supplied with a branched head.

Standards, excluding half standards and short standards, shall be designated by the size of stem circumference, measured 1 m from the ground level. For all standards other than weeping standards the overall height shall be stated when the plants are offered for sale. For all weeping standards the clear stem height shall be stated.

Dimensions of other tree forms

Designation	Circumference of stem measured 1 m from ground level	Min. overall height from ground level	Max. overall height from ground level	Clear stem height from ground level to lowest branch
	cm	m	m	m
Seeding	–	–	–	–
Transplant	–	–	1.20	–
Whip	–	1.20	1.50	–
	–	1.50	1.80	–
	–	1.80	2.10	–
	–	2.10	2.50	–
Feathered	–	1.80	2.10	–
	–	2.10	2.50	–
	see 11.2.2	2.50	3.00	–
Bush	–	–	–	30 to 60

11.2 Feathered tree

11.2.1 A feathered tree shall have been previously transplanted at least once in its life. It shall have a defined, reasonably straight, upright central leader and a stem furnished with evenly spread and balanced lateral shoots down to near ground level, according to its species.

11.2.2 Feathered trees shall be designated according to their overall height and shall be supplied with an overall height in one of the ranges detailed in table 2.

Trees over 3 m shall be specified in addition by the stem circumference measured at a point 1 m from ground level

11.3 Whip. A whip shall have been previously transplanted at least once in its life, shall not necessarily be staked, and shall be without significant feather growth and without head.

Whips shall be designated according to their overall height and shall be supplied with an overall height in one of the ranges detailed in table 2.

11.4 Bush tree. A bush tree shall have a well developed, balanced, branching head from which crossing branches have been removed.

The dimensions of bush trees shall be as detailed in table 2.

11.5 Transplant. A transplant shall have been transplanted or undercut at least once. The age and height shall be stated and the height shall be as detailed in table 2.

The number of transplants or undercuts shall also be stated if this has occurred more than once.

11.6 Seedling. Seedlings shall have been grown from seed and have remained undisturbed since sowing. Their age, in years, shall be specified when the plants are offered for sale.

2.4 Plant handling and planting techniques

Only bare-root stock has been used. Trees arriving from the commercial nurseries were carefully inspected to see if they conformed to the required specification stated in the purchase order; any stock that did not was rejected. The recommendations of the Committee for Plant Supply and Establishment (C.P.S.E.,1985) were followed.

Trees that were not planted immediately were temporarily heeled into a prepared trench; where this was not possible because of frost conditions, the trees were placed in a dark shed with the roots covered with moist peat or leaf mold so that the roots were not exposed to cold and drying winds. Two planting methods were used:

1) Notch Planting

All transplants were planted using the notch planting technique. The blade of the spade was pushed into the ground and rocked back and forth to make a notch in the soil. The roots of the transplant were pushed into the notch and gently pulled up and down so that the roots were spread out in the space and the soil was at the correct level of the stem. The notch was then closed by the spade being driven into the soil a few centimetres from the previous place and wriggled before the soil was firmed around the plant using the heel of the boot.

2) Pit planting

All planting pits were prepared in advance of planting. This meant hand digging a pit approximately 70 x 70 x 70cm. Untreated larch stakes, 2.5m long and 10cm in diameter, were driven firmly into the bottom of the planting pit, using a post driver. In all cases the stake was positioned on the windward side of the tree. All trees were planted to the same depth at which they were previously growing in the nursery, as shown by the 'soil mark' at the base of the trunk. When the tree had been positioned near the stake for ease of tying, the roots were spread evenly in the pit. Backfilling, using only the soil dug from the pit was carried out, care being taken to gently move the tree up and down to settle fine soil around the roots and to fill any cavities. The soil was then firmed by treading. The trees were then tied to the stake by a reinforced rubber strap with a rubber block as a spacer to prevent chaffing of the stem.

After planting, the trees were watered either through rainfall or artificial irrigation.

2.5 The experimental site

The experiments were carried out at the University of Liverpool's Botanic Gardens, Ness, Wirral, Cheshire (SJ305755).

All the field investigations were carried out in a single field at the site, which had a gently sloping westerly aspect. The soil type was a free draining, sandy loam, overlying sandstone. The depth of the soil averaged approximately 1m. The prevailing wind direction was westerly with a secondary concentration of south-easterly winds.

The climatic conditions found at the experimental site over the period of the investigations are shown in Figure 2.5.1. Total rainfall for the years 1987 and 1988 were 779.8mm and 731.2mm respectively. The rainfall during 1987 was unevenly distributed, with the spring and summer months (April to September) receiving 438.7mm compared to only 341.1mm for the remaining months. During 1988 the rainfall was more evenly distributed, with 333.6mm falling during the summer months compared to 397.6mm during the remaining months. During the first 7 months of 1989, 323.6mm of rainfall fell.

The coldest minimum temperatures were encountered during the first 3 months of 1987. The winters of 1987 and 1988 were relatively mild. Mean maximum temperatures were similar during the summers of 1987 and 1988 but were higher during the summer months of 1989.

2.6 Root excavation techniques

Three methods of root excavation were used. The techniques were developed during the course of the research and thus the excavation of second year material might have differed from the method used to excavate the roots during the first year. The methods were as follows:

Method 1

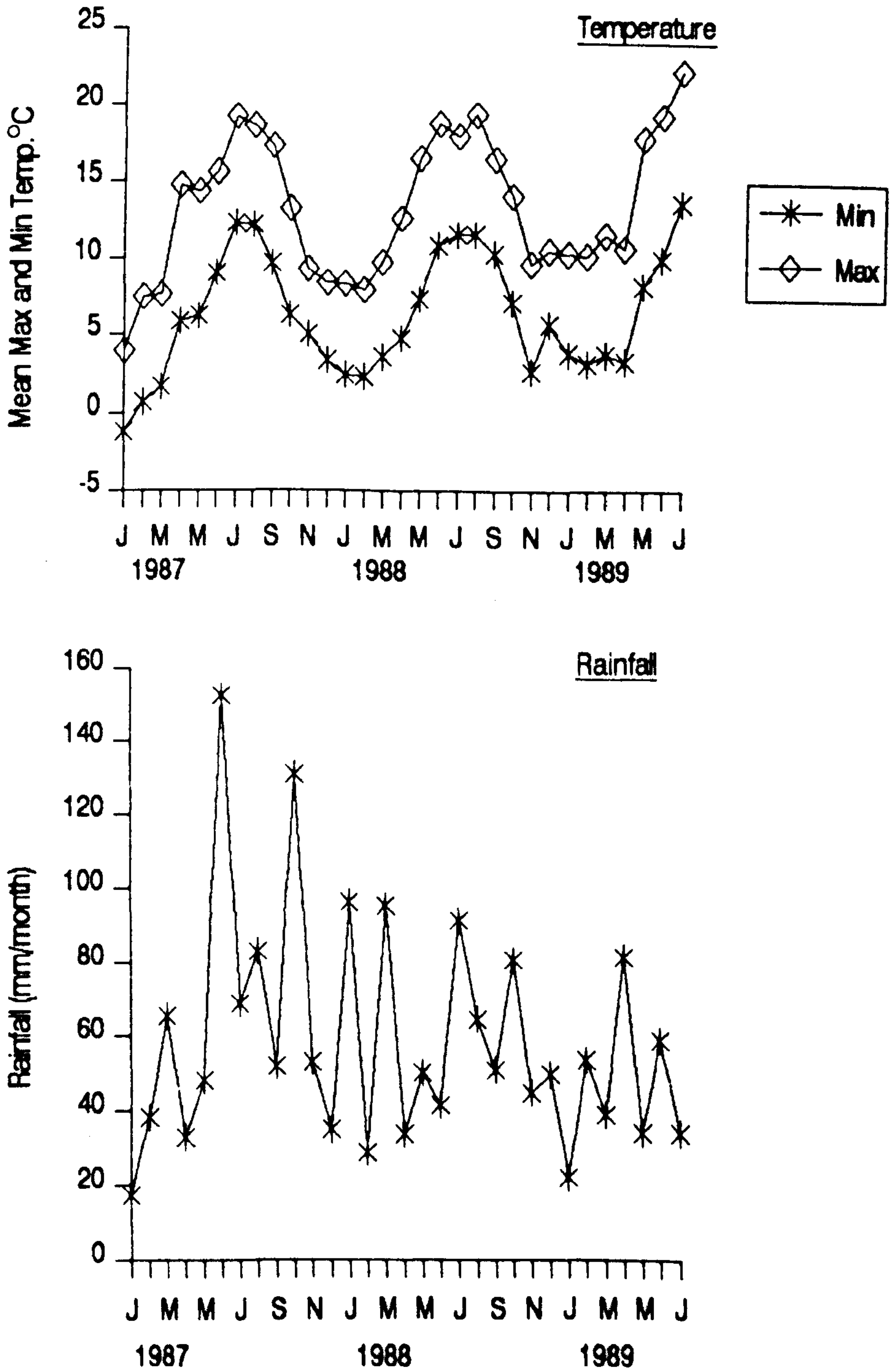
Roots were excavated using a garden fork. Although roots were broken on lifting they were easily recovered.

Method 2

This method utilised a high pressure water jet, to expose the roots and an industrial vacuum cleaner to remove the resulting soil suspension. This method proved to be the most accurate and reliable as the roots were not broken by the

Figure 2.5.1

Climatic conditions at the experimental site over the period of the investigations.



water jet and could be followed to their full extent. However, for standard trees this method proved to be extremely time consuming requiring up to one hour per tree. This method was found to be most satisfactory for transplants, whips and seedlings.

Method 3

This procedure combined the use of method 2 and excavation by a JCB excavator. Five roots from each experiment were excavated using method 2, from these maximum root extension was noted. A JCB was then used to gently lift a volume of soil containing the tree root. The volume of soil to be lifted was calculated from the measurements taken from the trees excavated by method 2. Due to the sandy nature of the soil, root breakage was very low and any broken roots were easily recovered by hand digging.

With all 3 excavation techniques, the majority of the dry weight of the root systems were recovered, however there is some uncertainty as to the proportion of fine roots lost.

2.7 Assessment of growth

Growth of trees can be assessed by a variety of means. For the purposes of these investigations a number of parameters have been measured as standard.

Root Growth

Root growth has been assessed by dry weight. For all trees, other than standards, the root has been taken as the total tissue below ground level. For standard trees it became necessary to differentiate between the root stock (which was included in the stem weight) and the remainder of the root system.

Shoot Growth

Total shoot extension (extension growth) was, in the majority of cases, assessed by linear measurement. For two investigations (see Chapter 6), where a large number of of seedlings were used, extension growth was measured as dry weight.

Shoot:Root Ratio

Shoot:root (dry weight) ratios have been reported for all tree sizes other than standards. The reason for not indicating shoot:root ratios of standard trees is because the dramatic increase in woody tissue with increasing tree size, results in the value of this parameter, as an indication of relative size for water absorption and transpiration, being reduced (Evans & Klett,1984).

Total Weight

Total weight (dry weight) has been reported for all tree sizes other than standards. The reason being that stem growth of the standard trees was extremely variable, prior to planting, and because of this changes in total productivity were masked.

Certain investigations, particularly studies into the effects of pruning practices necessitated that additional parameters be measured. These are discussed within the text, where required.

2.8 Statistical analyses

Statistical analyses have been performed by methods described by Sokal & Rohlf (1981). Analyses of variance tables (ANOVA) have been presented in the following manner:

Item	D.F.	M.S.	F	P
Total				
Groups				
Error				

Where:

D.F. - Degrees of Freedom
M.S. - Mean Square
F - Variance ratio
P - Probability

Chapter 3

Sensitivity of Root Growth and the Shoot:Root Relationship

3.1 Introduction

When a tree is transplanted, it physically undergoes considerable disruption and the balance between the root and shoot which existed in the nursery is normally completely destroyed (see Chapter 1). In the urban environment external stresses are then often placed on the newly planted trees which will affect to some degree the regeneration of the new root system and hence the developing relationship between the shoot and root (Perry,1982).

This investigation was designed to elucidate the sensitivity of root growth and the shoot:root relationship of the newly planted tree. The method used to disrupt the relationship, and from which it was known that the tree could recover, was defoliation (Parker & Houston,1971; Gregory & Wargo,1986). Indeed defoliation is not a totally unnatural phenomenon and does occur when leafed out trees are transplanted (Davies *et al.*,1972). Drought induces leaf abscission in some trees following changes in balances of growth hormones and synthesis of enzymes that hydrolyze the middle lamella between cells of the abscission layer (Kozlowski, 1985). In other trees the leaves simply dehydrate and wither as the drought intensifies (Davies *et al.*, 1972).

The mechanism by which defoliation is believed to affect root growth is by the reduction or cessation, depending upon the level of defoliation, of the production of photosynthates. Wassink & Richardson (1951) and Richardson (1953) showed that the roots of

Acer pseudoplatanus seedlings would only grow if they obtained assimilate directly from the leaves, similar results were obtained by Eliasson (1968) for *Populus tremula*.

Nevertheless, total defoliation has been put forward as a means of reducing transplanting shock and transplant loss. Goren, Mendel & Monselise (1962) found that defoliation was effective in increasing survival of bare root *Citrus sp.* and Askew *et al.*(1985) report that survivability of *Cornus florida* liners was improved by 100% defoliation at time of planting.

The following investigation examines the sensitivity of root growth, by partially and totally defoliating *Acer platanoides* transplants, under conditions of both an adequate watering supply and also drought. The imposition of a droughting treatment was included in the experimental design, as drought is often quoted in the literature as being perhaps the major external stress affecting the newly planted tree (Kozlowski,1985).

3.2 Materials and Methods

Thirty *Acer platanoides* (1+2) transplants were planted singly into root observation boxes situated inside a polythene tunnel house. The root observation boxes were constructed of wood with all the side walls consisting of a removable glass plate. Each box measured 45cm x 30cm x 45cm. A cover of black polythene was used to cover the glass and protect the roots from light (Figure 3.2.1). The bottom of the box contained drainage holes. Each box was filled with a mixture of 2 parts peat to 1 part coarse sand amended with a slow release fertiliser (8-9 month release 18-11-10 'Osmocote') at a rate of 3 Kg m^{-3}, and ground limestone and magnesium limestone at a rate

Figure 3.2.1

An *Acer platanoides* transplant, planted in one of the root observation boxes. A cover of black polythene has been used to cover the glass and protect the roots from light.

of 1 kg m^{-3}. Before the trees were planted care was taken to settle the mixture by wetting and draining until no further settling of the substrate was observed. Additional substrate was added to bring the level to within 2cm of the top of the box.

All the boxes were watered from above, three times a week until all the trees had leafed out. After this time half of the trees received no further water, the remaining trees continued to receive water on a daily basis. After 1 week three defoliation treatments were applied, to both the droughted and undroughted trees. These consisted of: no defoliation, 50% defoliation (achieved by removing one leaf from an alternate pair) and 100% defoliation. Hence there were 6 experimental treatments with 5 replicates (as single trees). The boxes were arranged in five blocks, with the treatments randomly arranged within each block.

Root length was estimated using the intersection method as proposed by Newman (1966) and Head (1966). Essentially this consisted of placing a 2x2 cm grid over one of the glass faces of the root observation box and recording the number of intersections of the tree roots with the vertical and horizontal grid lines. Curved roots were dealt with by recording single counts when the edges of the curved roots touched a line and recording double counts in cases where roots were lying a long a grid line. Intersection counts were converted to centimetre measurements using the equation given by Tennant (1975):

Root length (R) = 0.786 x No. of Intersections (N) x Grid Unit

The side of the box on which measurements were taken was chosen as being the one showing the most number of roots at the beginning of the observation phase of the investigation.

Root development was monitored over 7 weeks, after which time the trees were harvested, shoot and root dry weights were ascertained after drying in an oven at 90°C. Leaf areas were determined on a 'Hayashi Denko AAM-5' area meter. The water relations of the trees as measured by a 'Crump' diffusive porometer were also followed over the course of the experiment, measurements being taken at 11 am on the same day that root growth was examined. On each occasion, three readings per leaf were made on the lower surface of the youngest expanded leaf of the tree, the last recording being accepted as the stable measurement.

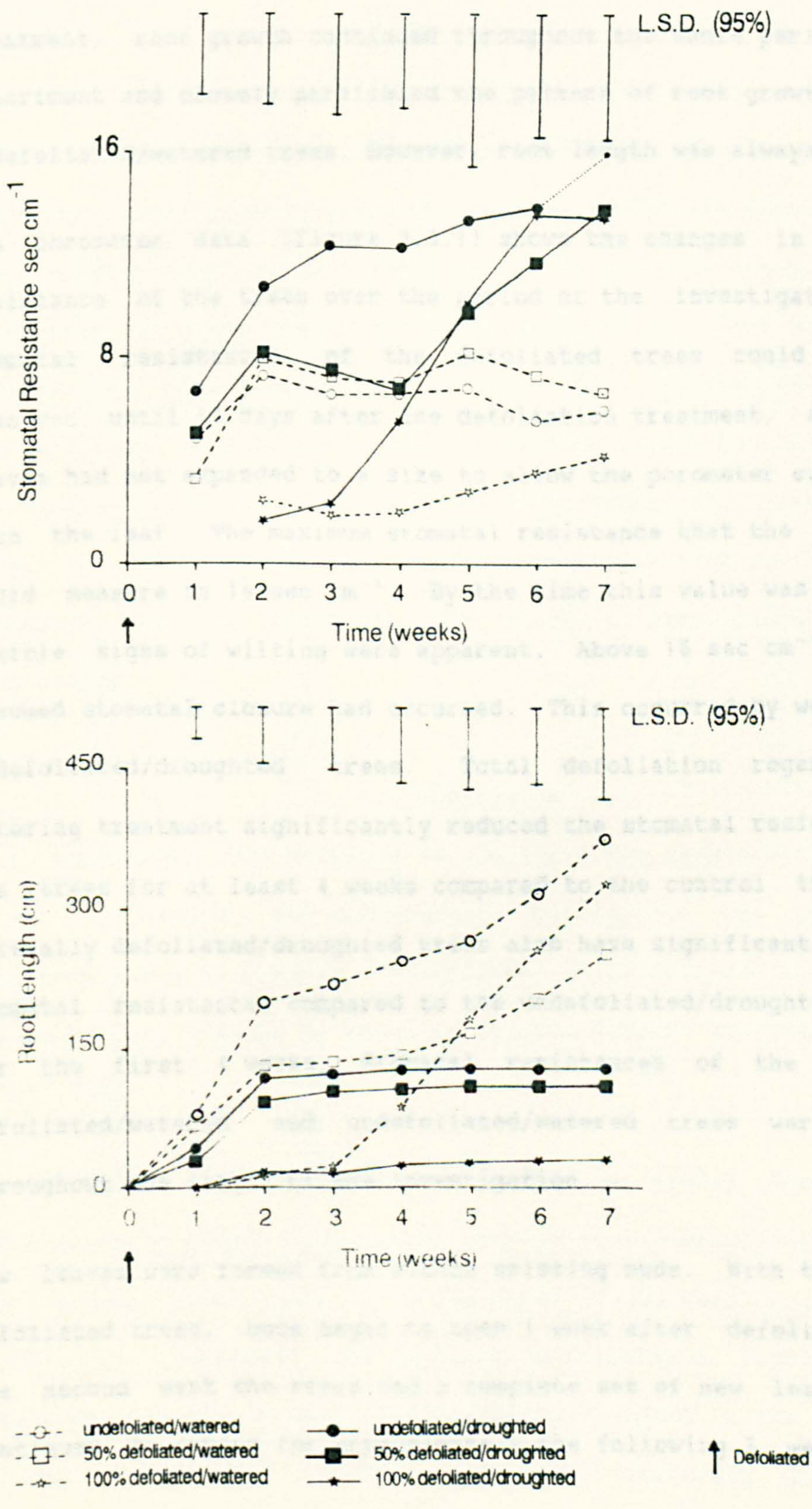
3.3 Results

The course of root development during the experiment as measured by the intersection method, is given in Figure 3.3.1. Complete defoliation resulted in a cessation of root growth for the succeeding 7 days regardless of the watering treatment. However by the second week following complete defoliation root growth had recommenced albeit at a a much slower rate than control and partially defoliated trees. By week 4, root growth of the completely defoliated/watered trees was proceeding at a increased rate compared to the control trees, whilst that of the totally defoliated/ droughted trees has ceased.

Root growth of the partially and non defoliated trees receiving the droughting treatment, closely followed the trend of the partially and non defoliated watered trees for the first 2 weeks, after which

Figure 3.3.1

The Effects Of Defoliation and Drought on Root Growth and Stomatal Resistances of *Acer platanoides*



.... signifies that the stomatal resistance was above the range that could be measured root growth proceeded at a very much slower rate up to week 5, after which root growth ceased.

For the trees that received the partially defoliated/watered treatment, root growth continued throughout the whole period of the experiment and closely paralleled the pattern of root growth of the undefoliated/watered trees. However, root length was always less.

The porometer data (Figure 3.3.1) shows the changes in stomatal resistance of the trees over the period of the investigation. The stomatal resistances of the defoliated trees could not be measured until 14 days after the defoliation treatment, as the new leaves had not expanded to a size to allow the porometer cup to fit onto the leaf. The maximum stomatal resistance that the porometer could measure is 16 sec cm^{-1}. By the time this value was attained, visible signs of wilting were apparent. Above 16 sec cm^{-1} it was assumed stomatal closure had occurred. This occurred by week 7 with undefoliated/droughted trees. Total defoliation regardless of watering treatment significantly reduced the stomatal resistances of the trees for at least 4 weeks compared to the control trees. The partially defoliated/droughted trees also have significantly reduced stomatal resistances compared to the undefoliated/droughted trees, for the first 4 weeks. Stomatal resistances of the partially defoliated/watered and undefoliated/watered trees were similar throughout the length of the investigation.

New leaves were formed from within existing buds. With the totally defoliated trees, buds began to open 1 week after defoliation, by the second week the trees had a complete set of new leaves which continued to expand for approximately the following 3 weeks. With the partially defoliated trees new leaf formation was later, a complete set of new leaves not being formed until week 3. The new set of leaves never attained the same size as the pre-existing leaves.

The final harvest data is shown in Figure 3.3.2 with analysis of variance shown in Table 3.3.1. Both the defoliation and droughting treatments significantly depressed all the parameters measured i.e. total weight, shoot weight, shoot extension and leaf areas, with the exceptions of root weight and shoot:root ratios. Root weight was reduced by both treatments although this proved not to be statistically significant. With increasing levels of defoliation, the shoot:root ratios of the watered trees decreased, however this trend was not apparent for the trees which received the droughted treatment. For no character was there a defoliation/ drought interaction.

3.4 Discussion

This experiment was designed to elucidate the sensitivity of root growth to drought and defoliation. Defoliation was used as a treatment since in natural circumstances it is believed to be one of the mechanisms adopted by trees to improve drought tolerance (Davies *et al.*,1972).

The findings indicate that root growth is highly sensitive to disturbance. A single defoliation results in a complete cessation of root growth which lasts until the onset of new leaf growth. This appears to contradict the findings of Gilbertson (1987) that a single defoliation of *Acer pseudoplatanus* resulted in the cessation of root growth for at least one month following defoliation.

Figure 3.3.2

The Effects of Defoliation and Drought on the Growth of *Acer platanoides*

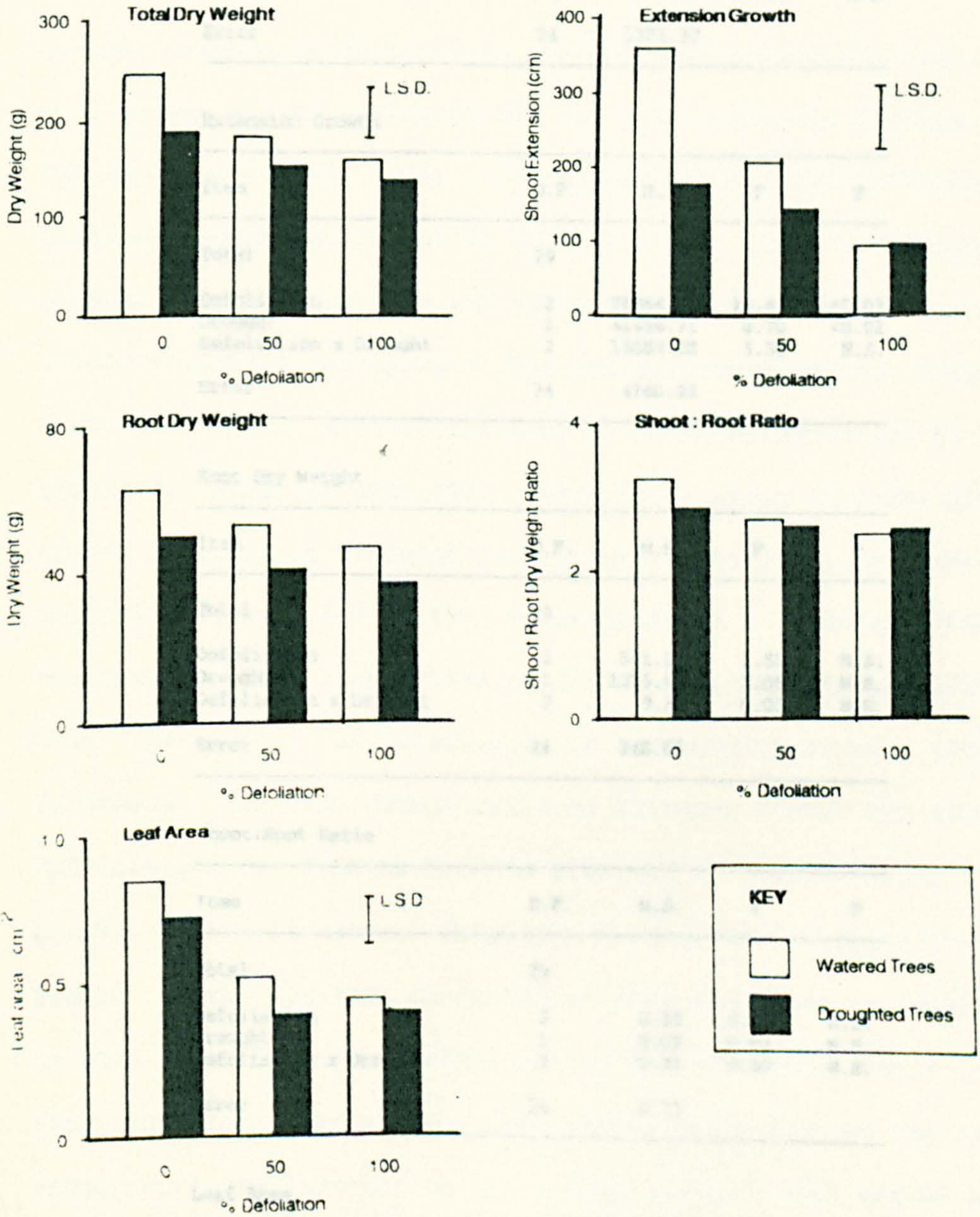


Table 3.3.1

ANOVA of the effects of defoliation and drought on the growth of *Acer platanoides*

Total Dry Weight

Item	D.F.	M.S.	F	P
Total	29			
Defoliation	2	12031.97	8.90	<0.01
Drought	1	10521.76	7.79	<0.05
Defoliation x Drought	2	966.57	0.72	N.S.
Error	24	1351.32		

Extension Growth

Item	D.F.	M.S.	F	P
Total	29			
Defoliation	2	78264.05	16.44	<0.01
Drought	1	41426.71	8.70	<0.01
Defoliation x Drought	2	16089.58	3.38	N.S.
Error	24	4760.23		

Root Dry Weight

Item	D.F.	M.S.	F	P
Total	29			
Defoliation	2	541.11	1.55	N.S.
Drought	1	1075.45	3.08	N.S.
Defoliation x Drought	2	9.30	0.03	N.S.
Error	24	348.65		

Shoot:Root Ratio

Item	D.F.	M.S.	F	P
Total	29			
Defoliation	2	0.50	0.68	N.S.
Drought	1	0.02	0.03	N.S.
Defoliation x Drought	2	0.37	0.50	N.S.
Error	24	0.73		

Leaf Area

Item	D.F.	M.S.	F	P
Total	29			
Defoliation	2	37438141.65	29.89	<0.01
Drought	1	6428523.80	5.13	<0.05
Defoliation x Drought	2	566518.15	0.45	N.S.
Error	24	1252654.27		

Richardson (1957) in a similar defoliation experiment with very young *Acer saccharinum* seedlings established that the stimulation necessary for root elongation could be supplied by very young leaves, a finding which is supported by this investigation i.e. that root growth will recommence as soon as leaf buds begin to open.

General effects of defoliation on root development has been reported by a number of other workers and for many different species of tree. For example, Taylor & Odom (1970) showed that *Carya illinoensis* stem cuttings required leaves to produce roots. *Pinus resinosa* root growth was reduced, as was the number of new roots, to very low levels following defoliation (Van den Driessche,1978). According to Redmond (1959), 100% defoliation of *Abies balsamea* led to a root mortality rate of over 75%. Total defoliation of young plants of *Camellia sinensis* reduced root growth to only 45% of the intact control (Visser,1969), for *Pinus contorta* a similar defoliation treatment caused a reduction of 27% in root weight (Britton,1988). That the effect of defoliation on root growth occurs soon after treatment, has been demonstrated by Eliasson (1968) who showed that defoliation of *Populus tremula* resulted in the cessation of root growth within 24 hours. Gregory & Wargo (1986) suggest that a key factor in the survival mechanism of *Acer saccharum* to defoliation, is the ability of the shoot apices to accelerate their rate of leaf primordia initiation. Head (1969) observed that not only was defoliation detrimental to the current seasons root growth but that the effect was carried over into the following season, where the onset of root growth of *Malus domestica* was delayed by a month.

The experiment demonstrates that both shoot extension and leaf area development were also detrimentally affected by defoliation. Similar observations have been reported by other workers. Total defoliation resulted in a reduction of 55% in shoot weight of *Camellia sinensis* (Visser,1969) and *Pinus contorta* (Britton,1988). However Llewelyn (1968) found that partial defoliation of *Malus domestica* had no effect on either shoot extension or shoot number. Gregory & Wargo (1986) report that although leaf number was not affected by defoliation of *Acer saccharum*, leaf areas were noticeably less than intact control trees. Heichel & Turner (1983) observed that the leaf areas of refoliated trees depended upon the level of the defoliation treatment with 50, 75 and 100% defoliation resulting in 48%, 39% and 32% of the leaf area of the intact control plants. Late defoliation in September or October has also been reported to significantly reduce the leaves formed the following spring. Total defoliation during this period, caused a reduction of 52% in leaf weight the following spring.

One important limitation of the experimental design is that the droughting treatment only commenced one week before defoliation was carried out. Indeed, on inspection of the porometry data, this was verified, as maximum stomatal resistances in the droughted control trees did not occur until the seventh week. This points to an anomaly within the results, in so much as root growth in the droughted trees was negligible from the third week onwards, yet it is known that the trees were under no apparent water stress at this point. There are a number of possible explanations that could account for this observation. It could be due to a lack of root proliferation in the relatively dry soil at the glass interface (caused by shrinkage of the substrate away from the glass), or because of the death of roots in this region or possibly because of the difficulties caused to the measuring procedure as a result of the air gap at the interface.

Clear inhibitory effects of droughting on the long term development of the trees were observed. Water deficits are known to affect cambial growth either directly or indirectly through decreased synthesis and downward transport in the stem of hormonal growth regulators (eg.Zahner,1968; Kozlowski,1985; Kramer, 1987). The rate of photosynthesis begins to decrease when leaves are only slightly water stressed and continues to decline during a prolonged drought. Photosynthesis is reduced early during drought as stomatal closure reduces CO_2 diffusion into the leaves. As the leaves become more severely dehydrated the photosynthetic process is inhibited through adverse effects on chloroplast activity (Kramer 1987).

Figure 3.3.1 clearly shows that the totally and partially defoliated trees receiving the droughting treatment were under considerably less water stress than the undefoliated droughted trees for at least the first 4 weeks of the experiment. Similar results have been discussed by Askew *et al.*(1985) who found that increasing levels of defoliation significantly reduced the shoot water potential of *Cornus florida*. Heichel & Turner (1983) demonstrated that with increasing levels of defoliation the stomatal resistances of *Acer rubrum* and *Quercus rubra* were reduced. Total defoliation therefore appears to be a method by which water stress can be reduced.

The question therefore arises as to why this reduced water stress was not translated into either shoot or root growth? There was no sign of a defoliation/drought interaction, which would have occurred if defoliation was able to relieve the effect of drought. Kozlowski & Davies (1975) noted that shoot pruning although reducing the transpirational area, also reduces the level of photosynthesis. However, Heichel & Turner (1983) showed that *Acer rubrum* which had been completely defoliated, had a rate of net photosynthesis in leaves of the refoliated crown, that was 50% higher than in the primary foliage of undefoliated trees, yet despite this photosynthetic enhancement, net assimilation after refoliation decreased because of a considerable reduction in total leaf area. In the present investigation leaf area was reduced by not only the defoliation treatment but also by the droughting treatment. It is known that in most deciduous trees carbohydrate reserves decrease sharply during spring growth to a minimum in early summer (Kozlowski,1985) and carbohydrate reserves are immediately exhausted by refoliation (Wargo,Johnson & Houston 1972). Hence it is postulated that although defoliation can reduce water stress, reduced photosynthesis and stored carbohydrates restrict both root regeneration and shoot extension sufficiently to offset any possible beneficial effects on the control of water loss.

On inspection of the results, there appears to be an anomaly between the data obtained for root growth by the intersection method and the final harvest, in so much as from the intersection data, it was apparent that the totally defoliated trees by the end of the experimental period had more root length than the partially defoliated trees. Yet from the final harvest data it was found that root growth was depressed with increasing levels of defoliation. However this can be explained by the fact that the intersection method does not purport to obtain an absolute value of root length but instead allows major changes in root behaviour to be followed.

A number of criticisms of the intersection technique can be made. Firstly, the roots are not growing in natural surroundings, especially when they hit the glass panel and grow along it. However, Rogers (1939) suggests a glass panel can be considered to be like a large smooth flint stone or a grain of sand. A second drawback was that root development could not be recorded to maximum rooting depth. Temperature fluctuations were also above ambient, this could have been rectified by burying the boxes into the ground, but this would have proved impractical. Perhaps the major problem encountered during this investigation, was the development of air gaps at the soil-glass interface. This was particularly prevalent with the droughted trees towards the end of the experiment. Nevertheless, all these disadvantages were outweighed by the fact that continuous determinations of the major changes in root behaviour could be made.

Chapter 4

The Water Supply to the Transplanted Tree.

4.1 Introduction

To the newly planted (bare-root) tree, water is the primary problem affecting survival. This is basically a consequence of the extremely truncated root system of the transplanted tree. Grace (1987) has suggested that trees remain at risk for up to 2-3 years after planting because the root system is inadequate for supplying the water demands of the tree. The degree of root loss upon lifting has been suggested as being in the region of 50% for young transplants (Kendle, 1988), whilst for larger standard trees this value may be as much as 95% (Watson, 1987).

British Standard 4043 (Anon.,1966) recommends that for semi-mature trees the prepared root system should be 12 times the diameter of the stem measured at 0.9m above the ground, and reduce to 9 times as the size of the tree increases. No such recommendation exists for trees other than semi-mature trees and British Standard 3936 (Anon., 1980) on nursery stock, only states that the root system should be well balanced in relation to the plant. However, extrapolating the BS 4043 recommendation to a standard tree (with a stem diameter of 9cm at 0.9m), assuming a rooting depth of 50cm, would provide a tree with a rooting volume of $0.58m^3$, whilst for a light standard tree (with a stem diameter of 7cm at 0.9m) a rooting volume of $0.35m^3$. It has been found however that the majority of standard trees, purchased from a number of suppliers, during the course of this investigation had root systems with a diameter on average of only 0.6m; this would provide a rooting volume of only $0.18m^3$.

Vrecenak (1988) has suggested rates of water loss from individual trees. Assuming that the crown of the standard tree covers a ground area with a radius of 0.5m, the amount of water transpired per day would lie in the range 1.13 to 4.52 litres depending upon the leaf area index of the tree. This is in general agreement with other workers eg. Bradshaw (1985) who calculated a likely transpiration rate of 2 l day^{-1} for a newly planted *standard Tilia sp.*, whilst Thorpe *et al.* (1978) found that a 1.6m *Malus pumila* used 4.6 l of water over a 16 hour, sunny summer day.

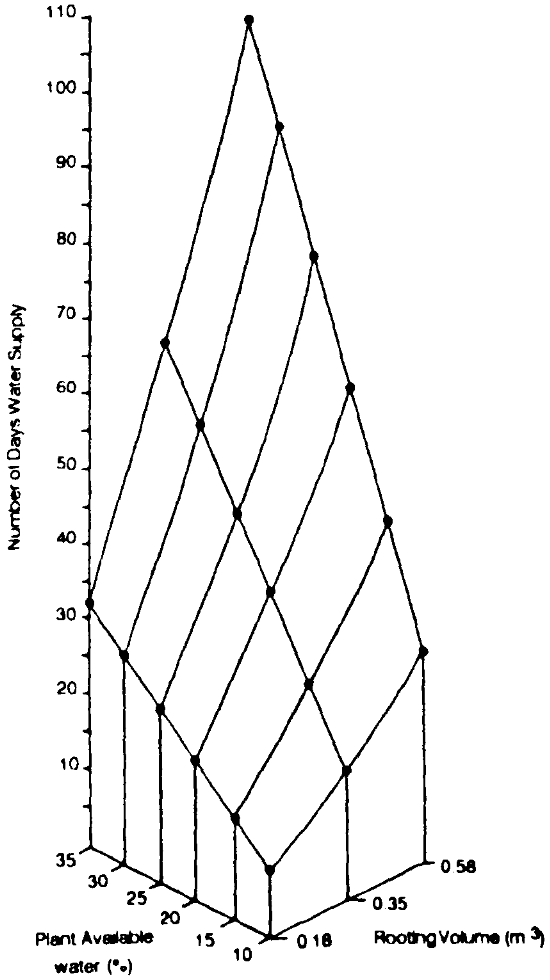
Using this information a model for the potential number of days water supply that a given volume of soil, exploited by the root system of the tree, can provide in the absence of water input and in relation to the water capacity of the soil can be constructed. Figure 4.1.1 shows this model, assuming transpiration rates similar to those suggested by Thorpe *et al.*(1978) and Bradshaw (1985) and that the volume of soil exploited by the newly planted tree similar to those calculated from B.S.4043 and from personal observation. This model is based upon that presented by Gilbertson *et al.*(1987).

The model produced is extremely simple, the reason being that it was constructed to impress the importance of root size to people involved in amenity tree planting and not scientists. It takes no account of a number of very important variables that could significantly affect the number of days water supply that a given volume of soil can provide to the tree. These include:

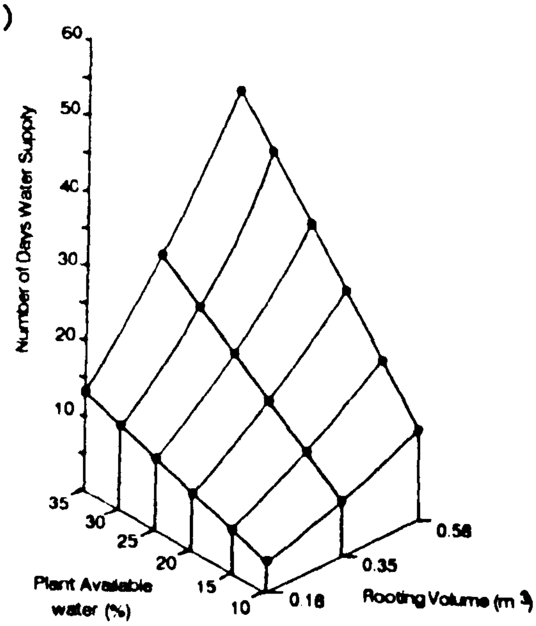
Figure 4.1.1

Model of the potential number of days water supply that a given volume of soil can provide to a newly planted tree. Assuming a transpiration rate of either a) 2 l/day or b) 4.6 l/day.

a)



b)



Planting Pit Dimensions

108cm x 108cm x 50cm = 0.58m³

84cm x 84cm x 50cm = 0.35m³

60cm x 60cm x 50cm = 0.18m³

a) water lost via evaporation from the soil.

b) water availability differences in different depths of soil.

c) transpiration of water previously stored in the plant.

d) climatological variables altering the rate of transpiration.

e) alteration of the transpiration rate as the tree becomes stressed due to closure of stomata.

f) movement of water into the rooting zone from adjacent areas by hydraulic conduction.

g) reduction in hydraulic conductivity of the soil as the soil water potential declines.

h) lack of uniformity of distribution of roots within the soil volume.

More detailed models have been published by a number of workers (Taylor & Klepper, 1978 ; Thorpe *et al.*,1978). Nevertheless the simple model indicates very clearly what might be expected.

According to Kozlowski & Davies (1975) the most important considerations in increasing growth and survival of transplanted trees are that; transpiration should be reduced, absorption of water should be increased, or both should occur.

The work discussed in this chapter therefore tests the proposed model by firstly determining the volume of soil that the tree roots actually exploit for water. Secondly the transpiration rate of standard *Platanus x hispanica* trees is measured directly by a gravimetric method. Finally, the use of cross-linked polyacrylamides as a simple method of directly increasing the water supply to the rooting zone of the newly planted tree, is investigated.

4.2 Examination of the development of soil moisture tensions around the roots of newly planted trees.

4.2.1 Introduction

For the purposes of producing the model, described in Figure 4.1.1, it was necessary to hypothesise that the only water available to the newly planted tree was that contained within the volume of soil directly surrounding the roots. This supposes that there is very little lateral movement of water into the rooting zone (Scott Russell,1977; Kozlowski,1987). In order to test this hypothesis an experiment was designed that would allow the water tensions (including their distribution) that develop around the roots of the newly planted tree to be followed, by use of a neutron probe.

The neutron probe is designed to measure *in situ* the volumetric water content of the soil. The measurement is made by means of a probe which is lowered into an aluminium access tube installed vertically into the soil profile. The probe contained a sealed Americum-Beryllium radioactive source from which fast neutrons are emitted into the soil. Collisions with the nuclei of the soil atoms, predominantly those of the hydrogen of the soil water, cause the neutrons to scatter, to slow and to use energy. Thus a cloud of slow neutrons is generated within the soil around the source. The density of the cloud, which is largely a function of the soil water content, is sampled by a boron trifluoride slow neutron detector in the probe. The count rate at each depth is then converted into a volumetric soil moisture content by means of an appropriate calibration curve (Bell,1976).

4.2.2 Material and methods

a) Planting Design

Two 40m tunnel houses were erected. Thirty six *Platanus x hispanica* (12' standards) were planted in February 1987 within each tunnel house in 2 rows with a space of 2m separating the individual trees within a row and each row being split in the middle of the tunnel house by a space of 4m. All the trees were root pruned so that the root diameter was between 60 and 65 cm. To prevent water infiltration, gaps in the polythene were sealed using tape. Strings were attached to the upper part of the trunk to allow water to run away from the trunk and down the strings. Absorbant material was placed below each seal to capture any water that might have penetrated the seal. Irrigation was given using perforated plastic pipes until all the trees had leafed out. Droughting treatments were then applied equivalent to what might happen naturally. Figure 4.2.1 shows the tunnel houses after the trees had been planted.

b) Experimental Details

Year 1

One end of each tunnel house was chosen at random to either continue receiving the irrigation treatment or to have all water withheld and designated either the irrigated or droughted end respectively. Around six of the trees at the droughted end of the tunnel house, neutron probe tubes were sunk at distances of 10, 40, 70 and 100cm, away from the base of the trunk, in both a north and easterly direction. Every three days neutron probe readings were taken at at depths of 30, 35 and 40cm down each tube. Unfortunately because of the inclement weather during the summer of 1987, it proved impossible to completely prevent water infiltration for more than

Figure 4.2.1

Tree crowns emerging from one of the tunnel houses, used to examine the development of soil moisture tensions around the roots of newly planted *Platanus x hispanica* trees.

an 18 day period. During September 1987 the six trees from which readings had been taken at the droughted end of the tunnel house plus six others selected at random (three from each tunnel house) were harvested as were six of the irrigated trees from each tunnel house. During November of 1987 the remaining trees from the droughted end of the tunnel house were lifted for use in other experiments, including the one described in section 4.3.

Year 2

All of the remaining twenty four trees from the irrigated end of the tunnel houses were lifted during 1987. Six were immediately rejected as they had been damaged. Care was taken not to lose any significant part of the root system. The root systems had diameters of between 140 and 150cm. Nine of these trees had their entire root system preserved and nine trees had their root systems pruned, to what would have been typical of nursery stock, so that their root diameter was between 60 and 65cm. All were then transplanted to the droughted end of the tunnel house. The trees were watered in and intermittent irrigation given until the trees had leafed out. The polythene covering of the tunnel house was again sealed by the methods already outlined. Neutron probe tubes were installed around three of the trees with both the large and small root system in each tunnel house, in both a northerly and easterly direction. The tubes were spaced at 10, 40, 70, 100, 130 and 160cm away from the trunk of the trees with the large root systems and 10,40,70 and 100cm away from the trunk of the trees with the small root systems. Neutron probe readings were taken at 30,35 and 40cm depths down each tube. From these volumetric soil water percentages were calculated.

Again water penetration of the seals was a problem and it was only possible to take readings over a 21 day period, nevertheless these gave valuable results. At the end of the experimental period, shoot extension of the trees with both the large and small root systems was ascertained.

4.2.3 Results and Discussion

First year results, Figure 4.2.2, clearly demonstrate that the water that was utilised by the tree had effectively come from an area with a radius of less than 40cm (root radius was 30cm). There is no evidence of lateral movement of water within the soil profile otherwise there would have been depression of soil water content at 40cm radius and beyond.

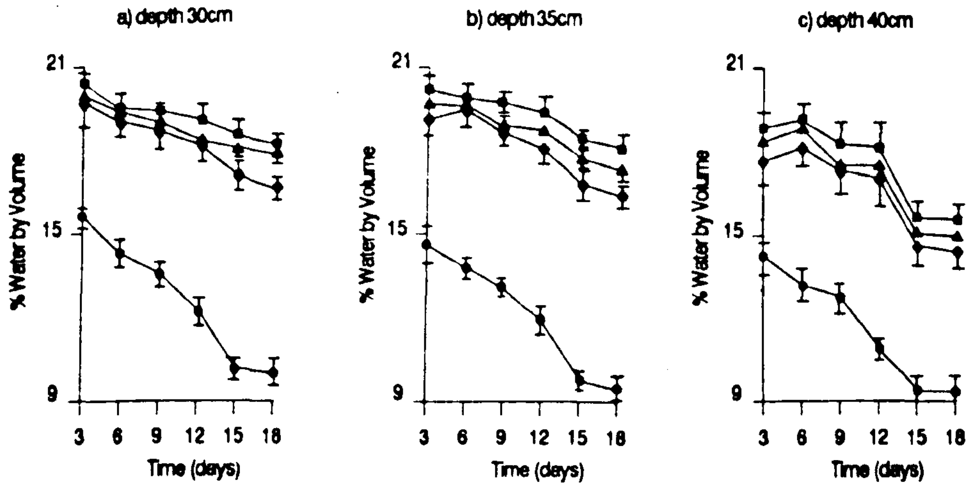
Similar patterns of developing water tensions around the roots of the trees with the smaller root system was also apparent during the second year (Figure 4.2.3). Towards the end of the investigation, the results suggest that possibly the water tensions were developing at 40 cm away from the trunk of the tree (at depths of 35 and 40cm). This could easily be accounted for by root extension into this area.

A totally different pattern of developing water tensions around the roots of the tree with the larger root systems was apparent. Tensions diminished with distance away from the base of the trunk. Towards the end of the investigation it was apparent that the water being utilised was being taken from an area with a radius more than 70cm but less than 100cm. It is known that on planting the root systems had radii of 70-75cm.

Figure 4.2.2

Developing moisture tensions around the roots of *Platanus x hispanica* at three soil depths and four distances from the base of the trunk (first year)

Root diameter at planting 60-65cm



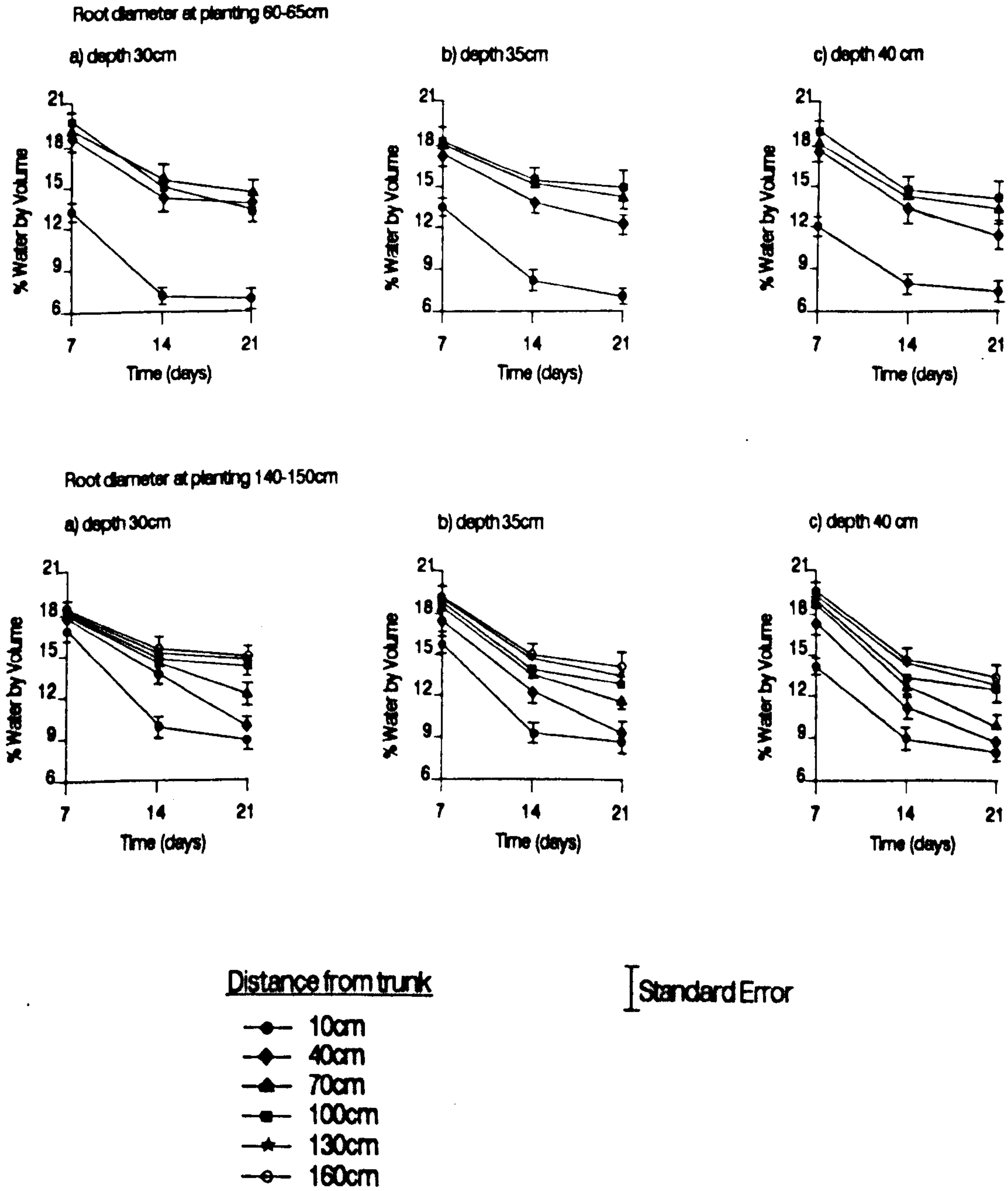
Distance from trunk

—•— 10cm —◆— 40cm —▲— 70cm —■— 100cm

I Standard Error

Figure 4.2.3

Developing moisture tensions around the roots of *Platanus x hispanica* with two sizes of root system. Measurements taken at three soil depths and upto six distances from the base of the trunk (second year).



During both years there was reduction in the percentage water content of the soil over the course of the investigation even at the maximum distance away from the base of the tree. This was presumably due to evaporation from the soil.

The results therefore suggest that the assumption made by the model, that the only water effectively available to the newly planted tree is that contained within the volume of soil immediately surrounding the roots, holds true. This becomes more obvious if the results are plotted so that perentage water decrease is shown against distance from trunk (Figure 4.2.4). This is in agreement with other workers who suggest that water in the portion of soil that is not permeated by roots is largely unavailable for absorption by tree roots (Kozlowski,1987).

A simple calculation of water movement in an unsaturated soil system would suggest that hydraulic conductivity would not be able to maintain a constant supply of water to the region containing the root system. Hillel (1971) has suggested that the hydraulic conductivity in an unsaturated sandy soil would approximate to 10^{-8} cm sec^{-1}. Assuming the dimensions of the planting pit were 60 x 60 x 60 cm and amount of pore space in the soil was 50%, then water movement into this volume of soil would be:

Surface area of pit x pore space x hydraulic conductivity

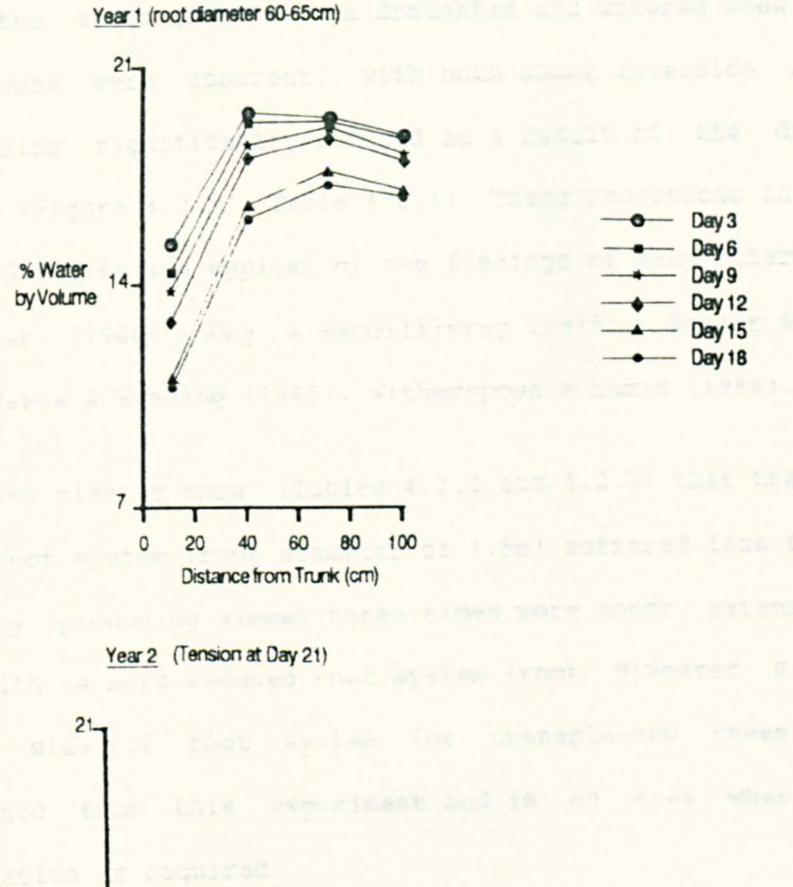
$$= 18000 cm^2 \times 0.5 \times 10^{-8} \text{ cm sec}^{-1} = 9 \times 10^{-4} \text{ cm}^3 \text{ sec}^{-1}$$

$$\text{or } 78 \text{ cm}^3 \text{ day}^{-1}$$

Assuming that the transpiration demands of a newly planted tree approximate to 2 l day^{-1} (as used in the model) then it can be seen that recharge of soil water into the rooting volume would not in any

Figure 4.2.4

Developing moisture tensions around the roots of *Platanus x hispanica*



way be able to keep pace with the volume of water lost via transpiration.

Although it proved impossible to completely prevent water infiltration during the experiment, significant growth differences between the trees grown at the droughted and watered ends of the tunnel house were apparent, with both shoot extension and root growth being significantly reduced as a result of the droughting treatment (Figure 4.2.5, Table 4.2.1). These reductions in response to water deficits are typical of the findings of many other workers eg. Zahner (1968), Day & MacGillivray (1975), Seiler & Johnson (1984), Vance & Running (1985), Witherspoon & Lumis (1986).

The results clearly show (Tables 4.2.2 and 4.2.3) that trees with a larger root system (root diameter of 1.5m) suffered less transplant shock, by producing almost three times more shoot extension than trees with a more reduced root system (root diameter 0.6m). The optimum size of root system for transplanted trees was not ascertained from this experiment and is an area where further investigation is required.

However, it has been demonstrated from an experiment on severing the root system of 15 to 18 year old *Abies amabilis*, that the root system of trees may have an excess absorptive capacity (Teskey, Grier & Hinckley, 1985). Severance of as much as one third of the root system had no effect on the water relations of the tree the following day, whilst severance of more that half of the root system led to partial stomatal closure. This therefore suggests that it may not be necessary to move the complete root system of the tree when it is transplanted. Indeed from the present experiments a total

Figure 4.2.5

The effects of a droughting treatment on the shoot extension and root growth of *Platanus x hispanica*

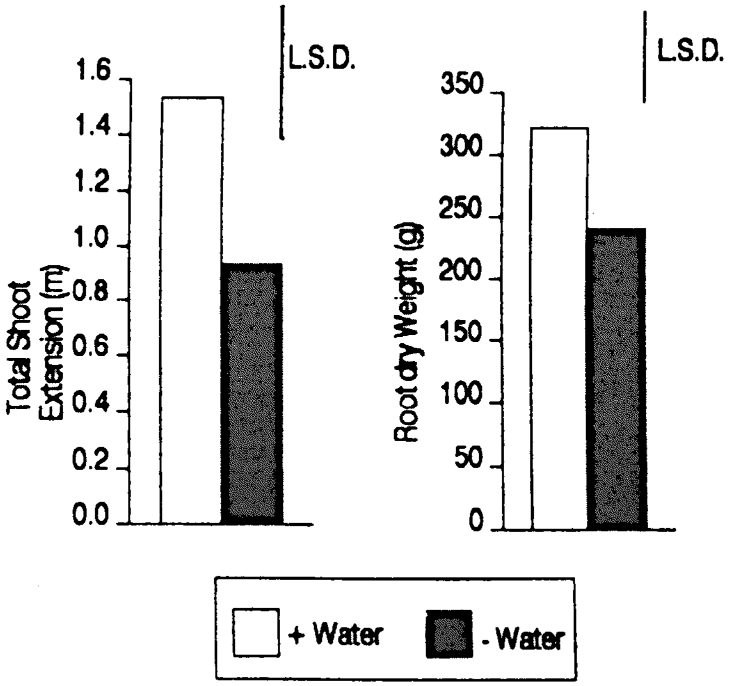


Table 4.2.1

ANOVA of the total shoot extension and root growth of *Platanus x hispanica* following a droughting treatment.

Total shoot Extension

Source of Variation	D.F.	M.S.	F	P
Total	17			
Drought	1	1631420.05	11.63	P<0.01
Error	16	140279.43		

Root Dry Weight

Source of Variation	D.F.	M.S.	F	P
Total	17			
Drought	1	29260.18	4.97	P<0.05
Error	16	5883.82		

Table 4.2.2

The effect of the size of the root system of *Platanus x hispanica* at planting on subsequent shoot extension.

	Root Diameter at Planting (cm) 60-65	140-150
Total Shoot Extension (cm)	421	1238.25

Table 4.2.3

Anova of the total shoot extension of *Platanus x hispanica* planted with different size root systems

Total shoot Extension

Source of Variation	D.F.	M.S.	F	P
Total	17			
Size of Root	1	3006152.00	54.58	P<0.01
Error	16	55082.03		

shoot extension of close to 12.5m, obtained under a restricted watering regime, would appear to be more than adequate for producing the appearance of a vigorously growing tree.

4.3 The transpiration rate of a newly planted *Platanus x hispanica* tree

4.3.1 Introduction

The model assumes a water loss for a standard tree of either 2 or 4 l day^{-1}. Most of the information pertaining to water use by trees has been gathered from communities forming complete canopies (Landsberg & McMurtrie,1984) and experimental data on water use by isolated trees is sparse (Thorpe *et al.*, 1978). However Kramer & Kozlowski (1979) have listed average transpiration rates for a number of species which lie in the range of 6.4 g dm^{-2} day^{-1} (*Acer negundo*) to 14.21 g dm^{-2} day^{-1} (*Quercus alba*). According to Kopinga (1985) a street tree transpires about 1.5 to 2 times as much as a forest tree, which on average transpires about 500mm a year. This section attempts to determine the transpiration rates of newly planted *Platanus x hispanica* trees.

4.3.2 Methods and Materials

Six *Platanus x hispanica* (12'standards) were planted into drums containing 120 litres of a 2:1 peat:coarse sand mixture amended with, 8-9 month release 'Osmocote' resin coated 18:11:10 fertiliser (4 kg m^{-3}) and ground limestone (1 kg m^{-3}) and ground magnesium limestone (1 kg m^{-3}). The roots of the trees before planting were root pruned so as to give a root diameter of 0.6m. The drums were kept watered until the trees were fully leafed out. Water infiltration into the drum was then prevented by using a black polythene sheet, tied around the trunk of the tree and the base of the pot. Figure 4.3.1 shows the experimental details before the polythene had been attached. The trees were then weighed approximately twice a week, at 10.00 am, using a 'Avery' sack scale balance, and the weight loss recorded.

4.3.3 Results and Discussion

Figure 4.3.2 shows the cumulative rate of water loss. For the first 14 days of the investigation, transpiration rates as measured by changes in the weight of the pots remained constant, being 1.20 l day^{-1}. After the 14th day, transpiration rates began to slow. Between days 14 and 21, and 21 and 28 the transpiration rate was reduced to 0.69 l day^{-1} and 0.17 l day^{-1} respectively. After the 28th day of the experiment the trees were defoliated during a sudden summer storm. However before this occurred the leaf areas of 3 of the trees was ascertained using a 'Hayashi Denko AAM-5' area meter, a value of $1.03m^2$ +/- $0.09m^2$ being obtained. Hence the transpiration rate could be expressed on a leaf area basis, being 11.7 g dm^{-2} day^{-1}. This compares favourably with the values obtained by other workers. For example Kramer & Kozlowski (1979) cite values of 8.8, 6.4 and 12.2 g dm^{-2} day^{-1} respectively, for *Platanus occidentalis*, *Acer negundo* and *Acer saccharum*. Direct comparisons of the results of any similar experiments are difficult to make, as each will have been conducted under a different set of environmental conditions.

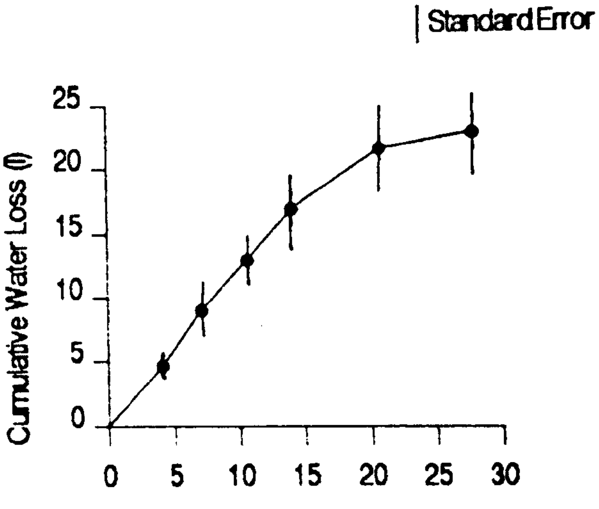
From the information given by Kopinga (1985) on the available water contents of a number of substrates, the amount of available

Figure 4.3.1

The experimental procedure for determining transpiration loss of a standard tree, being evaluated before use. In the actual trial, water infiltration into and evaporation from the drum was prevented by using a black polythene sheet.

Figure 4.3.2

The cumulative water loss from standard *Platanus x hispanica* trees over a 28 day period



water of the peat:sand substrate used during this experiment can be calculated as being between 29% and 35%. Using this information it is possible to test the model knowing that:

a) The transpiration rate of a newly planted *P. x hispanica* tree is 1.171 day^{-1} m^{-2}.

b) The only water available to the tree is that directly within the volume of soil occupied by the roots. Which in this case is the volume of soil present within the container i.e. 120 l.

c) The percentage of available water in the peat:sand substrate amounts to between 29% and 35%.

The model would predict, using these parameters that the number of days water supply that the volume of soil within the container could support, in the absence of irrigation, would lie between 30 and 36 days. The actual number of days water supply determined from the experiment amounted to 28 days i.e.lying within the 10% range of the lower value predicted by the model.

It can therefore be concluded that the size of the root system transplanted with the tree has a major direct influence on the water reserves of the soil that are available to the tree. Increasing the size of the root system leads to an increase in the volume of water available to the tree. Under conditions where the recharge of water to the soil reservoir is restricted, as is often the case under urban conditions (Craul, 1985) it has been demonstrated that the not only is shoot growth adversely affected but so too is root growth. It can thus be speculated that under these conditions, a vicious circle arises, in which (i) because of the small root system (ii) the water supply is restricted, which in turn (iii) restricts root growth and consequently (iv) restricts the volume of water available to the tree the following season. Thus the length of time required to establish an adequate shoot:root ratio will be extended, compared to a tree transplanted with a larger root system. This is an area which justifies further investigation.

4.4 The effect of the cross-linked polyacrylamide polymer 'Aquastore' on the growth and water relations of transplanted *Acer pseudoplatanus*.

4.4.1 Introduction

Since it has been demonstrated that the volume of soil and therefore water resources that a newly planted tree can exploit is limited, some management procedure is required, either to modify the plant water balance, perhaps by the use of antitranspirants or pruning, or by facilitating water uptake.

The latter is accomplished very simply by supplying the root system with an adequate reservoir of available water. This could easily be achieved by a watering programme. However the cost of this can be prohibitive. For example, in 1984 the City of Westminster introduced a maintenance watering contract, costing £8 per tree for the season, which assured each tree was watered every 3 weeks (Anon, 1984).

Recently however a new generation of soil conditioners has been developed, namely cross-linked polyacrylamides (Assam,1980). Some of these have the ability to absorb up to 500 times there own weight of distilled water (Johnson,1984a). However not all the water is actually available to the plant, with up to 50% of the water remaining bound to the polymer at permanent wilting point (pF 4.2). Soluble salts within the soil solution may also reduce the absorption capacity of the polymers (Johnson,1984b).

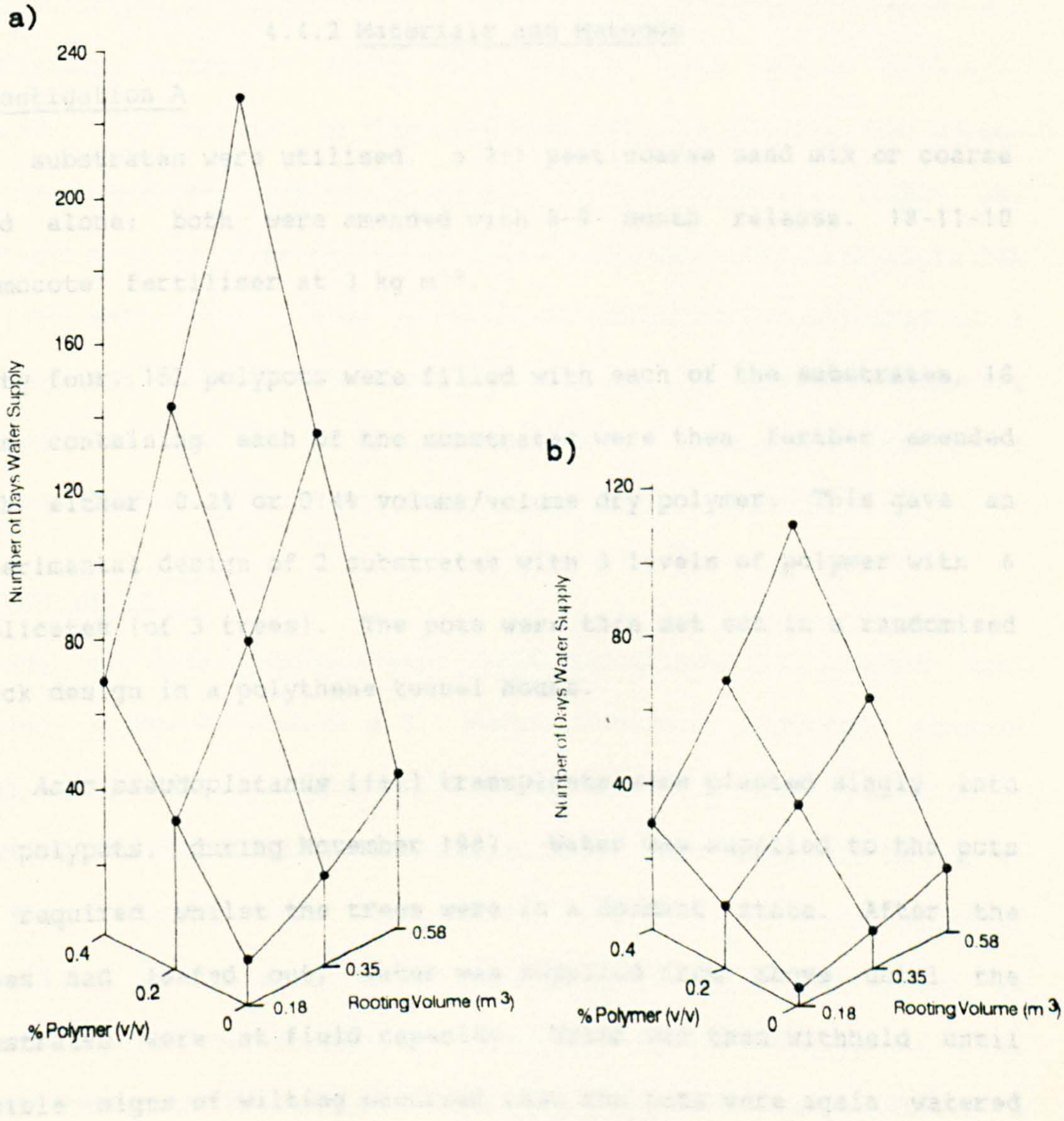
The use of water storing polymers as an aid to increasing the water supply to the root zone of the newly planted tree was therefore investigated.

The polymer used was 'Aquastore', a cross-linked polyacrylamide, which in a dry state is in the form of a white crystalline powder. Woodhouse (1989) examined the properties of 'Aquastore' and other polymers and demonstrated that the absorption of the polymer was dependent upon the conductivity of the soil solution. 'Aquastore' could absorb approximately 380 mls of deionised water per gramme of dry polymer. This figure was reduced to 205 ml g^{-1}, when a soil water extract was used (the soil used, being that found at the University of Liverpool Botanic Gardens). Using sand as a control addition of 0.2% weight/weight of polymer increased the available plant water by over 260%. Only around 8% of the polymer bound water was unavailable to plants i.e. at tensions > pF 4.2.

Using this data the the model proposed by Gilbertson *et al.*(1987) (section 4.1) can be modified (Figure 4.4.1) to include the use of the polymer 'Aquastore' as a potential method of increasing the available water supply to the newly planted tree. The figures presented assume that the percentage of available water of the unamended soil was 15% (which according to Gilbertson *et al.*(1987) is typical of a poor urban soil). As can be seen the potential benefits are dramatic. The use of only 0.2% and 0.4% volume/volume polymer effectively doubled and quadrupled the potential number of

Figure 4.4.1

Model of the potential number of days water supply, that a given volume of soil, amended with the polymer 'Aquastore', can provide to the newly planted tree. Assuming a transpiration rate of either a) 2 l/day or b) 4.6 l/day, with the available water capacity of the unamended soil being 15%.



Planting Pit Dimensions

108cm x 108cm x 50cm = 0.58m³

84cm x 84cm x 50cm = 0.35m³

60cm x 60cm x 50cm = 0.18m³

days water supply that the given volume of soil could support compared to unamended soil.

Although it was not possible to test this model using standard trees, the effects of the use of the polymer on the water relations and growth of *Acer pseudoplatanus* transplants was examined both under artificially droughted and field conditions.

4.4.2 Materials and Methods

Investigation A

Two substrates were utilised, a 2:1 peat:coarse sand mix or coarse sand alone; both were amended with 8-9 month release, 18-11-10 'Osmocote' fertiliser at 3 kg m^{-3}.

Fifty four, 15L polypots were filled with each of the substrates, 18 pots containing each of the substrates were then further amended with either 0.2% or 0.4% volume/volume dry polymer. This gave an experimental design of 2 substrates with 3 levels of polymer with 6 replicates (of 3 trees). The pots were then set out in a randomised block design in a polythene tunnel house.

108 *Acer pseudoplatanus* (1+1) transplants were planted singly into the polypots, during November 1987. Water was supplied to the pots as required whilst the trees were in a dormant state. After the trees had leafed out, water was supplied from above until the substrates were at field capacity. Water was then withheld until visible signs of wilting occurred when the pots were again watered to field capacity. This procedure was repeated throughout the experimental period, which lasted one growing season. At the end of the investigation the roots of the trees were carefully washed to

remove the polymer before shoot and root dry weights were ascertained after drying in an oven at 90°C.

Investigation B

Eighty one *A. pseudoplatanus* (1+1) transplants were pit planted during November 1987, in a randomised block design of 3 blocks, within which 3 different treatments were incorporated. The size of each planting pit amounted to $0.13m^{-3}$. The treatments consisted of 3 different backfills, field soil amended with either 0.4% v/v polymer, 25% peat v/v, or field soil to act as a control. The volume of peat amendment was chosen in accordance with Harris (1983) who advised that to be effective any amendment must constitute 25 to 50% of the soil volume. Each treatment consisted of 3 replicates of 9 trees. The trees were harvested, using the high pressure water jet method, at the end of the growing season, when shoot and roots weight were ascertained after drying in an oven at 90°C.

Investigation C

Thirty six *Acer pseudoplatanus* (1+2) transplants were planted into either a coarse sand or a 2:1 peat:coarse sand substrate amended with 0.2 or 0.4% (volume/volume) dry aquastore and including a control as described in investigation A. Each substrate had been further amended with 8-9 month release 18-11-10 'Osmocote' fertiliser at 3 kg m^{-3}. The experiment was conducted inside an unheated polythene tunnel house during the 1988 growing season. The trees were divided into 2 sets so that each set contained 3 replicates (as single trees) of each substrate. On planting all the trees were watered to field capacity and weighed.

Water was then totally withheld from one group of the trees, which were weighed at least once a week when stomatal resistances were also measured. A 'Crump' diffusive porometer was utilised to measure stomatal resistances, on each occasion 3 readings per leaf were made on the lower surface on the youngest expanded leaf on the tree, the last recording being accepted. Measurements were taken at 10.00 am. This treatment was continued until all the trees had ceased transpiring and wilted at which point the trees were harvested. Growth parameters being ascertained as dry weight after drying in an oven at 90°C.

The second group of trees were droughted but only until the first signs of wilting occurred where upon they were re-watered to field capacity. This cycle was repeated twice. The trees were again weighed and stomatal resistances measured approximately every 3 days. At the end of the second cycle the trees were harvested. Growth parameters being ascertained as dry weight after drying in an oven at 90°C.

4.4.3 Results

Investigation A

Under controlled environmental conditions in which the trees were repeatedly droughted until they wilted and then rewatered, shoot growth increased with increasing levels of polymer in both the peat:sand and sand substrates (Figure 4.4.2, Table 4.4.1). Amendment of the peat:sand substrate with 0.2% and 0.4% v/v polymer, caused shoot extension to be significantly ($P<0.05$) increased by 51% and 84% respectively, compared to the control. On the sand substrate increases of 52% and 136% were observed; however these differences proved not to be statistically significant.

Figure 4.4.2

The Effect of Aquastore on the Growth of *Acer pseudoplatanus*.

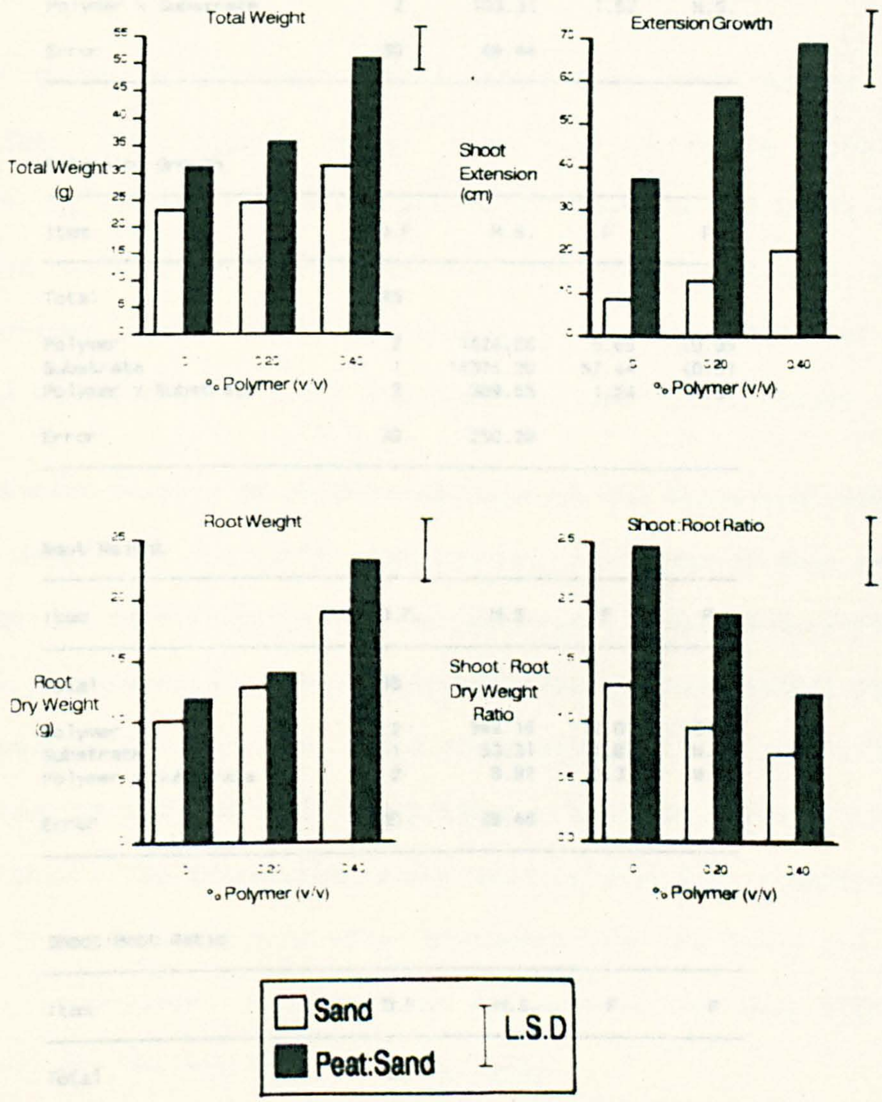


Table 4.4.1

ANOVA of the effects of amendment of either a sand or peat/sand substrate with 3 levels of the polymer 'Aquastore' on the growth of Acer pseudoplatanus.

Total Weight

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	651.57	9.52	<0.01
Substrate	1	1520.87	22.22	<0.01
Polymer x Substrate	2	103.91	1.52	N.S.
Error	30	68.44		

Extension Growth

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	1424.66	5.69	<0.05
Substrate	1	14375.20	57.44	<0.01
Polymer x Substrate	2	309.55	1.24	N.S.
Error	30	250.28		

Root Weight

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	342.16	12.01	<0.01
Substrate	1	53.31	1.87	N.S.
Polymer x Substrate	2	8.82	0.31	N.S.
Error	30	28.48		

Shoot:Root Ratio

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	2.43	6.54	<0.01
Substrate	1	6.83	18.43	<0.01
Polymer x Substrate	2	0.34	0.92	N.S.
Error	30	0.37		

A similar effect of increasing levels of polymer on root development was also noted. Root weight increased by 18% and 97% in the peat:sand substrate after amendment with of 0.2% and 0.4% v/v polymer. With the sand substrate increases of 28% and 88% were noted. However, for both substrates, only the higher level of polymer increased root growth significantly ($P<0.01$) compared to the control.

Total plant weight was also significantly affected by polymer addition, with higher levels of polymer increasing total plant weight by 14% and 63% in the peat:sand substrate and by 6% and 36% in the case of the trees grown in the sand substrate. However, statistical analysis revealed that only the higher level of polymer led to significant ($P<0.01$) increases in total plant weight.

Significant effects of polymer addition on the shoot:root ratio were also apparent. For both substrates, increases in the level of polymer led to a reduction of the shoot:root ratios i.e. rooting was relatively increased. The shoot:root ratio of the control plants in the peat:sand substrate was 2.47 reducing to 1.9 and 1.24 with addition of 0.2% and 0.4% v/v polymer. With the trees in the sand substrates, the shoot:root ratios were reduced from a control level of 1.31 to 0.96 and 0.74 after amendment with the lower and higher levels of polymer. However these differences were only significant ($P<0.01$) for the higher level of polymer.

Investigation B

As in investigation A, the effects of polymer amendment to the backfill material significantly increased root mass ($P<0.01$) and led to significantly reduced shoot:root ratios ($P<0.05$) (Figure 4.4.3, Table 4.4.2) . Increases, although not statistically significant were also observed for total weight and shoot extension of the trees grown with polymer.

The amendment of the backfill material by peat also led to a significant increase in root weight ($P<0.01$), although not to the same extent as amendment with polymer, as well as to a significant reduction ($P<0.05$) in the shoot:root ratios of the trees. Total weight and shoot extension of the trees was also increased by peat addition but as with the polymer treatment this again proved not to be statistically significant.

Investigation C

The polymer had significant effects on the rate of evapotranspiration, as measured by changes in the weights of the pots (Figure 4.4.4). With the peat:sand substrate, significant differences ($P<0.05$) existed only between the control and the higher level of polymer during cycles 1 and 2 and for the first 16 days of cycle 3 (with the exception of the first reading for each cycle, where no significant differences were found). By day 28, of cycle 3, significant differences existed between all treatments.

With the sand substrate, again apart from the first 3 days of each cycle, significant differences between the treatments ($P<0.05$) existed. During cycle 1, significant differences in the rate of evapotranspiration existed only between the control and higher polymer treatment. During cycle 2, significant differences existed between the control and both polymer treatments. For cycle 3, significant differences were apparent only between the control and

Figure 4.4.3 The effects of soil amendment with peat or polymer, on the growth of field grown *Acer pseudoplatanus*

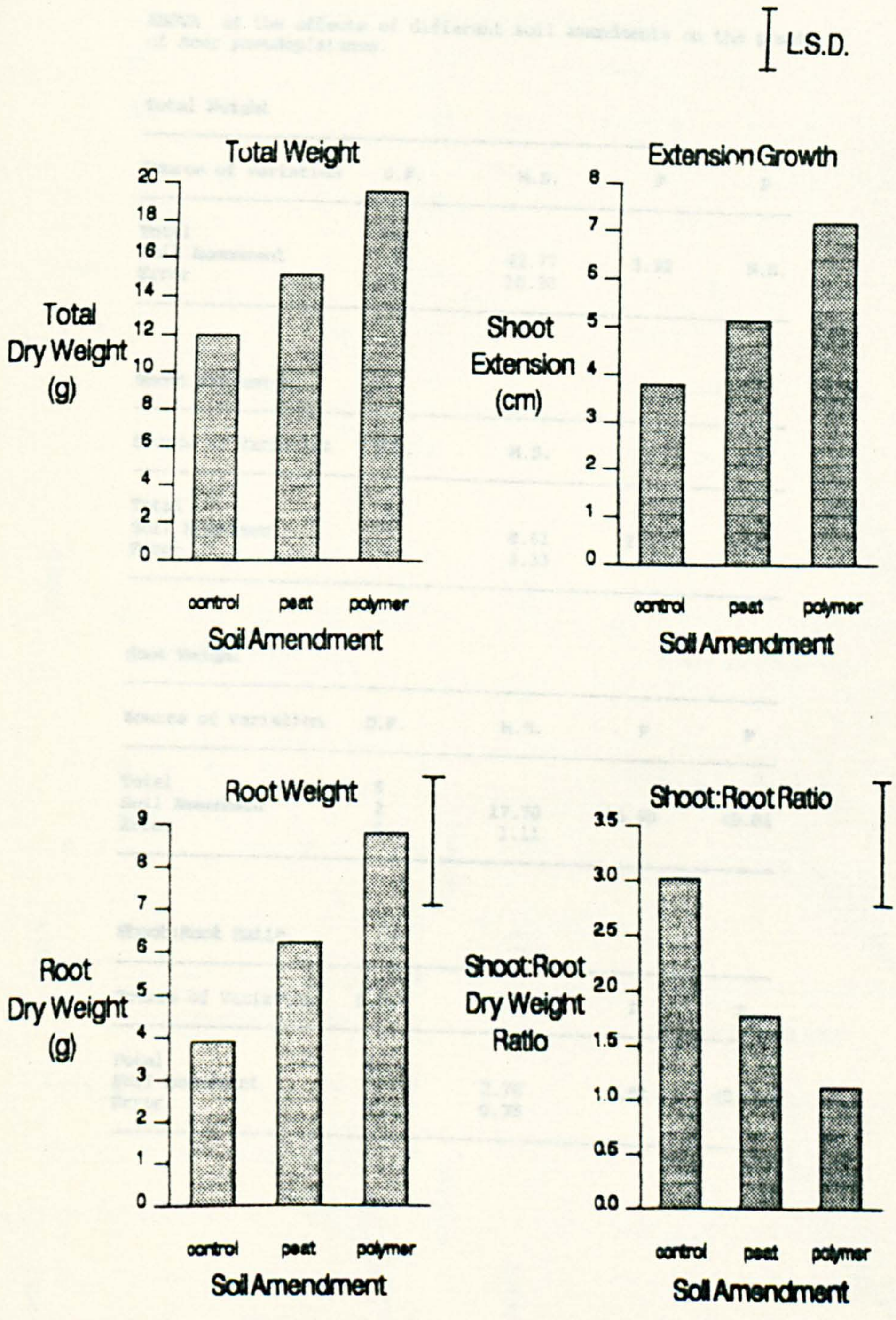


Table 4.4.2

ANOVA of the effects of different soil amendments on the growth of Acer pseudoplatanus.

Total Weight

Source of Variation	D.F.	M.S.	F	P
Total	8			
Soil Amendment	2	42.77	3.92	N.S.
Error	6	10.90		

Shoot Extension

Source of Variation	D.F.	M.S.	F	P
Total	8			
Soil Amendment	2	8.61	2.59	N.S.
Error	6	3.33		

Root Weight

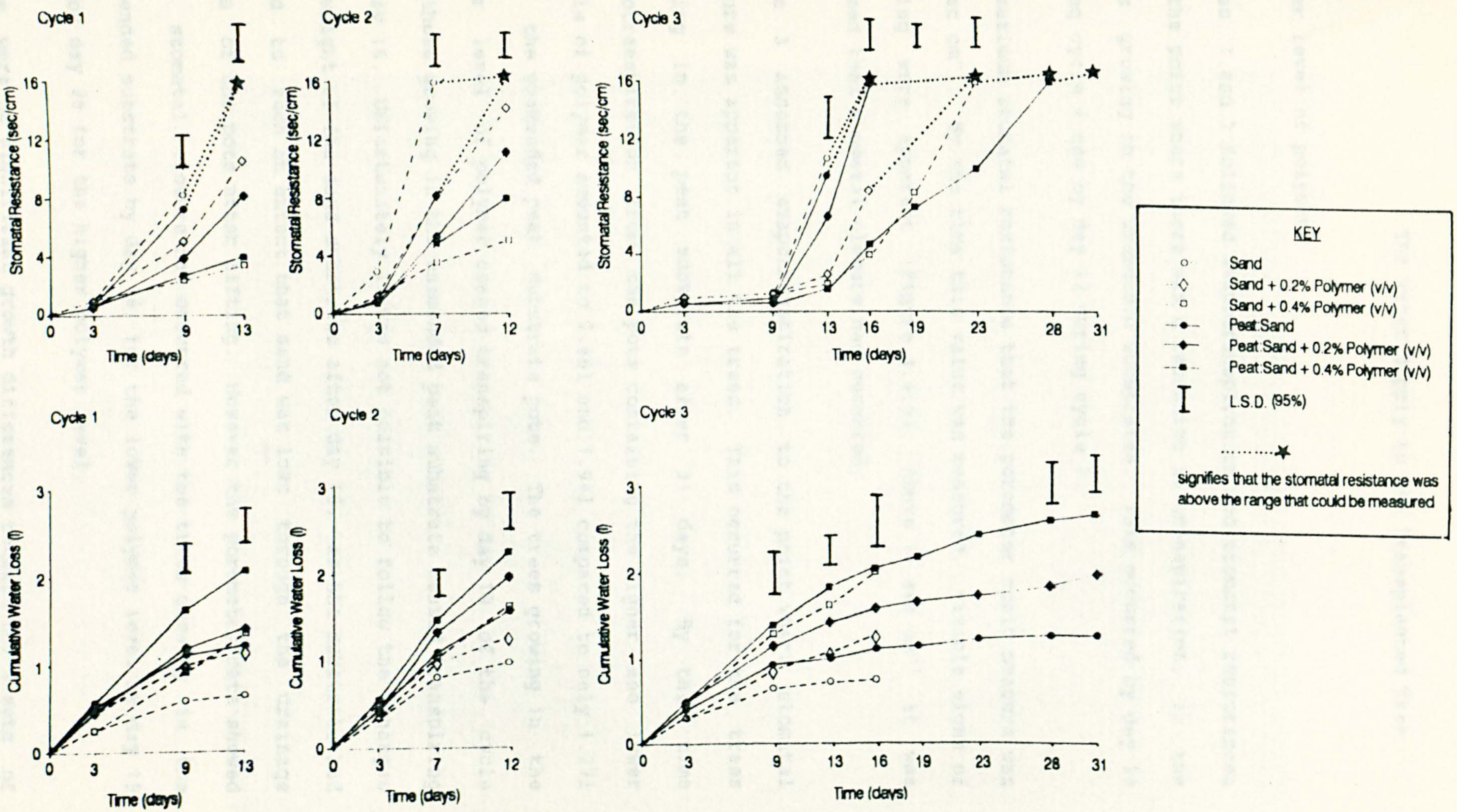
Source of Variation	D.F.	M.S.	F	P
Total	8			
Soil Amendment	2	17.70	15.95	<0.01
Error	6	1.11		

Shoot:Root Ratio

Source of Variation	D.F.	M.S.	F	P
Total	8			
Soil Amendment	2	2.76	7.81	<0.05
Error	6	0.35		

Figure 4.4.4

The effects of the polymer 'Aquastore' on the water relations of *Acer pseudoplatanus*



higher level of polymer.

Cycles 1 and 2 followed evapotranspiration and stomatal resistances to the point where there was a cessation in transpiration, in the trees growing in the unamended substrates. This occurred by day 13 during cycle 1 and by day 12 during cycle 2.

The maximum stomatal resistance that the porometer could measure was 16 sec cm^{-1}. By the time this value was measured, visible signs of wilting were apparent (Figure 4.4.5). Above 16 sec cm^{-1} it was assumed that stomatal closure had occurred.

Cycle 3 assessed evapotranspiration to the point where stomatal closure was apparent in all the trees. This occurred for the trees growing in the peat substrate after 31 days. By this time evapotranspiration from the pots containing the higher and lower levels of polymer amounted to 2.661 and 1.941 compared to only 1.271 from the unamended peat substrate pots. The trees growing in the lower level of polymer ceased transpiring by day 19 of the cycle and those growing in the unamended peat substrate ceased transpiring by day 16. Unfortunately it was not possible to follow the changes in weight of the sand substrate after day 16, as the substrate had dried to such an extent that sand was lost through the drainage holes of the pots after lifting. However the porometry data showed that stomatal closure had occurred with the trees growing in the unamended substrate by day 16, for the lower polymer level by day 19 and by day 28 for the higher polymer level.

There were no significant growth differences between the 2 sets of trees used. Therefore, for the purposes of analysing growth data,

Figure 4.4.5

Acer pseudoplatanus transplants grown in a peat/sand substrate amended with different levels of the polymer 'Aquastore', 16 days after last being watered. From left to right: 0.4% v/v polymer, 0.2% v/v polymer, no polymer amendment.

the observations have been combined to give six replicates. Total weight and shoot extension were not significantly affected by the polymer treatments (Figure 4.4.6, Table 4.4.3). Maximum shoot extension was recorded for the trees grown with the lower level of polymer in the peat:sand substrate but with the higher level of polymer in the sand substrate. Root growth increased with increasing levels of polymer in both substrates; however, only the difference between the control and higher level of polymer in the sand substrate proved to be statistically significant ($P<0.05$). Figure 4.4.7 shows typical examples of the root systems of the trees grown in the sand substrate. Both levels of polymer significantly reduced the shoot:root ratio of the trees but only in the sand substrate ($P<0.01$).

4.4.4 Discussion

The use of the polymer 'Aquastore' as an effective method of increasing the growth of establishing trees has clearly been demonstrated from this series of experiments.

Investigations on the use of polymers in amenity tree planting schemes is sparse. Gilbertson (1987) found no effect of polymer amendment (also using a cross-linked polyacrylamide) on the growth of *Sorbus aria* and *Acer pseudoplatanus* on urban sites in Liverpool. Incorporation of starch based polymer to a peat based compost improved the growth of containerised shrubs (Greenwood *et al.*,1978). Anon (1985b) reported that addition of polymer to the backfill increased survival from 80% (no amendment) to 100% and led to a doubling in extension growth of a number of species of amenity trees. Similar results have also been observed, where the polymer has been used at planting of *Malus domestica* in an orchard

Figure 4.4.6

The effects of 'Aquastore' on the growth of *Acer pseudoplatanus*.

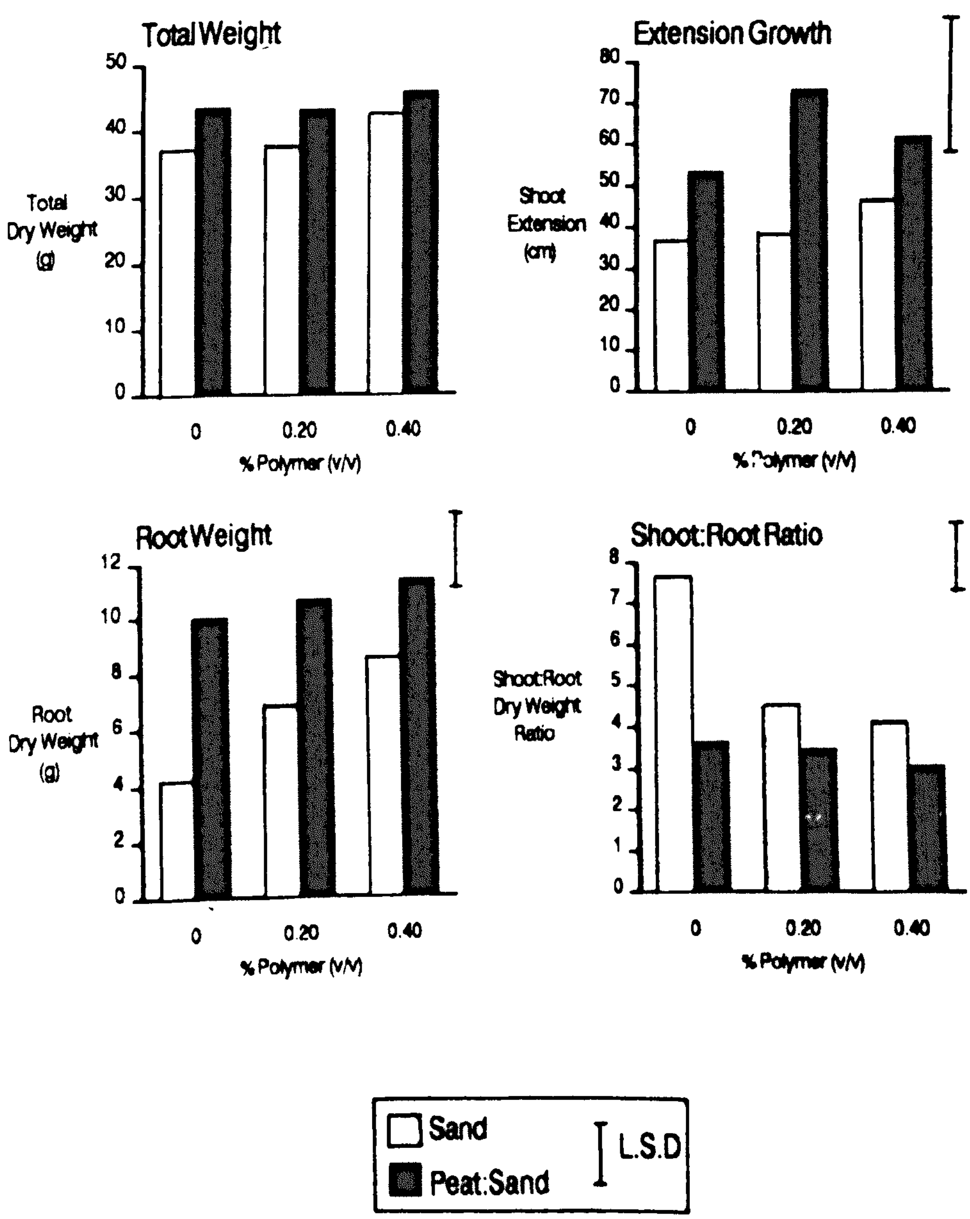


Table 4.4.3

ANOVA of the effects of amendment of either a sand or peat/sand substrate with 3 levels of the polymer 'Aquastore'on the growth of *Acer pseudoplatanus*.

Total Weight

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	59.15	0.40	N.S.
Substrate	1	242.11	1.63	N.S.
Polymer x Substrate	2	7.40	0.05	N.S.
Error	30	148.74		

Extension Growth

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	392.25	0.60	N.S.
Substrate	1	4444.44	6.75	<0.05
Polymer x Substrate	2	379.53	0.58	N.S.
Error	30	658.00		

Root Weight

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	24.09	4.92	<0.05
Substrate	1	156.54	31.95	<0.01
Polymer x Substrate	2	6.91	1.41	N.S.
Error	30	4.90		

Shoot:Root Ratio

Item	D.F.	M.S.	F	P
Total	35			
Polymer	2	13.49	11.24	<0.01
Substrate	1	37.99	31.66	<0.01
Polymer x Substrate	2	10.73	8.94	<0.01
Error	30	1.20		

Figure 4.4.7

Typical examples of the root systems of *Acer pseudoplatanus* transplants grown in a sand substrate amended with different levels of the cross-linked polymer 'Aquastore'. From left to right: no amendment, 0.2% v/v polymer, 0.4% v/v polymer.

(Lovelidge,1985).

A major finding of these investigations has been that root growth is more responsive to polymer amendment than shoot growth. It is therefore surprising to find that those workers that have reported the effects of polymer addition of transplanted trees, whether it be in temperate climates (eg. Gilbertson,1987; Woodhouse,1989, Lovelidge,1985) or arid conditions (Callaghan *et al.*,in press a,b) fail to examine the response of roots to polymer amendment, even though each discusses the use of the polymer in respect of increasing the water supply to the rooting zone.

Reports as to the effects of polymers on the root growth of plants, other than tree species, have been discussed by a number of workers. King, Eikhof & Jensen (1973) report root growth of *Raphanus sativa* was significantly increased by the use of a polymer. Similar results were obtained for *R. sativa* by Woodhouse (1989) as well as increases in root growth of *Lactuca sativa and Lycopersicum esculentum* but not of *Hordeum vulgare*. Barletta (1984) discusses the improvement of the root systems of *Nasturtium officinale* after the production system was changed from a peat based one to a polymer based system.

According to Johnson (1989) moisture limiting conditions can lead to changes in the distribution of the root system, with aggregation around the expanded granules. This aggregation is clearly seen in Figure 4.4.8. Root penetration into the gel fragments is occurring. This could have important implications for the use of polymers in the nursery. This penetration and aggregation of the roots around the gel particles could provide an effective buffer against desiccation of the roots during transport and the transplanting

Figure 4.4.8

Aggregation of the root system of *Acer pseudoplatanus* transplants around the expanded polymer granules.

procedure, and remove the necessity to have a good soil-root contact after transplanting. In the course of this investigation it was noted that trees grown with polymer could be removed from the soil, stored for considerable periods (at least 6 weeks) in paper bags in a cool room and then supplied with water and would leaf out. Unfortunately this was only an observation, a full experimental investigation was not conducted.

Polymers have been used in the past and at present, to achieve the same objective, but in the form of root dips. These are applied to the roots after the tree has been lifted and variable reports to their usefulness and success have been published (Goren *et al.*,1962; Dunsworth,1985; Magnussen,1986; Filer & Nelson,1987). However this use has a fundamental flaw in that the polymer is only at the root surface to improve contact with the soil, and not in the soil to improve waterholding. However for the limited purpose for which they are designed their use may be justified.

Polymers are prepared from propylene and ammonia which are used to prepare the intermediary acrylonitrile which is then hydrated to produce the acrylamide monomer which is subsequently polymerised (Woodhouse,1989). 'Aquastore' cost approximately £4.00 per kg. The cost of amending 0.18, 0.35 and 0.58m^3 of soil with 0.2% v/v 'Aquastore' (the volumes of soil of typical and recommended planting pits) therefore amounts to £1.08, £2.13 and £3.52 respectively. Although not taking into account the costs of application, this still compares favourably with the costs of £8 per tree for a maintenance watering contract (based on 1984 prices). According to Gilbertson (1987) incorporation of polymer into the backfill of the planting pit does not slow the planting procedure.

The use of sphagnum peat as an amendment to the backfill material also proved beneficial. The costs of amending 0.18, 0.35 and 0.58m^3 of soil, with 25% v/v with peat, would cost, assuming 300 l of peat cost £6.50, approximately £0.98, £1.90 and £3.14 respectively. These costs do not vary greatly from the costs of using 'Aquastore'. However the labour and transport costs would be greater, as a large volume of peat would be required. For example, to amend a planting pit of 0.58m^3 in size, with 25% v/v peat or 0.4% v/v 'Aquastore' would require 145 l of peat but only 2.32 l of the polymer.

The use use of the polymer is clearly of considerable value as a means of increasing the amount of available water that a given volume of soil can supply, the higher level of polymer effectively doubling the amount of water lost from the pots by evapotranspiration and doubling the time to stomatal closure. Similar results were discussed by Gehring & Lewis (1980) investigating the use of polymers as an soil amendment for containerised bedding plant production, and concluded that the use of a polymer was as effective as doubling the size of the container in respect of the water relations of the plant.

The present investigation examined the response of *A.pseudoplatanus* to only one example of one type of polymer namely the cross-linked polyacrylamides. Extrapolation of the results must be limited to this group only. There are four major groups of polymer in current use: hydrolysed starch-polyacrylonitrile graft co-polymers, urea-formaldehyde resin foams, vinyl alcohol-acrylic acid co-polymers and cross-linked acrylamide co-polymers (Johnson,1985). Each of the groups has different properties and different longevities in the soil. Starch and urea based polymers are liable to microbial degradation in a short time whereas cross-linked polyacrylamides are not subject to decomposition in the short to medium term.

This series of investigations have also however clearly demonstrated the beneficial affects of a polymer in causing a marked increase in root growth and therefore a reduction in the shoot:root ratio. From the point of view of the newly planted tree this is just as important as increase in available soil water (Figure 4.4.1).

This series of investigations have concerned only a) one species b) transplants. The results appear so important that it is suggested that the work must be extended to include standard trees and a number of the important amenity tree species.

Chapter 5

The Influence of Shoot Pruning on Tree Establishment

5.1 Introduction

In London & Wise's (1717) abridgement of De La Quintiney's 'The Complete Gard'ner' is found:

> "First as we prejudice a Tree when we pluck it up, by weakening it thereby, and abating it's vigour and activity for sometime; so we must therefore disburthen its Head, proportionable to the strength and activity we take from it by recovering it to a new place, and retrenching some of its Roots."

De la Quintiney evidently contemplated pruning the shoots as well as the roots before planting and also considered the balance between the shoot and root.

Many reports still appear in the scientific, educational, trade and popular press that shoot pruning greatly aids in reducing transplanting shock and promotes successful plant establishment (Pirone 1978; Helliwell,1983; James,1972). The reasons in favour of pruning at planting appear obvious. By reducing the total leaf area, it is possible to reduce the transpiration demand that the shoot puts onto the truncated root system. For this reason alone Kozlowski (1975), Harris (1975) and Hensley (1979), all recommend thinning of the crown. However there is an opposing theory, that is, that pruning is of no value or is actually detrimental to the subsequent growth of the tree. Whitcombe (1979), supporting the latter theory, believes that the intact crown of the tree plays a more beneficial role in carbohydrate production, auxin release and subsequent root regeneration, than in transpiring water resulting in moisture stress.

An implicit assumption, made by those workers who advocate pruning at planting time is that root growth will be unaffected or increased by shoot pruning. Reports on the effect of pruning on root growth vary. Chandler (1919) working with *Prunus persica* reported that root weight was significantly reduced by pruning. Knight (1934) found a decrease in the production of both fine and coarse roots of *Malus domestica* upon pruning. The more severe the pruning the smaller was the weight of roots subsequently produced. Similar results were reported by Alexander & Maggs (1971) who investigated the response of *Citrus sinensis* seedlings to various pruning treatments. In contrast Kelly & Moser (1983) have demonstrated that maximum root regeneration and shoot growth of *Liriodendron tulipifera* occurred when shoots were pruned to 15 or 30 cm. However Stirling & Lane (1975) reported a lack of response of root growth to shoot pruning of *L.tulipifera*.

The following group of experiments therefore examines the response of newly planted trees to pruning treatments in an attempt to secure data of such a nature as to furnish a more definite basis for judging the effect and value of the common practices and principles of pruning tress upon planting.

Initially the effect of both dormant and summer pruning on root growth and response to drought was compared. To see whether response is species specific, the effects of dormant pruning on the growth of a number of species was then examined. To test extremes, the use of a severe dormant pruning treatment, which would reduce the load placed upon the stem of the tree and negate the necessity to stake the tree, was also investigated. Finally the effect of various levels of severity of dormant pruning on leaf area development was examined.

5.2 The effect of dormant and summer pruning on root growth of *Acer platanoides*.

5.2.1 Introduction

To be an effective treatment in reducing transplanting stress, pruning must not detrimentally affect the development of the root system. As has been discussed, conflicting reports as to the effects of pruning on root growth appear in the literature. Some workers suggest that pruning might have no effect on root development or may actually be beneficial. For example, Evans & Klett (1984,1985) found that dormant branch thinning had no effect on root production of *Malus sargentii* or *Prunus cerasifera*, whilst pruning of *Quercus rubra* seedlings in autumn substantially reduced root growth potential after March planting, moderate pruning in spring may have been beneficial (Larson,1975). According to Lee *et al.* (1974), pruned *Quercus coccinea* seedlings had greater root growth potential than unpruned seedlings, while pruning *Q.palustris* had generally deleterious effects. With *Picea glauca* seedlings, 25-50% removal of shoots slightly increased the number of new roots produced, whilst 75% removal significantly decreased new root initiation (Carlson,1977).

It has previously been demonstrated (chapter 3) that root growth is highly sensitive to disturbance, defoliation of the tree resulting in a cessation of root growth until new leaves are produced. Similarly the majority of reports in the literature suggest that a dormant pruning treatment does restrict the development of the root system. For example, Head (1967) noted that the effect of shoot pruning of *M.domestica* and *Pyrus communis* was to stimulate more intense shoot growth, the greater the pruning treatment, the greater was the reduction in new root growth during the summer. Young & Werner (1982) noted that shoot pruning of *M. domestica* on planting resulted in very little root growth up to 8 weeks after planting, concluding a competitive inhibition of root growth by rapid shoot growth.

However in all this work little or no attention was paid to whether shoot pruning had any effect on the response to drought. This experiment therefore examined the response of root growth of *Acer platanoides* transplants to both a dormant and summer pruning treatment in combination with a drought treatment. Root growth was continually monitored by the using the root observation boxes as described in chapter 3.

Summer pruning was included as an experimental treatment as it has been used particularly during fruit production to control tree shape, and redirect tree growth and because it is supposed to have a greater retarding influence on net increase in size than a corresponding winter pruning (Chandler & Cornell, 1952; Taylor & Ferree, 1981; Rom & Ferree, 1983). Indeed Hensley (1979) suggests that some amenity trees such as *Betula sp.*, *Acer sp.*, *Ulmus sp.* and *Cornus sp.* are best pruned during the summer to prevent sap being lost from the wound following spring pruning. But there is also the possibility that by reducing leaf area, transpiration and therefore drought stress would be reduced.

5.2.2 Materials and Methods

Twenty four *Acer platanoides* (1+2) transplants, were planted singly into root observation boxes situated inside a polythene tunnel house (for a detailed description of the root observation boxes, see chapter 3). Each box was filled with a mixture of 2 parts peat to 1 part coarse sand amended with 8-9 month release 'Osmocote' resin coated 18:11:10 fertiliser (4 kg m^{-3}) and ground limestone (1 kg m^{-3}) and ground magnesium limestone (1 Kg m^{-3}). Before the trees were planted, care was taken to settle the mixture by wetting and draining until no further settling of the substrate was observed.

All the boxes were watered from above after planting. Immediately after this half of the trees received no further water, the remaining trees continued to receive water on a daily basis after leafing out. Three pruning treatments were then superimposed. These consisted of no pruning, dormant pruning (achieved by removing half the length of then stem of the tree, the day after planting) and summer pruning (achieved by removing half the length of the stem of the tree during mid May, when the trees were fully in leaf).

Root length was estimated by using the intersection method as proposed by Newman (1966) and Head (1966), and amended by Tennant (1975), which has been described in detail in Chapter 3. Root development was monitored over 10 weeks, after which the trees were harvested, shoot and root dry weights being ascertained after drying in an oven at 90°C. Total leaf areas were also measured by using a 'Hayashi Denko AAM-5' area meter. The stomatal resistances of the trees as measured by a 'Crump' diffusive porometer were also followed over the course of the experiment, measurements being taken at 11am on the same day as root growth was examined. On each occasion 3 readings per leaf were made on the lower surface of the youngest expanded leaf of the tree, the final recording being accepted as the stable measurement.

5.2.3 Results and Discussion

Pruning is advocated at planting in order to (i) reduce the transpiration demand placed upon the truncated root system by (ii) reducing total leaf area and (iii) effectively shifting the shoot:root ratio towards the pre-transplanting level. However the scenario assumes that root growth is not detrimentally affected by the process of pruning. It has been shown, in chapter 3, that root growth is however sensitive to disturbance.

The observation boxes allowed root growth of the trees to be monitored over the course of the investigation (Figure 5.2.1). Root development of the unpruned and dormant pruned trees appeared to proceed with a similar pattern, suggesting that root growth was unaffected by the dormant pruning treatment. Summer pruning however reduced the rate of root growth immediately following the pruning treatment. Significant differences were found only between root growth in the watered and droughted treatments irrespective of the pruning treatments. However, the intersection technique only allowed major changes in the behaviour of the root system to be followed, and did not purport to obtain an absolute value of the root length.

Data from the final harvest (Tables 5.2.1 and 5.2.2) shows

Figure 5.2.1

The effect of dormant and summer pruning in combination with a droughting treatment on the root development and water relations of *Acer platanoides*

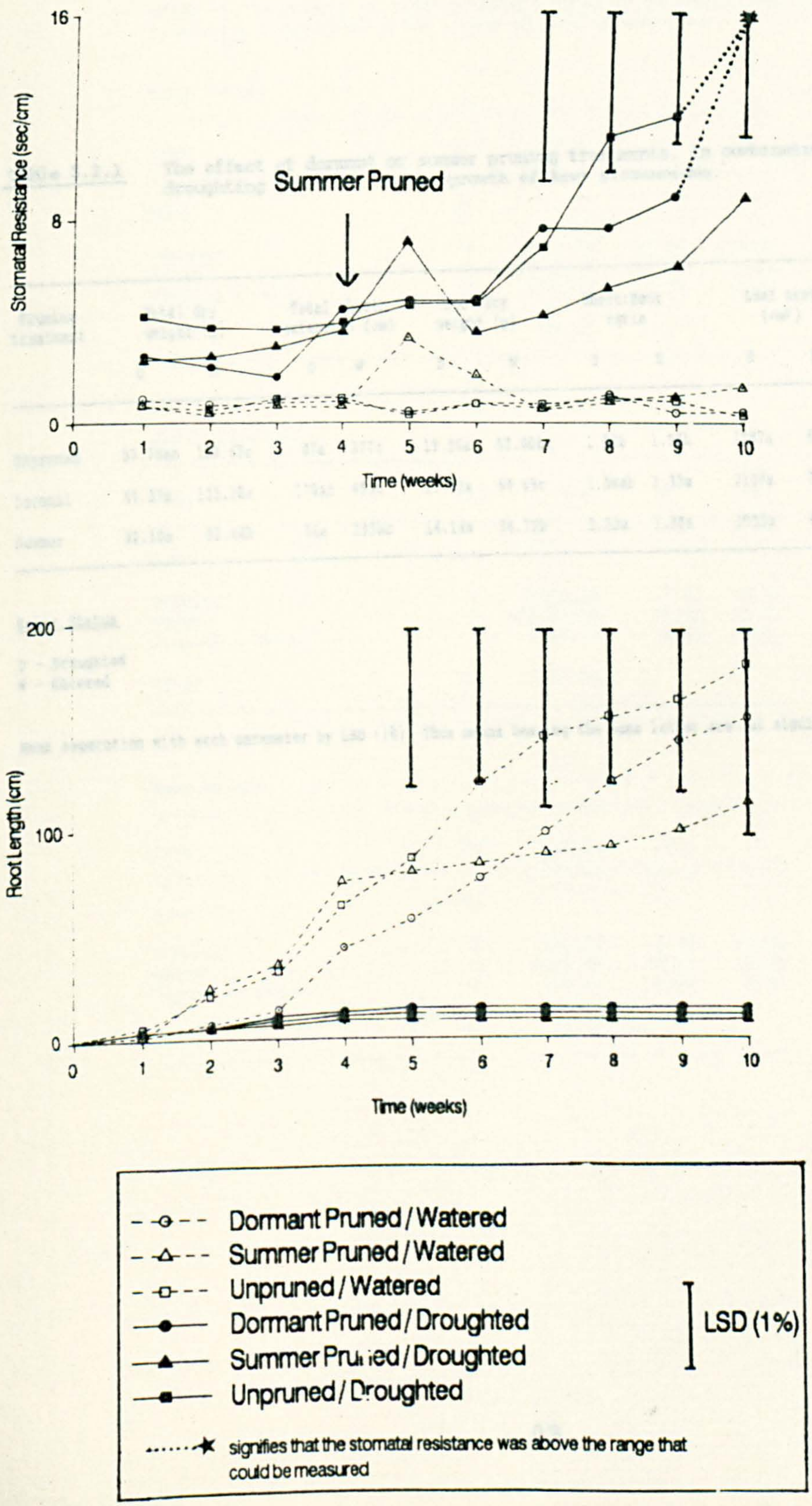


Table 5.2.1 The effect of dormant or summer pruning treatments, in combination with a droughting treatment on the growth of *Acer platanoides*.

Pruning treatment	Total dry weight (g)		Total shoot extension (cm)		Root Dry weight (g)		Shoot:Root ratio		Leaf area (cm^2)		Leaf number	
	D	W	D	W	D	W	D	W	D	W	D	W
Unpruned	57.70ab	153.67c	87a	377c	19.56a	52.80bc	1.93b	1.93b	1387a	6145bc	89ab	210c
Dormant	44.37a	135.58c	178ab	459c	19.31a	58.69c	1.38ab	1.33a	2127a	7012c	71a	159bc
Summer	32.18a	82.44b	56a	293bc	14.14a	36.72b	1.33a	1.30a	1033a	4750b	89ab	151bc

Water Status

D - Droughted
W - Watered

Mean separation with each parameter by LSD (1%). Thus means bearing the same letter are not significantly different

Table 5.2.2

ANOVA of the effects of three pruning treatments in combination with 2 watering treatments on the growth of *Acer platanoides*.

Total Weight

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	4872.36	19.76	<0.01
Water	1	37585.17	152.47	<0.01
Pruning x Water	2	1263.45	5.13	<0.05
Error	18	246.51		

Shoot Extension

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	42032.67	7.42	<0.01
Water	1	435781.50	76.93	<0.01
Pruning x Water	2	1586.00	0.28	N.S.
Error	18	5664.58		

Root Weight

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	410.24	6.26	<0.01
Water	1	6041.39	92.13	<0.01
Pruning x Water	2	144.54	2.20	N.S.
Error	18	65.58		

Table 5.2.2 continued

Shoot:Root Ratio

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	0.956	12.256	<0.01
Water	1	0.005	0.064	N.S.
Pruning x Water	2	0.003	0.038	N.S.
Error	18	0.078		

Leaf Area

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	5634503.09	6.13	<0.01
Water	1	118968930.90	129.38	<0.01
Pruning x Water	2	822095.52	0.89	N.S.
Error	18	919560.99		

Leaf Number

Item	D.F.	M.S.	F	P
Total	23			
Pruning	2	2802.04	2.17	N.S.
Water	1	49051.04	38.06	<0.01
Pruning x Water	2	1790.55	1.39	N.S.
Error	18	1288.71		

that dormant pruning had little effect on root growth, indeed the dormant pruned/watered trees had the largest root mass. However, summer pruning significantly reduced the root mass of the trees compared to the unpruned trees by 28% and 31% in the droughted and watered treatments respectively. It would thus appear that the premise that root growth is unaffected by dormant pruning treatments holds true.

Clear reductions in shoot:root ratios by both the dormant and summer pruning treatments were apparent. This must have been due in some part to the loss of half of the original weight of the stem of the tree on pruning. With the dormant pruning treatment, an increase in shoot growth (this is discussed further in section 5.5) was observed, but this did not compensate for the original loss, whilst root growth was unaffected by the treatment. The summer pruning treatment, by contrast, resulted in reduced shoot extension and also reduced root growth.

The assumption that total leaf area would be reduced by the dormant pruning treatment, from these results, would appear to be a fallacy. Total leaf area was significantly increased by the dormant treatment by 53% and 14% with the droughted and watered trees respectively. But it was reduced by the summer pruning treatment by 25% and 23% in the droughted and watered trees respectively. In contrast, leaf number was unaffected by either of the pruning treatments. Similar reductions in leaf area following summer pruning have been reported by a number of workers (Chandler & Cornell, 1952; Taylor & Ferree, 1981; Rom & Ferree, 1985). With the exception of the summer pruning treatment of the droughted trees where leaf numbers were unaffected, both the pruning treatments reduced the number of leaves developing. The effects of dormant pruning treatments on leaf area development is discussed in section 5.4.

As a mechanism of relieving drought stress pruning would appear to be ineffective, as although significant differences in stomatal resistances between the watered and droughted trees were apparent (Figure 5.2.1), no such differences were observed between the pruning treatments. Satoh, Kriedmann & Loveys (1977) report similar findings. One immediate effect of summer pruning, however, was to increase the stomatal resistance of the trees irrespective of the watering treatment, however this effect was transient and was no longer observable after 14 days with the droughted trees and 21 days with the watered trees.

However, although there were no significant differences between the pruning treatments, it was apparent that the summer pruned/droughted trees, following the peak in stomatal resistance, had the lowest stomatal resistances of the droughted trees for the remainder of the investigation. Analogous increases in the level of photosynthesis following summer pruning have been reported for *Malus domestica* (Feree *et al.*,1983; Marini & Barden 1982; Taylor & Ferree 1981).

In general, there was a lack of pruning x drought interactions for the various growth parameters, which would have been expected if pruning was able to relieve the effect of drought. There was however, an interaction for total weight, which can be explained by the fact that total weight of the summer pruned trees was significantly less reduced by drought than the unpruned or dormant pruned trees. This effect is small, but does suggest some reduction of the drought effect by summer pruning. However the overall negative effect of summer pruning, suggests that this is not a sensible option.

Many of the results from this investigation are in broad agreement with the findings of other workers. For example a number of reports detail a similar lack of effect of dormant pruning on root growth (Evans & Klett,1984,1985; Stirling & Lane,1975). However the majority of reports over quite a long period of time suggest an adverse effect of dormant pruning on root development(Knight,1934; Chandler & Cornell, 1952; Head, 1967; Alexander & Maggs, 1971; Lee *et al.*, 1974; Young & Werner, 1982)

The effects of summer pruning on root growth have been discussed by a number of other workers. Satoh & Ohymama (1976) reported a short term decrease in root dry weight that corresponded with a rapid increase in regrowth. Increased severity of summer pruning led to a greater reduction in root weight (Leiser *et al.*, 1972). Chandler & Cornell (1952) suggest that a severe mid summer pruning would reduce root growth to such an extent that shoot growth the following spring would be adversely affected. Summer pruning of *Camellia sinensis* has been demonstrated to result in cessation of root growth using a similar observation technique as used during this investigation (Fordham,1972). Root weight of *Ilex crenata* was similarly reduced following a summer pruning treatment (Randolph & Wiest,1981) as was root weight of *Malus domestica* (Hatton & Amos, 1927).

One possible explanation for the observed effects of pruning on root growth involves carbohydrate supply and growth hormone production. That the growth of the shoot and root systems of plants are closely interrelated and indeed 'compete' with each other for current photosynthate was demonstrated in chapter 3, where defoliation resulted in a cessation of root growth until new leaves were formed and photosynthetic productivity resumed, a view consistent with the observations of other workers (Eliasson, Richardson & Webb, 1976).

It has been suggested that the growth hormone auxin is involved, exerting its effect either directly through transport to the root (where it inhibits root development) or through the production of a metabolic sink in the shoots (Webb & Dunbroff,1978). But of course the depression of root development following the summer pruning treatment could simply be a consequence of the reduction in the photosynthetic area and therefore a reduction in the amount of photosynthate produced.

Farmer (1975) has demonstrated that in properly grown *Quercus rubra* seedlings sufficient carbohydrate reserves are present to support abundant new growth of roots and shoots, with approximately 40% of the root dry weight being starch. With the emergence of rapid shoot growth, a rapid decline in food reserves occurred and reached a low level of approximately 12%. Once rapid shoot growth ceased, the reserves were replenished. Dormant pruning would therefore result in reduction in the number of actively growing regions, the reserves being more than sufficient to supply the demands of the reduced shoot system. In contrast, carbohydrate reserves would have been depleted before the summer pruning occurred. With the shoot acting as an effective sink for any remaining reserves, root growth would be adversely affected. Richardson (1956) demonstrated that both the duration and rate of root growth were determined by the level of carbohydrate reserves present in the seedlings of *Acer saccharinum*.

There appears to be an anomaly for the root growth data, in so much as root growth of the droughted trees was almost nil from week 3 onward. Yet from the stomatal resistance data, it is known that the trees were under no apparent water stress until at least week 6 and only by week 9 were visible signs of wilting becoming apparent. However as with the investigation described in chapter 3, it was noticed that the soil immediately adjacent to the glass panels of the observation boxes, dried before the remainder of the substrate in the boxes. This caused the substrate to shrink away from the side of the glass panel and made root counts difficult. This lack of root proliferation in the relatively dry interface coupled with the death of roots in this region, together with the difficulty of counting roots are possible reasons to account for the anomaly.

The results of this investigation therefore suggest that root growth of newly establishing trees is unaffected by dormant pruning, whilst summer pruning will severely inhibit root growth, that dormant pruning is ineffective as a means of reducing transplant stress, and that although summer pruning may have a positive effect, this is cancelled out by the overall negative effect of summer pruning on growth.

5.3 The effects of pruning and staking on the growth of Platanus x hispanica

5.3.1 Introduction

The previous experiment suggests that there is little value in pruning to reduce transplanting shock or the effects of subsequent drought. Evelyn (1678) however gives another reason why trees should be pruned at planting:

> "Prune off the branches, and spare the tops; for this does not only greatly establish your plants by diverting the sap to the roots; but likewise frees them from the injury and concussions of the winds, and makes them to produce handsome, strieght shoots, infinitely preferable to such as are abandon'd to nature, and accident, without this discipline".

Today, British Standard 4428 (Anon 1969) recommends that:

> "newly planted trees be held firmly enough although not rigidly by staking to prevent a pocket forming around the stem and newly formed fibrous roots being broken by mechanical pulling as trees rock".

Leiser & Kemper (1968), however, have mathematically modelled stresses placed upon staked trees and showed that a force applied to a tree with a branch free stem supported to the base of the crown is six times greater than the same load applied to an unstaked tree. Moreover the stress per cross sectional area is 3 to 5 times as great at the point of staking when a sapling is staked near the top than when the point of staking was near ground level. Patch (1987) has since recommended that stakes should not exceed more than a third of the total tree height and should be attached to the stem only at the top of the stake. However, if removal of the tree crown at planting by severe pruning as recommended by Evelyn (1678) could reduce the load placed upon the tree, then it ought to be possible to remove the necessity to provide any stake.

Larson (1965) has suggested that pruning may artificially regulate the passive growth distribution of the stem. As the live crown recedes with increasing levels of severity of pruning, the position of maximum growth recedes upwards and stem taper at the base of the trunk reduces. According to Leiser *et al.*(1972) and Leiser & Kemper

(1973) this situation would require that the trees were staked.

This investigation, therefore examines the response of *Platanus x hispanica* to a combination of a severe pruning treatment with different staking treatments, in order to discover if removal of a significant part of the tree crown, by pruning, could mean that staking of standard trees is unnecessary. Establishment success is examined in terms of shoot and root growth.

5.3.2 Materials and Methods

Seventy two *Platanus x hispanica* (12' standards) were planted in early April 1987, whilst the trees were still in a dormant state, in the experimental site, which since it slopes down westward to the estuary of the River Dee, is very exposed. Planting took place in 3 replicate blocks, each block containing six treatment plots each of 4 trees.

The treatments were the 6 combinations of 2 levels of shoot pruning with 3 stake sizes. Shoot pruning levels consisted of shoots unpruned or a reduction of branch length and number of buds by approximately 75%. The staking treatments included a tall stake (1.5m), short stake (0.5m) or no stake.

At the end of the first growing season, September 1987, 3 trees per treatment were harvested i.e. 1 from each replicate group. By this date all shoots had set terminal buds and leaf expansion was complete. The root systems were hand dug using a garden fork (see chapter 2, method 1). Treatment effects were determined by assessment of the growth parameters discussed in chapter 2. In addition leaf areas were measured by a ' Hayashi Denko AAM-5' area meter. Due to the length of time required to estimate leaf area only the leaf area of the pruned and unpruned short staking treatments were measured.

The remaining trees were harvested at the end of the second growing season, November 1988; this harvest utilised the JCB to excavate the root system (see chapter 2, method 3). Before the trees were lifted, the degree to which the unstaked trees had been blown off vertical was assessed. In addition stem diameter was measured at 0.1, 0.25. 0.5 and 1m above ground level. The same parameters as for the first harvest were determined as well as the length of dead shoots. Leaf areas of the pruned and unpruned, short staked trees were measured at the end of September 1988.

5.3.3 Results and Discussion

Shoot extension was significantly affected during both the first and second years by shoot pruning (Figures 5.3.1 and 5.3.2). The median shoot extension of the unpruned trees after the first year being 8.86, 11.2 and 10.5 cm for the unstaked, short and tall staked trees respectively, and for the pruned trees 22.3, 23.1 and 21.21 cm respectively. During the second year the median shoot extension values of the unpruned trees were 17.1, 19.3 and 19.7 cm for the unstaked, short and tall staked treatments respectively, and for the pruned trees 22, 26.6 and 27.7 cm.

The growth parameters of the trees (Table 5.3.1, Table 5.3.2) show that by the end of the first growing season, the total crown length of the pruned trees was only 50% of that of the unpruned trees, and after the second season, the unpruned trees

Figure 5.3.1

Frequency of the extending shoots of *Platanus x hispanica* following pruning and staking treatments

Year 1

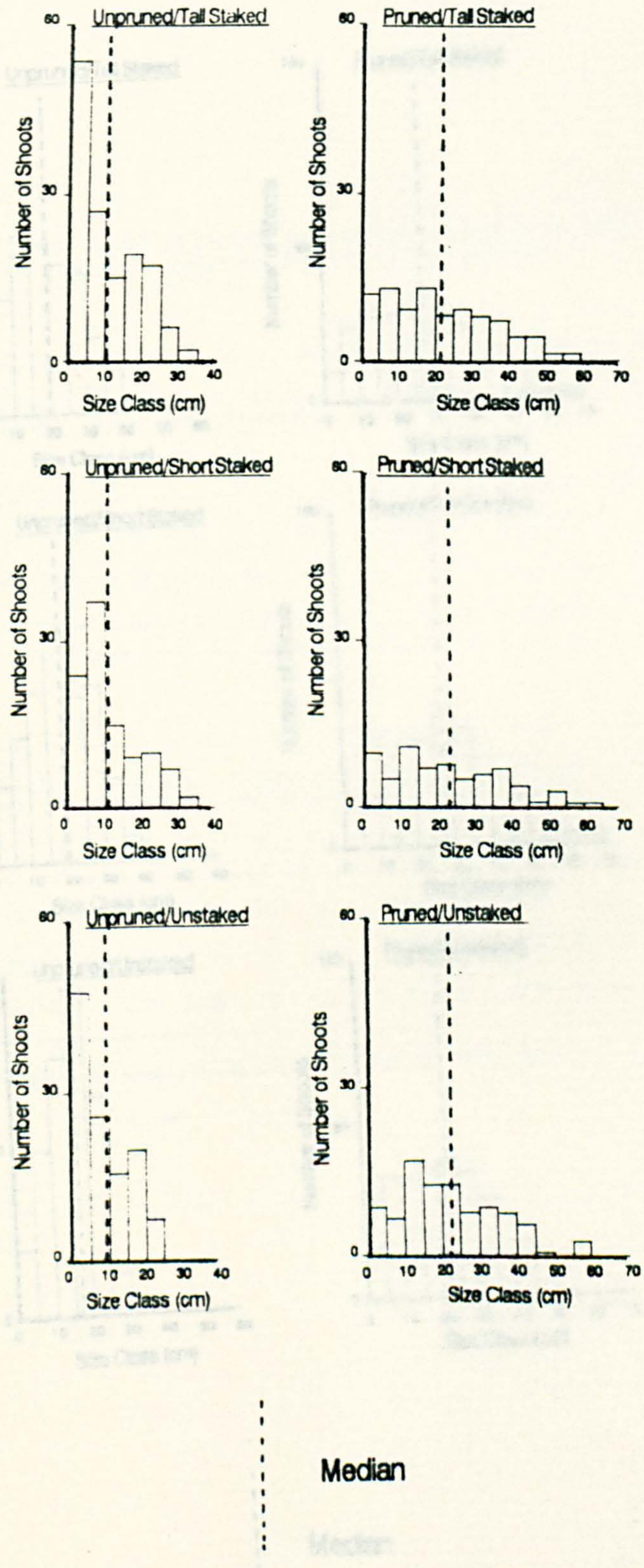


Figure 5.3.2 Frequency of the extending shoots of *Platanus x hispanica* following pruning and staking treatments

Year 2

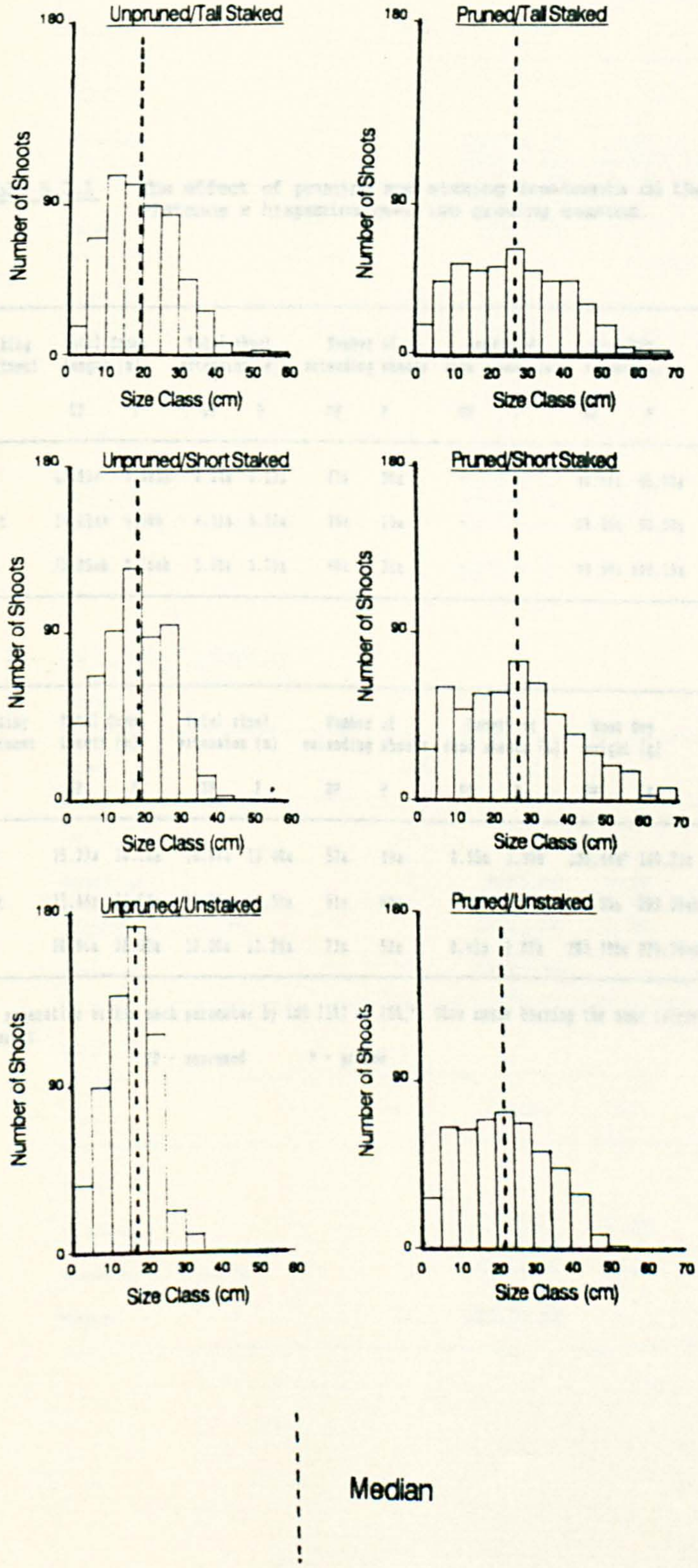


Table 5.3.1 **The effect of pruning and staking treatments on the growth of *Platanus x hispanica* over two growing seasons.**

Year 1

Staking treatment	Total Crown Length (m)		Total shoot extension (m)		Number of extending shoots		Length of dead shoots (m)		Root Dry weight (g)		Leaf area (m^2)		Leaf number	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Tall	17.93a	7.88ab	4.84a	6.12a	47a	30a	-	-	94.03a	95.03a	-	-	-	-
Short	14.11ab	6.60b	4.21a	5.22a	35a	23a	-	-	88.35a	90.50a	0.08a	0.16b	135a	137a
None	15.85ab	8.76ab	3.85a	6.75a	40a	31a	-	-	99.50a	100.13a	-	-	-	-

Year 2

Staking treatment	Total Crown Length (m)		Total shoot extension (m)		Number of extending shoots		Length of dead shoots (m)		Root Dry weight (g)		Leaf area (m^2)		Leaf number	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Tall	25.23a	20.16a	10.87a	13.40a	57a	49a	8.55a	1.96b	135.44a*	160.21a	-	-	-	-
Short	21.44a	21.54a	11.73a	15.32a	61a	58a	9.22a	1.87b	142.53a	203.33ab	0.95a	1.81b	189a	218a
None	28.86a	20.02a	12.00a	11.26a	73a	52a	8.41a	2.82b	285.39bc	220.78ab	-	-	-	-

Mean separation within each parameter by LSD (1%) or (5%)*. Thus means bearing the same letter are not significantly different.

UP - unpruned P - pruned

Table 5.3.2

ANOVA of the effects of pruning and staking treatments on the growth of *Platanus x hispanica*.

TOTAL CROWN LENGTH

Year 1

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	106995.39	1.63	N.S.
Pruning	1	3037290.89	46.26	<0.01
Staking x Pruning	2	38744.06	0.59	N.S.
Error	12	65661.56		

Year 2

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	132031.72	0.13	N.S.
Pruning	1	953580.49	0.90	N.S.
Staking x Pruning	2	302163.51	0.28	N.S.
Error	12	1064073.06		

TOTAL SHOOT EXTENSION

Year 1

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	9585.06	0.25	N.S.
Pruning	1	135026.72	3.57	N.S.
Staking x Pruning	2	15615.06	0.41	N.S.
Error	12	37807.46		

Year 2

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	57642.67	0.32	N.S.
Pruning	1	144901.39	0.80	N.S.
Staking x Pruning	2	76286.89	0.42	N.S.
Error	12	181123.83		

Table 5.3.2 continued

NUMBER OF EXTENDING SHOOTS

Year 1

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	132.17	0.83	N.S.
Pruning	1	722.00	4.55	N.S.
Staking x Pruning	2	30.50	0.19	N.S.
Error	12	158.56		

Year 2

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	146.81	0.44	N.S.
Pruning	1	508.38	1.52	N.S.
Staking x Pruning	2	128.42	0.39	N.S.
Error	12	333.49		

LENGTH OF DEAD SHOOTS

Year 2

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	2114.39	0.12	N.S.
Pruning	1	1904501.39	109.16	<0.01
Staking x Pruning	2	11734.06	0.67	N.S.
Error	12	17447.61		

ROOT DRY WEIGHT

Year 1

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	162.00	0.194	N.S.
Pruning	1	7.16	0.009	N.S.
Staking x Pruning	2	0.94	0.001	N.S.
Error	12	833.73		

Year 2

Item	D.F.	M.S.	F	P
Total	17			
Staking	2	18217.56	4.88	<0.05
Pruning	1	231.13	0.06	N.S.
Staking x Pruning	2	6277.63	1.68	N.S.
Error	12	3731.32		

Table 5.3.2 continued

LEAF AREA

Year 1

ITEM	D.F.	M.S.	F	P
Total	23			
Pruning Treatments	1	3517909.11	96.72	<0.01
Error	21	36371.34		

Year 2

ITEM	D.F.	M.S.	F	P
Total	17			
Pruning Treatments	1	333868734.80	17.45	<0.01
Error	15	19137423.11		

LEAF NUMBER

Year 1

ITEM	D.F.	M.S.	F	P
Total	23			
Pruning Treatments	2	3927.04	1.15	N.S.
Error	21	3411.50		

Year 2

ITEM	D.F.	M.S.	F	P
Total	17			
Pruning Treatments	2	296.06	0.08	N.S.
Error	15	3520.39		

still had 20% more canopy than the pruned trees. However, when the length of the shoots that had died back is taken into account, the pruned trees actually had a larger living canopy than the unpruned trees.

As expected the pruning treatment significantly reduced the number of shoots extending during the first year. Although this trend continued during the second year, the differences were not significant. However, total shoot extension during both years was greater following the pruning treatment, although this again was not statistically significant. The three staking treatments had no effect on either number of shoots extending or total shoot extension in either year.

No differences in stem diameter were apparent as a result of the pruning treatment (Figure 5.3.3, Table 5.3.3) however stem diameter was significantly affected by the staking treatments. A consistent feature being that the trees which were not staked had larger stem diameters than the trees with short stakes which in turn were larger than those with the tall stakes. However these differences were only statistically significant at 10 and 25 cm from the base of the stem. This promotion of growth at the base of the stem, produced by the swaying action of wind, has been discussed by Larson (1965) who demonstrated that trees staked with a tie showed increased stem growth above the point of support at the expense of growth on the lower stem. This can have important consequences for trees that have been artificially prevented from swaying for a period of years may no longer be stable when again exposed to normal wind conditions (Jacobs,1954). Unstaked unpruned trees can develop characteristics

Figure 5.3.3

The effects of pruning and staking treatments on the stem diameter of *P. x hispanica*

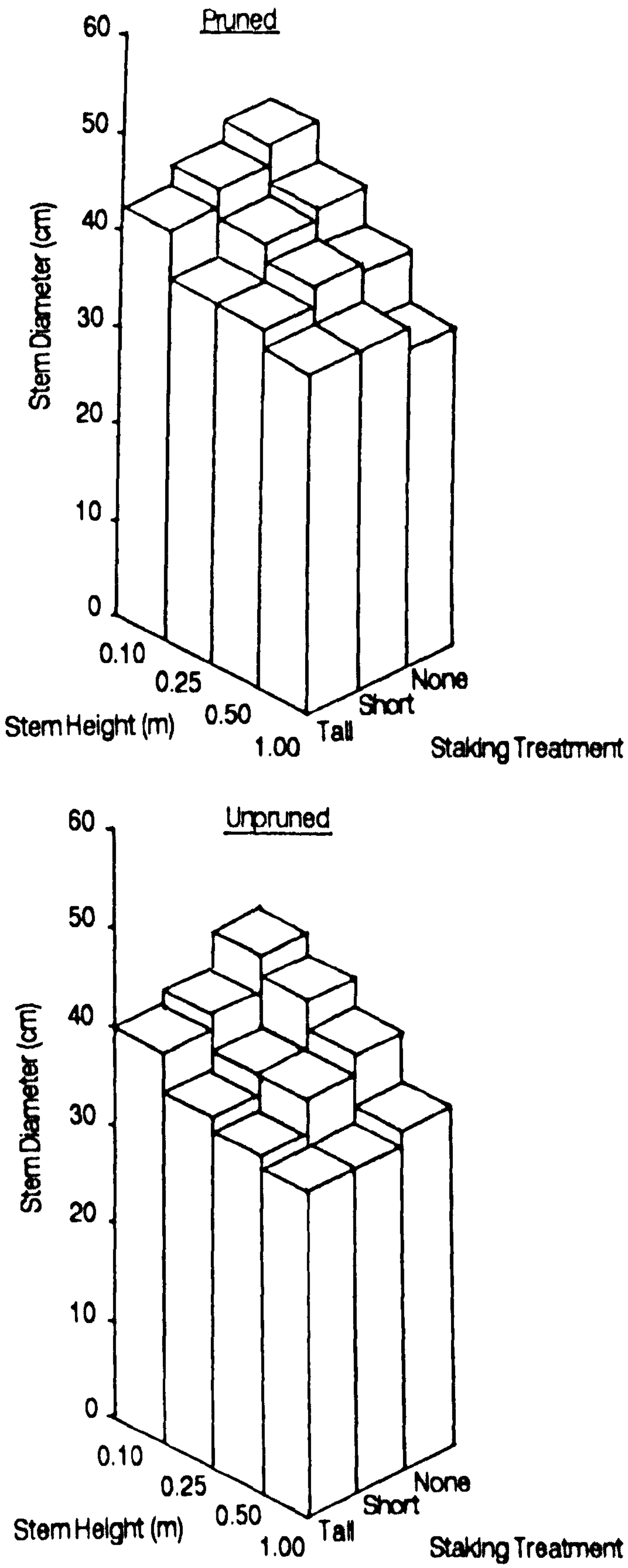


Table 5.3.3

ANOVA of the stem diameter of *Platanus x hispanica* measured at different heights following different pruning and staking treatments.

Item	D.F.	MS	F	P
Total	71			
Pruning	1	3.55	0.46	N.S.
Staking	2	83.10	10.68	<0.01
Height	3	291.40	37.46	<0.01
Pruning x Staking	2	21.18	2.72	N.S.
Pruning x Height	3	0.55	0.07	N.S.
Staking x Height	6	17.26	2.22	N.S.
Pruning x Staking x Height	6	2.09	0.27	N.S.
Error	48	7.78		

Table 5.3.4

The effects of pruning on the stability of unstaked *P.x hispanica*

	Unpruned	Pruned
Stem Angle (Degrees from Vertical)	29.5	21.7

Table 5.3.5

ANOVA of the stem angles (from vertical) of *P. x hispanica* following a pruning treatment

Item	D.F.	MS	F	P
Total	5			
Pruning Treatment	1	85.88	2.14	N.S.
Error	4	40.15		

that make them better able to withstand wind (Harris & Hamilton, 1969). However this investigation (Tables 5.3.4 and 5.3.5) demonstrates that it is impractical not to stake a standard tree of the size used even when the canopy has been severely reduced by pruning because root anchorage will not be great enough during the first year to prevent the tree from being blown off vertical.

A striking consequence of pruning was that the total leaf areas of the pruned trees were double those of the unpruned trees during both experimental years. This could not be explained in terms of leaf number, as the pruning treatments reduced leaf numbers by a factor of three compared to the unpruned trees during the first year. By the second year the pruned trees still had more leaves but the differences caused by the pruning treatment was no longer significant. Unfortunately, it was not possible to assess leaf area development over the course of the investigation (see section 5.5). Nevertheless, the dramatic increase in leaf area during both experimental years appears to cause some conflict, if the reason for pruning the trees was to reduce leaf area and thus the transpiration demand placed upon the truncated root system as suggested by many authors including Kozlowski (1975) and Harris (1975).

Shoot:root ratios were not ascertained for the reasons discussed in chapter 2. Root weight was unaffected by either the pruning or staking treatments during either the first year. Second year growth was again demonstrated to be unaffected by the pruning treatment. However, root growth was significantly affected by the staking treatment. The largest root growth was observed for the unstaked/unpruned trees. Increasing the size of the stake appeared to decrease the amount of root growth, although the differences were not significant. The action of swaying is known to increase the diameter growth of the root, the differences being noticable up to 1m from the base of the stem (Fayle 1968,1976,1978). This explanation would certainly account for the differences observed during this investigation.

This investigation clearly demonstrates the beneficial effects of pruning on the growth of *P x hispanica*. However it suggests that with normally prepared root systems some form of staking remains necessary if standard trees are being planted in exposed places. However it is likely that staking would not have been necessary if half standard trees had been used, as half standards which were unstaked in the same field remained in an upright position. It also indicates two area for further research. Firstly, how does dormant shoot pruning affect leaf area development over the course of the growing season? Secondly, do other species respond to dormant pruning in a similar manner as *P.x hispanica*? These are investigated in the following sections.

5.4 The effect of pruning on the progress of leaf area development of Platanus x hispanica.

5.4.1 Introduction

One of the major assumptions by those people advocating pruning upon planting is that shoot pruning will always result in a reduction in leaf area (Harris,1975) and therefore reduce the likelihood of drought stress. However few workers have specifically measured the effects of pruning on the progress of leaf area development. Maggs (1962) has shown that the shoots of a young tree act additively, so that each extra shoot results in an increase in leaf area. Hence it is not surprising that as pruning results in the removal of shoots,leaf areas will be reduced. Chandler (1919) found that pruning of 4 year old *Prunus persica* resulted in a reduction of leaf area by 43% when measured in June but by only 18% when measured in September. One year old *Malus domestica*, showed a reduction in leaf area with increasing levels of shoot pruning (Maggs,1959). Similarly, Chandler & Cornell (1952) state that leaf area will be invariably less on a dormant pruned tree than on an unpruned tree. However a totally opposite response to shoot pruning has been reported by Alderman & Auchter (1916), heavy and moderate dormant pruning of *M.domestica* resulted in increases in leaf areas of 73% and 38%, respectively compared to light pruning. Forshey & Marmo (1985) found that pruning 13 year old *M.domestica* trees had no effect upon total leaf area.

Other workers although not directly measuring leaf area have assessed the effect of pruning on leaf development by weighing. The validity of this measurement is open to question as Maggs (1959) found that the correlation between leaf area and final leaf dry weight depended on the growth habit of the tree. With trees where the shoots grew long, the correlation was highly significant, there was no correlation with trees where shoots remained short. But using this parameter Shoup, Reavis & Whitcombe (1981) conclude that 3 levels of shoot pruning, 15%, 30% or 45% had no effect on leaf development of *Quercus palustris, Cercis canadensis, Pyrus calleryana, Malus sp., Fraxinus pennsylvatica* or *Prunus serrulata*. Likewise, Evans & Klett (1985) found that branch thinning had a negligible effect on leaf production of *Prunus cerasifera*. However a 50% removal of branches resulted in a 31% reduction in leaf weight of *Malus sargentii* (Evans & Klett,1984). Pruning *Citrus sinensis* seedlings by one third increased leaf weight by 15%, but a decrease in leaf weight of 5% was recorded after pruning the shoot by two thirds.

This investigation therefore attempts to examine the development of leaf area of *Platanus x hispanica* after 3 levels of dormant shoot pruning.

5.5.2 Materials and Methods

Thirty six *Platanus x hispanica* (12 foot standards) were planted in February 1989 in four replicate blocks, so that each block contained 3 treatment plots of three trees.

The treatments included:

a) moderately pruned (by reducing the length of all branches by 50%)

b) heavily pruned (by removing all branches and heading back).

c) unpruned.

It was intended that the progress of leaf area development would be followed by measurement at three different times during the growing season, by removing the leaves from one tree per treatment plot per replicate block. The first measurement was taken at the end of May 1989, the second at the beginning of July 1989. Due to a combination of drought and a sudden summer storm during which time the remaining trees were defoliated, it proved impossible to take a third measurement. Leaf areas were measured on a 'Hayashi Denko AAM-5' area meter.

5.4.3 Results and Discussion

The merits of the investigation were reduced because of the lack of a full data set. However, a number of important observations were made. Firstly the unpruned trees developed leaf area more quickly than the pruned trees, so that early in the season (mid May), the unpruned trees had 1000% more leaf area than the severely pruned trees. The difference between the leaf areas of the unpruned and moderately pruned trees were less dramatic being only 15% greater in the unpruned trees (Tables 5.4.1 and 5.4.2).

By mid July, the leaf areas of the unpruned and moderately pruned trees had remained static from the mid May values, whilst the leaf areas of the severely pruned trees had increased by over 700%.

Although later values of leaf areas were unobtainable, it is known from a previous experiment using *Platanus x hispanica* (Section 5.3), that a moderate pruning treatment resulted in almost twice as much leaf area than unpruned trees, by the end of the growing season. This increase in leaf area following pruning was observable for at least two years following the pruning treatment, statistical analysis demonstrating that the results were highly ($P<0.01$) significant.

Other reports of leaf area development following shoot pruning suggest that early in the season, pruning results in reduced leaf area, as in the case of this investigation. Lasko (1984) reported similar results in so much as, unpruned and pruned *Malus domestica* at bloom had 32% and 18% of their final leaf area, respectively.

Table 5.4.1

The effects of pruning on the leaf area and leaf number development of *Platanus x hispanica* at two dates during the growing season.

Pruning Treatment	Leaf Area (cm^2)		Leaf Number	
	Mid May	Mid July	Mid May	Mid July
Unpruned	5365a	5256a	292a	142a
Moderate	4592a	4412a	215a	113a
Severe	536b	3894a	54a	100a

Mean separation within columns by LSD (5%). Thus means bearing the same letter are not significantly different.

Table 5.4.2

ANOVA of the leaf areas of *Platanus x hispanica* following different pruning treatments.

Harvest 1 (Mid May)

Source of Variation	D.F.	M.S.	F	P
Total	11			
Pruning Treatments	2	26908655.10	6.26	P<0.05
Error	9	4300505.17		

Harvest 2 (Mid July)

Source of Variation	D.F.	M.S.	F	P
Total	11			
Pruning Treatments	2	1891313.58	0.34	N.S.
Error	9	5626758.64		

Table 5.4.3

ANOVA of the leaf numbers of *Platanus x hispanica* following different pruning treatments.

Harvest 1 (Mid May)

Source of Variation	D.F.	M.S.	F	P
Total	11			
Pruning Treatments	2	59262.34	1.06	N.S.
Error	9	55649.52		

Harvest 2 (Mid July)

Source of Variation	D.F.	M.S.	F	P
Total	11			
Pruning Treatments	2	1849.34	0.42	N.S.
Error	9	4433.58		

Mika (1975) also found that pruning reduced leaf area early in the season but went on to show that pruning had no effect on final leaf area.

Leaf numbers were reduced by pruning and with increasing levels of severity of pruning (Tables 5.4.1 and 5.4.3), although the differences were shown not to be statistically significant. This is in general agreement with the findings of other workers eg. Gardner (1952), Harris (1975), Lasko (1984). By mid July, the mean leaf area for the unpruned, moderately and severely pruned trees were $37cm^2$, $39cm^2$ and $39cm^2$ respectively.

The results from this experiment and those from section 5.3, taken together, therefore suggest that whilst dormant shoot pruning reduces leaf area early in the growing season, the tree rapidly establishes a new crown and leaf area greater than an unpruned tree.

5.5 The effects of dormant pruning on the growth of *Acer platanoides*, *Fraxinus excelsior* and *Tilia cordata*.

5.5.1 Introduction

According to Maggs (1959) the general growth responses of trees to dormant winter pruning are fairly well established. Firstly the individual shoots arising from a pruned branch are larger than those from an unpruned branch. Secondly, despite the faster growth of individual shoots the pruned tree does not equal the unpruned tree in size, at the end of the growing season. Finally, for a given degree of pruning the size of the shoot growing from the pruned stem is positively correlated with the length of the stem before pruning.

The majority of the research on which these three conclusions are based have come from investigations using fruit trees particularly *Malus domestica* and *Pyrus communis* (see eg. Gardner, Bradford & Hooker,1952; Lockard,1956). This investigation attempts to elucidate if three species of trees commonly used for amenity purposes will respond in a similar manner to three levels of dormant shoot pruning.

A severe pruning treatment was included although it would not be used in the field as it completely disrupts the form of the tree to a far greater extent than the moderate pruning treatment. It was used to provide an extreme treatment for the investigation. But it must be noted that it is a standard planting treatment for *Platanus sp.* in China.

5.5.2 Materials and Methods

Twenty seven light standards (7 feet), nine each of *Acer platanoides, Fraxinus excelsior* and *Tilia cordata* were planted into 3 replicate blocks so that each block contained 3 trees of each species, randomly arranged. Planting took place during February 1989.

One tree of each species per block was then either moderately pruned (by reducing the length of all branches by 50%) or heavily pruned (by removing all branches and heading back) or left unpruned.

At the beginning of August 1989 the trees were harvested, using the JCB method of excavation (method 3 of chapter 2). Shoot and root dry weights were ascertained after drying in an oven at 90°C.

5.5.3 Results and Discussion

For all of the three species, pruning has shifted the distribution of shoot growth by stimulating many more shoots to become extension shoots rather than spur shoots (taken as 0-5cm), Figure 5.5.1. Responses between the species differed. The median shoot extension of *A.platanoides* increased from 5.7cm for the unpruned trees to 10.9 and 21.5cm for the moderately and severely pruned trees. The median shoot extension *T.cordata* following pruning treatments was not as responsive to pruning treatments as the other species , increasing from a value of 2.9cm for the unpruned trees to 3.5 and 7.9cm for the moderately and severely pruned trees respectively. With *F.excelsior* the median shoot extension increased from a value of 3.6cm for the unpruned trees to 6.5 and 11.1cm for the moderately and severely pruned trees respectively. This therefore agrees with the suggestion that individual shoots arising from a pruned branch are larger than those on an unpruned branch (Maggs,1959).

Overall, the effect of pruning of the three species has been to reduce the number of shoots extending (Tables 5.5.1-5.5.4), the differences being statistically significant ($P<0.05$) in the case of *F.excelsior* and *T.cordata*. This is not unexpected as pruning removed many buds. Differences in total shoot extension were also observed. With both *F.excelsior* and *A.platanoides* increasing severity of pruning led to increased shoot extension, although the differences are not statistically significant. Again this agrees with the conclusion of Maggs (1959) that for a given degree of pruning, the size of the shoot growing from the pruned stem is positively correlated with the length of the stem before pruning. However, this was not the case with *T.cordata* where, although the most severe

Figure 5.5.1 Frequency distribution of the extending shoots of *Acer platanoides*, *Tilia cordata* & *Fraxinus excelsior* following dormant pruning treatments

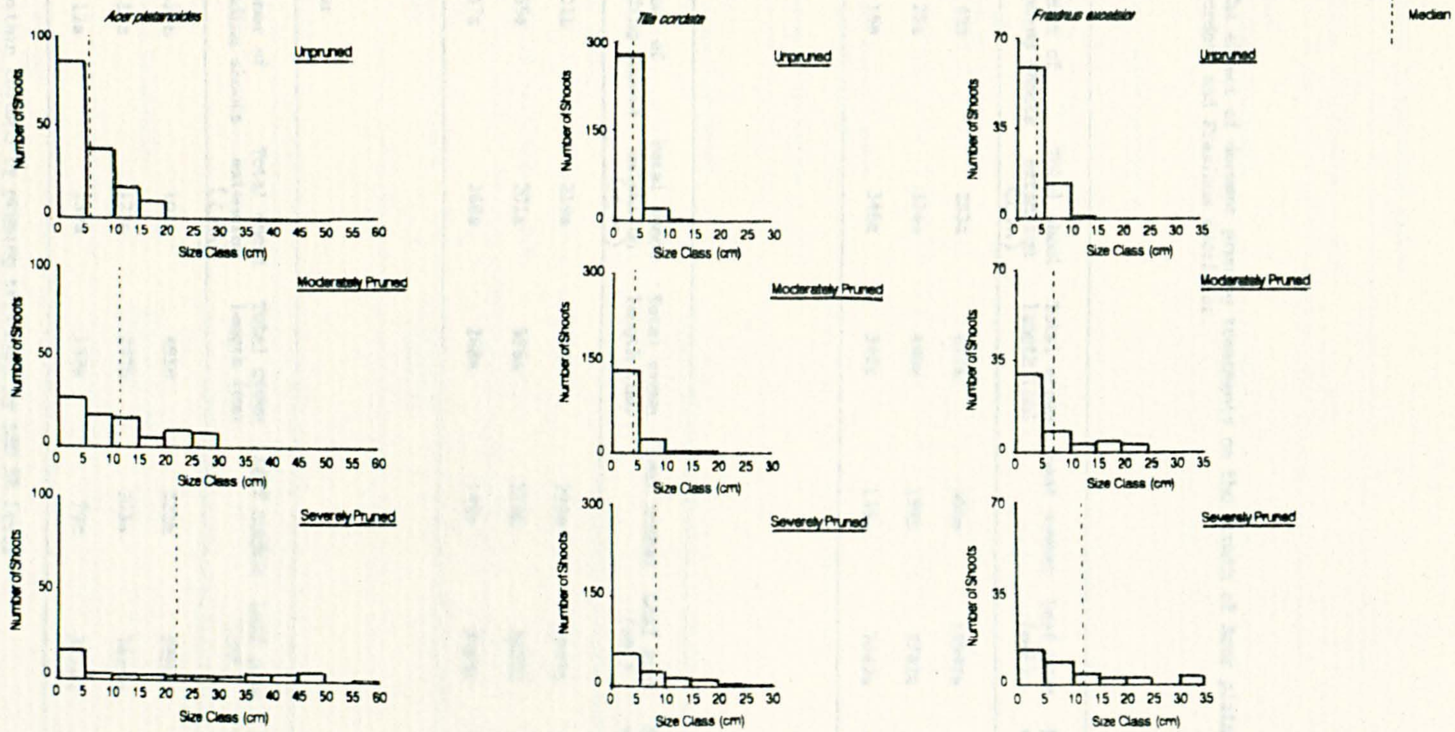


Table 5.5.1 The effect of dormant pruning treatments on the growth of *Acer platanoides*, *Tilia cordata* and *Fraxinus excelsior*.

Acer platanoides

Pruning treatment	Number of extending shoots	Total shoot extension (cm)	Total crown length (cm)	Leaf number	Leaf area (cm^2)	Root dry weight (g)
Unpruned	49a	283a	677a	308a	13597a	189.72a
Moderate	28a	324a	490a	196a	9742a	166.15a
Severe	16a	346a	346a	139a	7042a	121.71a

Tilia cordata

Pruning treatment	Number of extending shoots	Total shoot extension (cm)	Total crown length (cm)	Leaf number	Leaf area (cm^2)	Root dry weight (g)
Unpruned	101b	219a	1504b	282a	2993a	190.17a
Moderate	55a	201a	586a	116a	2809a	212.60a
Severe	37a	268a	268a	147a	3088a	208.12a

Fraxinus excelsior

Pruning treatment	Number of extending shoots	Total shoot extension (cm)	Total crown length (cm)	Leaf number	Leaf area (cm^2)	Root dry weight (g)
Unpruned	25b	101a	481c	222a	5900b	218.12a
Moderate	16a	123a	297b	203a	7816c	257.71a
Severe	12a	132a	132a	79c	3278a	157.05a

Mean separation within columns by pruning treatment by LSD 5% level

Table 5.5.2

ANOVA of the effects of pruning treatments on the growth of *Acer platanoides*.

Number of extending shoots

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	858.34	4.87	N.S.
Error	6	176.22		

Total shoot extension

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	3032.44	0.28	N.S.
Error	6	10709.22		

Total crown length

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	77719.11	1.61	N.S.
Error	6	48351.22		

Leaf number

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	22026.78	5.57	<0.05
Error	6	3952.33		

Leaf area

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	32559525.00	3.16	N.S.
Error	6	10318560.30		

Root Weight

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	3577.16	0.93	N.S.
Error	6	3836.67		

Table 5.5.3

ANOVA of the effects of pruning treatments on the growth of *Tilia cordata*.

Number of extending shoots

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	3295.45	5.72	<0.05
Error	6	575.78		

Total shoot extension

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	3596.78	0.38	N.S.
Error	6	9520.78		

Total crown length

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	1235054.12	44.68	<0.01
Error	6	27645.11		

Leaf number

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	23302.11	2.36	N.S.
Error	6	9885.00		

Leaf area

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	60515.42	0.03	N.S.
Error	6	1988652.23		

Root Weight

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	422.78	0.24	N.S.
Error	6	1744.78		

Table 5.5.4

ANOVA of the effects of pruning treatments on the growth of *Fraxinus excelsior*.

Number of extending shoots

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	125.78	7.08	<0.05
Error	6	17.78		

Total shoot extension

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	724.11	0.93	N.S.
Error	6	775.89		

Total crown length

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	91625.33	31.12	<0.01
Error	6	2944.22		

Leaf number

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	18217.33	10.66	<0.05
Error	6	1708.56		

Leaf area

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	15567070.30	26.53	<0.01
Error	6	586667.23		

Root Weight

Source of Variation	D.F.	M.S.	F	P
Total	8			
Pruning Treatments	2	7714.68	1.45	N.S.
Error	6	5314.76		

pruning treatment led to increased shoot extension, the moderate pruning treatment resulted in less shoot extension than the unpruned control. Although again these differences were not statistically significant.

Maggs (1959) also suggests that despite the faster growth rate of individual shoots the pruned tree does not equal the size of the unpruned tree at the end of the growing season. The results of this investigation agree with this conclusion.

As was discussed in greater detail in the preceding section of this chapter (section 5.4), an assumption made by those people who advocate pruning is that it will result in a reduction in leaf area (Harris, 1983). Certainly in this investigation pruning reduced the number of leaves. Leaf area development differed between species. With *F.excelsior*, the moderate pruning treatment resulted in a significant ($P<0.01$) increase in leaf area, whilst the severe pruning treatment resulted in significantly reduced leaf area ($P<0.01$). Increasing severity of pruning of *A.platanoides*, resulted in reduced leaf area although the differences proved not to be statistically significant. With *T.cordata* there appeared to be little effect of pruning in terms of leaf area development.

To be a useful tool to aid tree establishment however, pruning must either be beneficial or have no effect on root growth. In previous sections of this chapter it has demonstrated that root growth was unaffected by dormant shoot pruning. With *T.cordata* both pruning treatments resulted in greater root growth than the unpruned control, whilst with *A.platanoides* root weight decreased with increasing levels of pruning. Root weight of *F.excelsior* was greater following the moderate pruning treatment, but was reduced by the severe pruning treatment compared to the controls. But none of these differences were statistically significant.

Shoot:root ratios were not calculated because, as Evans & Klett (1984) have discussed, the value of this parameter is reduced with larger trees, as an indication of the relative size of surfaces for root water absorption and shoot transpiration, because of the dramatic increase in woody tissue with increasing tree size.

There therefore were discernible differences in the responses of the three species to pruning treatments and care must be exerted in extrapolation of published results from one species to another. Whilst shoot growth is generally enhanced by dormant pruning practices, the effect on root growth appears not only to be species dependent but dependent upon the degree of pruning. This therefore suggests that the common practice of reducing the crown of the tree on planting justifies further research. Greater replication if practicable might have been useful as it is believed that trends were masked because of variance in the material used.

5.6 Conclusion

These results have certain implications when considered in respect of tree establishment. It has been demonstrated that the soil water reserves available to the newly planted tree are limited (chapter 4), the situation being most severe during the very early part of the growing season when the rooting volume is at a minimum. These investigations have shown that pruning results in reduced leaf area development during this period. This should result in less transpiration demand being placed upon the truncated root system.

However it has been shown that leaf area development will quickly recover and depending on the species, may be greater by the middle of the growing season than unpruned trees and more importantly, that dormant pruning had no effect on the water relations of the tree as assessed by stomatal resistances. More over no interaction between drought and pruning was observed, which would be expected if pruning is capable of reducing the effects of drought.

That advantages of a moderate dormant pruning treatment at planting on shoot growth have been demonstrated. It has been shown that individual shoots arising from a pruned branch are larger than those on an unpruned branch. Despite the faster growth, the pruned tree do not equal the size of the unpruned tree by the end of the growing season and for a given degree of pruning the size of the shoot growing from the pruned stem is positively correlated with the length of stem before pruning.

The effects of pruning on root growth appear to be species specific. However, in general a moderate pruning treatment will not detrimentally affect root development. In contrast summer pruning restricted root development. Where shoot:root ratios were expressed, neither dormant or summer pruning had any effect.

The results therefore suggest that the common assumption that dormant shoot pruning at planting reduces transplanting stress is not true. However, there is no doubt that a moderate pruning treatment does lead to more vigorous shoot growth which is not achieved at the expense of root development. Thus, there appears to be no reason why the common practice of pruning on planting should not continue.

Chapter 6

The Effects of Fertiliser Addition on the Growth of Establishing Trees

6.1 Introduction

As an agricultural principal the benefits of fertilisation have been recognised for centuries. Yet the development of fertilisation practices of tree crops is relatively recent and falls basically into three phases. The first investigations considered the use of fertiliser addition to enhance the growth of forest trees, with research being begun as early as the middle half of the last century. By the 1920's many of the findings had started to be applied to orchard trees until today where the use of fertilisers in commercial softwood forestry and orchard management is now accepted and widespread. The third phase involved investigating the responses of broadleaf trees used for amenity purposes. Research in this field was begun in the 1930's in the USA, where even today the majority of this work is carried out (Capel,1980).

Thus there is over a century's worth of literature on the use of fertilisers on tree crops. However a lot of the information is not interchangeable between the three disciplines of forestry, fruit production and arboriculture. This is because each has a different aim: the forester will be trying to increase stem volume of established mature trees, the fruit producer will be aiming to increase cropping of mature trees, whilst to the arboriculturist the main provision is for the improved appearance and growth of often newly planted trees.

Although there is now a wealth of information pertaining to the nutrient requirements of particular species, many of these studies have been conducted by investigating ion uptake in solution culture (eg. McDonald, Lohammar & Ericsson,1986; Ingestadt & Lund,1979; Philipson & Coutts,1977). Bowen (1981) regards these studies as almost irrelevant to the soil situation, as in soil the limiting step is not usually the relative absorbing ability of the roots but the transfer of ions from soil to root, thus root abundance is a parameter of primary importance.

Bowen (1981) has suggested a simple model of tree growth and nutrition (Figure 6.1.1). The main determinant of ion absorption from the soil is root length. Thus the greatly truncated root system of the transplanted tree is likely to have important consequences on not only the water but also the nutrient supply to the tree (see chapter 4).

As Smith and Gilliam (1979) have pointed out, fertilisers are not a substitute for water and light but make up a portion of the environmental factors that must be in balance if the landscape plants are to fully develop.

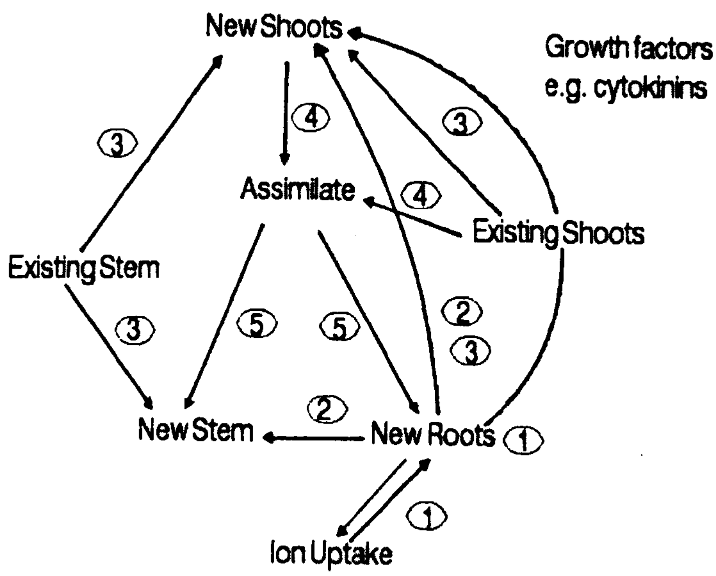
There are a number of different methods of fertilising trees. Harris (1983) lists five such methods.

- broadcast on the soil surface.
- placed in holes in the soil.
- injected into the soil in solution under pressure.
- sprayed on foliage.
- injected into or placed in holes in tree trunks.

The latter two methods, although effective in quickly correcting micronutrient deficiency in established trees, have a number of drawbacks which limit their wide scale use with amenity trees.

Figure 6.1.1

A simple model of tree growth and nutrition (from Bowen, 1981)



1. Ion uptake influenced by root abundance.
2. Distribution of recently absorbed nutrients to shoots and stems.
3. Redistribution of nutrients from existing shoots, stems and roots.
4. Assimilate production from new and older leaves.
5. Distribution of assimilate in the tree and its conversion to root and stem tissue.

Firstly, spraying may damage non targeted plants. Secondly, injection of nutrients requires a great deal of skill and time, and can lead to decay around insertion sites, if improperly performed.

Injecting nutrients into the soil under pressure, as discussed by Bernatzky (1978), is an ideal method of supplying nutrients in situations where the rooting zone of the tree is covered and surface application would be impossible eg. a street tree. According to Hamilton *et al.* (1981) surface application is the easiest method and can be maximally effective for nitrogen and most chelated micronutrient fertilisers, whilst soil incorporation into the rooting zone allows nutrients of low solubility to be more readily available to the tree.

There is no clear information as to the benefits or otherwise, of fertilising newly planted amenity trees. Gilbertson (1987) reports that fertiliser amendment is of no great benefit during the first few years following transplanting. However, Capel (1980) whilst demonstrating responses to nutrient amendment in the urban environment, suggests that the level of response varies, with both the type of substrate and the species used.

This series of investigations examines the responses of two species of trees, *Acer pseudoplatanus* and *Fraxinus excelsior*, to nutrient addition. Different rates and formulations of fertiliser were examined (section 6.2), as well as different methods of application (section 6.3) and the effects of applying nutrients to the soil at different times of the year (section 6.4). Finally to maximise the possible effects of fertilisation, the effects of nutrient addition in combination with irrigation and dormant pruning on the growth of

A.pseudoplatanus were examined (section 6.5). Due to a degree of similarity of the results, discussion of them is left to the end of the chapter.

6.2 Addition of different types of fertiliser on the growth of *Fraxinus excelsior*

6.2.1 Introduction

Nitrogen, phosphorus and potassium are essential nutrients for tree growth. It has often been assumed that each affects different parts of the tree eg. Van de Werken (1981) suggests that nitrogen stimulates vegetative development, high phosphorus supports bud development and fruit set, whilst high potassium improves fruit colour and increased sugar content. However, Kendle (1988) showed that root growth was as responsive as shoot growth, to nitrogen addition growing on china clay waste.

This investigation examined the effects of each of these nutrients, singly and in combination, on the growth of the newly planted tree.

6.2.2 Materials and Methods

Five hundred and seventy six *Fraxinus excelsior* (1+2) transplants were planted in February 1987 into a randomised block design. There were 4 blocks and 24 treatment plots per block. Hence each treatment plot consisted of 6 trees. Two treatment plots in each block (to be harvested in separate years) received one of the following fertiliser treatments:

control	NP	0.5N
N	NK	2N
P	PK	0.5NPK
K	NPK	2NPK

The rates of application were as follows:

N - 150 Kg ha^{-1} in the form of 'Nitram'
P - 50 Kg ha^{-1} in the form of superphosphate
K - 50 Kg ha^{-1} in the from of potash

The nitrogen application was given as three split doses in May, June and July of each year. The potassium and phosphorus applications were given as a single dose in the May of both experimental years.

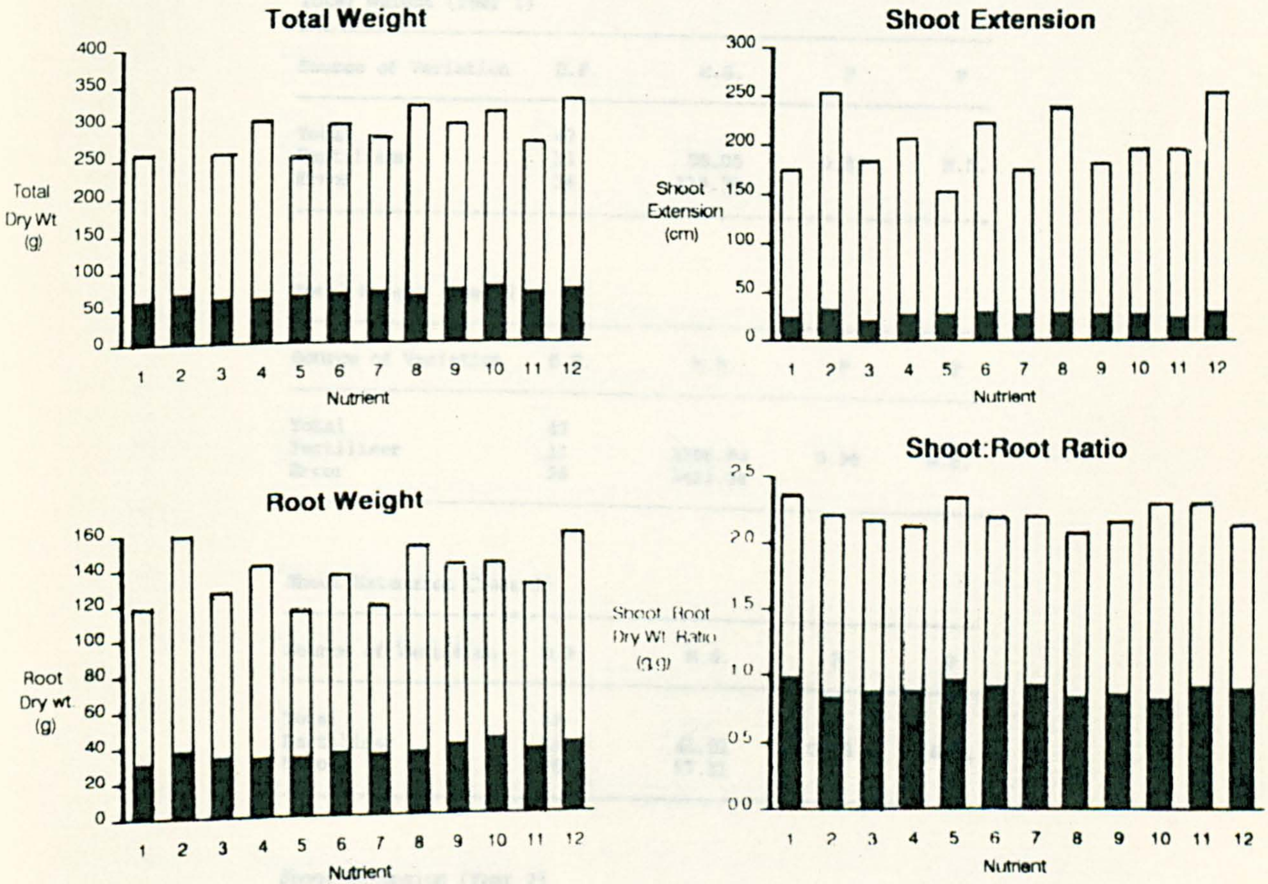
The plots were kept weed free by spraying with paraquat. Two harvests were taken, the first at the end of September 1987 and the second in December 1988. The first harvest was hand dug (method 1 of Chapter 2), the second utilised the JCB method (method 3 of Chapter 2). The dry weights of the trees were ascertained after drying in an oven at 90°C.

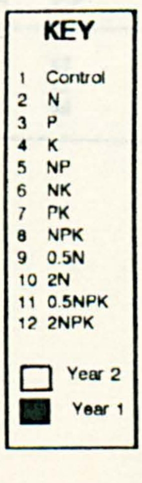
6.3 Results

Quite unexpectedly there appeared to be no clear differences in the growth responses of *F.excelsior* to the different fertiliser regimes (Figure 6.2.1). Analysis of variance (Table 6.2.1) demonstrates that none of the fertiliser treatments had any significant effect on any of the growth parameters measured during either the first or second years. There was no mortality of the planting stock throughout the course of the experiment.

Some trends were apparent from the results. All the fertiliser combinations which included nitrogen enhanced total, shoot and root weights and lead to a reduction in the shoot:root ratio, with the exception of the NP treatment. Similar growth enhancements were also apparent for all fertiliser combinations which included potassium, although the PK treatment proved to be the exception, having little effect on shoot extension or root growth.

Figure 6.2.1 The effects of nutrient addition on the growth of *Fraxinus excelsior*





Standard errors are not shown as none of the treatments differ significantly.

Table 6.2.1

ANOVA of the effects of different fertiliser treatments on the growth of *Fraxinus excelsior*.

Total Weight (Year 1)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	98.05	0.82	N.S.
Error	36	119.70		

Total Weight (Year 2)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	3286.83	0.96	N.S.
Error	36	3422.08		

Shoot Extension (Year 1)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	41.91	0.73	N.S.
Error	36	57.31		

Shoot Extension (Year 2)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	3895.60	0.93	N.S.
Error	36	4171.23		

Table 6.2.1 continued

ANOVA of the effects of different fertiliser treatments on the growth of *Fraxinus excelsior*.

Root Weight (Year 1)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	42.43	1.79	N.S.
Error	36	23.76		

Root Weight (Year 2)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	687.11	1.02	N.S.
Error	36	674.74		

Shoot:Root Ratio (Year 1)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	0.010	0.714	N.S.
Error	36	0.014		

Shoot:Root Ratio (Year 2)

Source of Variation	D.F.	M.S.	F	P
Total	47			
Fertiliser	11	0.021	0.553	N.S.
Error	36	0.038		

Variation between the treatments for the growth parameters measured was relatively small during the first year but increased dramatically during the second growing season.

6.3 The effects of two commercial slow release fertilisers on the growth of *Acer pseudoplatanus*

6.3.1 Introduction

Since it was demonstrated in the previous investigation, that surface application of nutrients failed to significantly affect the growth of newly planted *Fraxinus excelsior* transplants, it was decided to examine the response of a different species (*Acer pseudoplatanus*), to nutrient addition and to use two different methods of application (surface and sub-surface). *Acer pseudoplatanus* was chosen as it has been demonstrated to be particularly responsive to nutrient addition (Capel,1980).

The two slow release commercial fertilisers used were 'Osmocote' and 'Growstix'. Both were 17:10:10 fertilisers with suggested release times of 12-14 months for 'Osmocote' and 6 months for 'Growstix'. 'Osmocote' was in the form of resin coated granules, whilst 'Growstix' was a resin bound fertiliser contained within a cardboard spike that could be hammered into the soil around the tree.

6.3.2 Materials and methods

Forty five *Acer pseudoplatanus* (6' half standards) were planted and staked during the spring of 1987 into a randomised block design consisting of 3 replicate blocks of 5 treatments plots per block, with 3 trees per plot. Each treatment consisted of one of the following:

2 'Growstix' per tree
4 'Growstix' per tree
70g 'Osmocote' per tree (equivalent weight to one 'Growstix')
140g 'Osmocote' per tree (equivalent weight to two 'Growstix')
no fertiliser addition

Two 'Growstix' per tree was the recommended dose for the size of the tree used in this investigation and each 'Growstix' was comprised of 70g of 17:10:10 fertiliser. Hence the choice of 70g of 17:10:10 'Osmocote' as the single 'Osmocote' dose.

The 'Growstix' were inserted into the ground beneath the drip line of the tree, the 'Osmocote' was applied as a surface dressing. The fertiliser treatments were given before the trees had leafed out in the spring of both 1987 and 1988. Using the high pressure water jet technique (method 2 of Chapter 2), the trees were excavated during the winter of 1988. Growth parameters were ascertained after drying in an oven at 90°C.

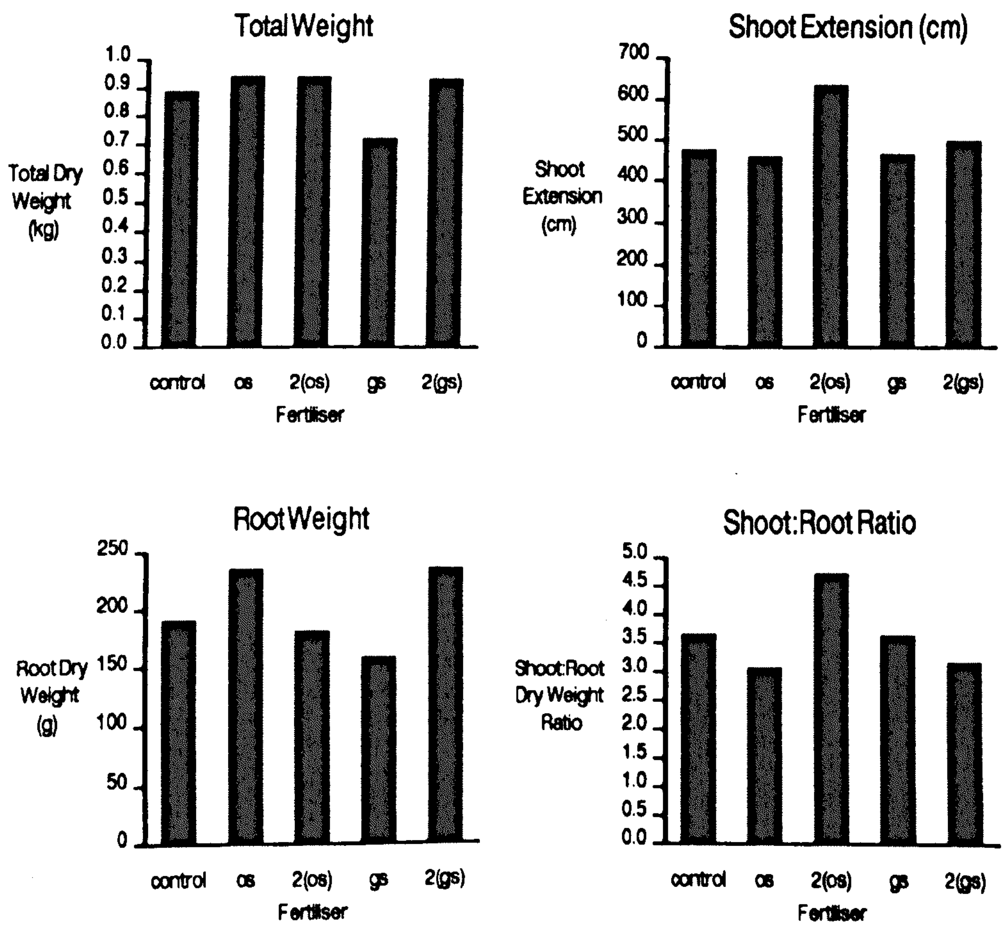
6.3.3 Results

Analysis of variance (Table 6.3.1) demonstrates that none of the fertiliser treatments had any statistically significant effect on the growth of *A.pseudoplatanus*. There were however large variations for the growth parameters measured, between the various treatments (Figure 6.3.1), but no logical pattern of response was apparent.

Total weight was relatively unaffected by fertiliser treatments with the exception of the normal 'Growstix' dose where total weight was 20% less than the control. Shoot extension again was similar, in all the fertiliser treatments, with the exception of the double

Figure 6.3.1

The effects of two commercial fertilisers, Osmocote and Growstix on the growth of *Acer pseudoplatanus*.



KEY

control - no fertiliser addition
os - 70g osmocote (surface dressing)
2(os) - 140g osmocote (surface dressing)
gs - 2 growstix (inserted into soil)
2(gs) - 4 growstix (inserted into soil)

Standard errors are not shown as none of the treatments differ significantly

Table 6.3.1

ANOVA of the effects of two commercial fertilisers, 'Osmocote' or 'Growstix' on the growth of *Acer pseudoplatanus*.

Total Weight

Source of Variation	D.F.	M.S.	F	P
Total	14			
Fertiliser	4	27468.99	0.47	N.S.
Error	10	57996.75		

Shoot Extension

Source of Variation	D.F.	M.S.	F	P
Total	14			
Fertiliser	4	16056.24	0.41	N.S.
Error	10	39456.42		

Root Weight

Source of Variation	D.F.	M.S.	F	P
Total	14			
Fertiliser	4	3439.60	1.94	N.S.
Error	10	1776.93		

Shoot:Root Ratio

Source of Variation	D.F.	M.S.	F	P
Total	14			
Fertiliser	4	1.28	2.72	N.S.
Error	10	0.47		

'Osmocote' dose where shoot extension was 34% greater than the control.

The 'Growstix' and double 'Osmocote' treatments resulted in less root growth, 16% and 5% less than the control respectively, whilst the double 'Growstix' and single dose 'Osmocote' treatment enhanced root growth by 25% and 24% respectively, compared to the control. Shoot:root ratios varied greatly between the fertiliser treatments. The single 'Growstix' dose had little effect on the shoot:root ratio, whilst the double 'Growstix' dose showed a reduction of 14% compared to the control. The 'Osmocote' treatment also led to a reduction in the shoot:root ratio by 16% whilst the double 'Osmocote' treatment increased the shoot:root ratio by 29%.

6.4 The effects of nutrient addition at different times of the year on the growth of *Acer pseudoplatanus*.

6.4.1 Introduction

There are a number of reports in the literature suggesting that the timing of fertiliser application may be an important factor governing the response of the trees to nutrient addition. Some workers recommend autumn application (Smith,1978) whilst others suggest spring or summer applications (Delap,1967).

This investigation, carried out in parallel with the previous one, was designed to elucidate the response of newly planted *Acer pseudoplatanus* transplants to nutrient addition at different times of the year. Again *Acer pseudoplatanus* was chosen as it is known to be responsive to nutrient amendment (Capel,1980).

6.4.2 Materials and Methods

Three hundred and eighty four *Acer pseudoplatanus* (1+1) transplants were planted, during the winter of 1987, into a randomised block design consisting of 4 replicate blocks with 16 treatments plots per block. There were 6 trees per treatment plot. The treatments consisted of applying fertiliser during each of the four seasons and all factorial arrangements of the seasons. A control treatment where no nutrients were added was included in the design. The seasons were defined for this experiment as:

Spring - March, April, May.
Summer - June, July, August.
Autumn - September, October, November.
Winter - December, January , February

The total rates of fertiliser application were as follows:

N - 150 Kg ha^{-1} as 'Nitram'
P - 50 Kg ha^{-1} as superphosphate
K - 50 Kg Ha^{-1} as potash

Potassium and phosphorus were given as single doses during the first month of each season. Nitrogen was given as a split dose during each month of the season. For example, the treatment requiring nutrient addition during all four seasons of the year, involved 4 applications of potassium and phosphorus (at 1/4 of the total rate) and 12 applications of nitrogen (at 1/12 of the total rate). The fertiliser treatments were begun in the spring of 1988.

The trees were harvested during June of 1989 by hand digging (method 1 of Chapter 2). Growth parameters were ascertained after drying in an oven at 90°C.

In order that these results might be compared if required to the results from the investigation described in section 6.5 (the effects of pruning, nutrient addition and irrigation on the growth of

A.pseudoplatanus) where the trees were harvested in a dormant condition, leaf weight has not been included in the total weight but has been reported separately.

6.4.3 Results

Although statistically significant differences between the treatments were again not apparent (Table 6.4.1), large variation in response to nutrient addition was observed (Figure 6.4.1). The greatest responses were observed after the spring/summer and spring/autumn applications for all the growth parameters measured apart from the shoot:root ratio. Increases in the growth parameters measured were also noted after the spring/summer/autumn, spring/summer/winter and spring/autumn/winter applications. All the growth parameters measured with the exception of the shoot:root ratio were less than the control value after spring application. Of all the single season applications only summer application increased growth responses.

It is difficult to see any obvious pattern of response emerging, particularly if the treatments are compared not only with the control but also with each other, and could well be just the effect of error.

6.5 The effects of nutrient addition, pruning and irrigation on the growth of *Acer pseudoplatanus*

6.5.1 Introduction

The availability of nutrients to the tree is dependent upon the soil solution. Thus any factor that disrupts the soil solution such as

Figure 6.4.1

The Effects of Applying Nutrients at Different Times of the Year on the Growth of *Acer pseudoplatanus*

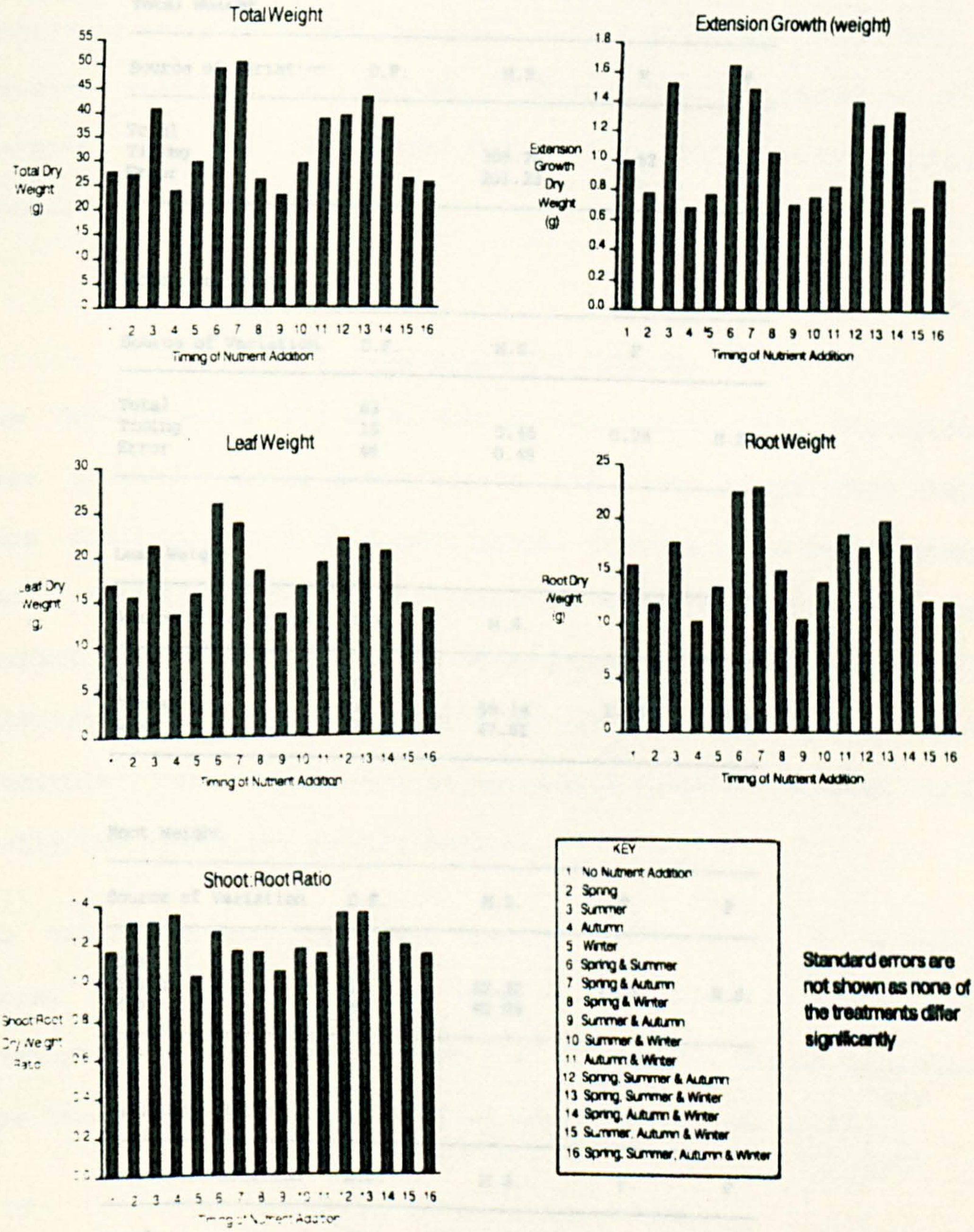


Table 6.4.1

ANOVA of the effects of applying fertiliser at different times of the year on the growth of *Acer pseudoplatanus*.

Total Weight

Source of Variation	D.F.	M.S.	F	P
Total	63			
Timing	15	305.28	1.52	N.S.
Error	48	201.23		

Extension Growth

Source of Variation	D.F.	M.S.	F	P
Total	63			
Timing	15	0.46	0.96	N.S.
Error	48	0.48		

Leaf Weight

Source of Variation	D.F.	M.S.	F	P
Total	63			
Timing	15	59.14	1.24	N.S.
Error	48	47.61		

Root Weight

Source of Variation	D.F.	M.S.	F	P
Total	63			
Timing	15	62.30	1.55	N.S.
Error	48	40.09		

Shoot:Root Ratio

Source of Variation	D.F.	M.S.	F	P
Total	63			
Timing	15	0.028	0.622	N.S.
Error	48	0.045		

drought will inevitably affect the nutrient supply to the tree (Russell,1988; Kramer & Kozlowski,1979; Goode,1974). In order to investigate if any interaction existed between the supply of water and response to nutrient addition by trees, and therefore if in practice, tree growth would only be maximised if both water and nutrients are given, the following investigation was undertaken. A pruning treatment was included to investigate the removal of stem material and the consequent reduction in the storage nitrogen content of the transplant.

6.5.2 Materials and methods

Two hundred and eighty eight *Acer pseudoplatanus* (1+1) transplants were planted, during the winter of 1987, into 3 replicates blocks each consisting of 8 treatments plots, with 12 trees per treatment plot. The treatments were a factorial arrangement of 2 levels of dormant shoot pruning (unpruned or pruned by 50%), 2 levels of nutrient addition (none or 70 gm^{-2} of 12-14 month release 17:10:10 'Osmocote') and two levels of irrigation (none or watered twice weekly throughout the growing season).

The experiment was kept weed free by applications of paraquat. During the winter of 1988 the trees were harvested using the high pressure water jet method (method 2 of Chapter 3). Growth parameters were determined as dry weight after drying in an oven at 90°C.

6.5.2 Results

A response to fertiliser addition in terms of shoot extension was apparent ($P<0.01$), regardless of either the pruning or watering treatment (Figure 6.5.1). The other growth parameters were unaffected by fertiliser addition. Pruning also resulted in a significant ($P<0.05$) increase in shoot extension (Table 6.5.1).

The only other statistically significant response observed was a reduction in the total weight of the plant following the pruning treatment ($P<0.05$). Although not significant, a reduction in root growth of the pruned trees regardless of fertiliser or irrigation treatments was also apparent. It was shown in chapter 6, that in general, a moderate dormant shoot pruning treatment has a negligible effect on root growth and may indeed lead to slightly increased root growth, although the response may be species dependent.

6.6 Discussion

This series of investigations has demonstrated a general lack of response by newly planted trees to nutrient addition. *Fraxinus excelsior* transplants showed no response to amendment with different combinations of both high and low levels of nitrogen, potassium and phosphorus. The growth of *Acer pseudoplatanus* (half standards) was unaffected by fertilisation with two commercial slow release fertilisers, and the growth of *A. pseudoplatanus* transplants was not enhanced by nutrient amendment at different times of the year. Only in one experiment, investigating the effects of nutrient addition, pruning and irrigation both alone and in combination on the growth of *A.pseudoplatanus* transplants, was an enhancement of growth observed as a result of nutrient addition.

There are a number of possible reasons that could explain the general lack of response that was observed. These can generally be

Figure 6.5.1

The effects of fertiliser addition, pruning and irrigation on the growth of *Acer pseudoplatanus*

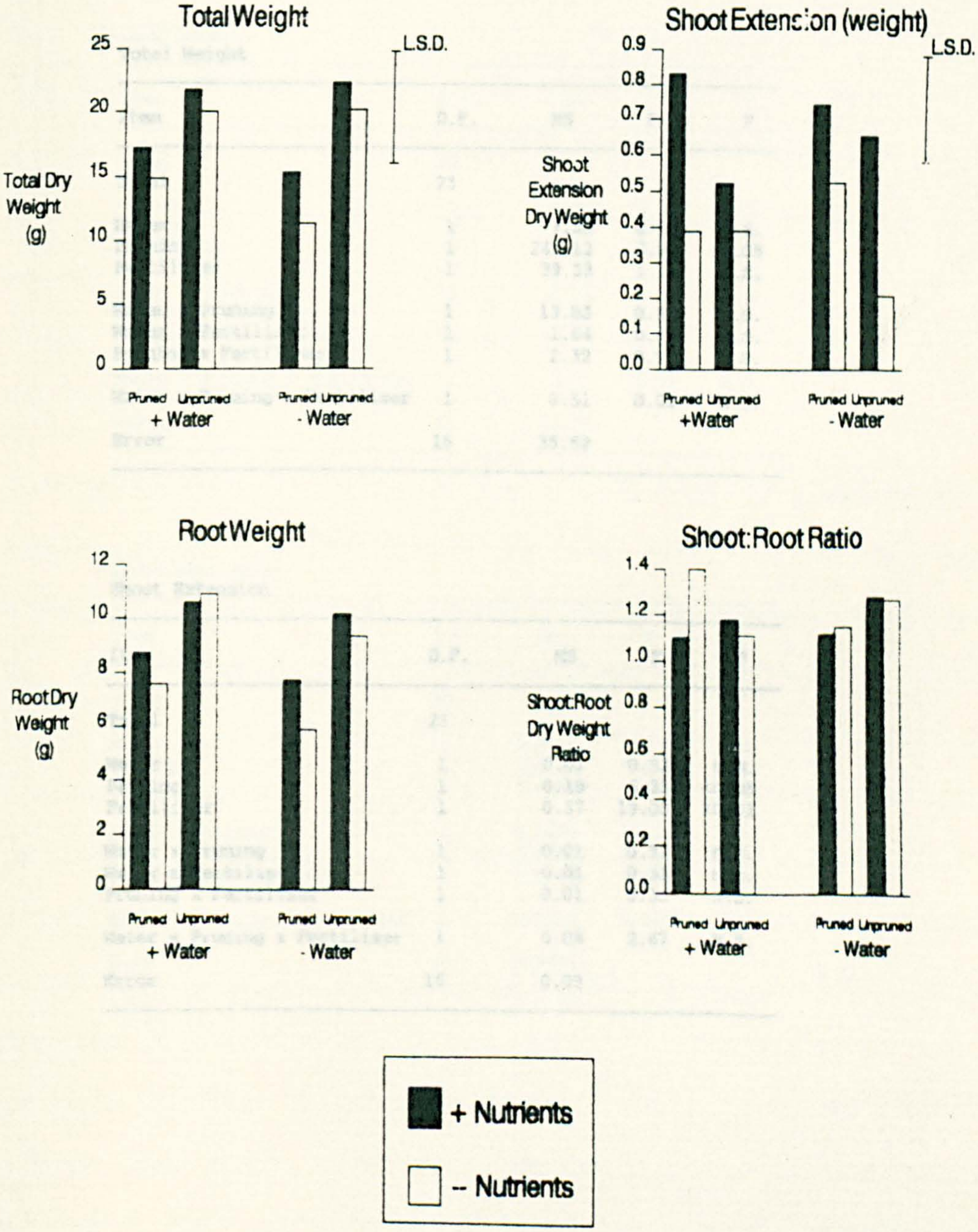


Table 6.5.1

ANOVA of the effects of pruning, fertiliser and watering treatments on the growth of *Acer pseudoplatanus*.

Total Weight

Item	D.F.	MS	F	P
Total	23			
Water	1	7.80	0.22	N.S.
Pruning	1	245.12	6.90	<0.05
Fertiliser	1	39.53	1.11	N.S.
Water x Pruning	1	13.83	0.39	N.S.
Water x Fertiliser	1	1.64	0.05	N.S.
Pruning x Fertiliser	1	2.32	0.07	N.S.
Water x Pruning x Fertiliser	1	0.51	0.01	N.S.
Error	16	35.52		

Shoot Extension

Item	D.F.	MS	F	P
Total	23			
Water	1	0.01	0.33	N.S.
Pruning	1	0.19	6.33	<0.05
Fertiliser	1	0.57	19.00	<0.01
Water x Pruning	1	0.01	0.33	N.S.
Water x Fertiliser	1	0.01	0.33	N.S.
Pruning x Fertiliser	1	0.01	0.33	N.S.
Water x Pruning x Fertiliser	1	0.08	2.67	N.S.
Error	16	0.03		

Table 6.5.1 continued

ANOVA of the effects of pruning, fertiliser and watering treatments on the growth of *Acer pseudoplatanus*.

Root Weight

Item	D.F.	MS	F	P
Total	23			
Water	1	8.02	0.67	N.S.
Pruning	1	46.29	3.87	N.S.
Fertiliser	1	4.60	0.38	N.S.
Water x Pruning	1	0.21	0.02	N.S.
Water x Fertiliser	1	1.27	0.11	N.S.
Pruning x Fertiliser	1	2.32	0.19	N.S.
Water x Pruning x Fertiliser	1	0.11	0.01	N.S.
Error	16	11.96		

Shoot:Root Ratio

Item	D.F.	MS	F	P
Total	23			
Water	1	0.0004	0.0045	N.S.
Pruning	1	0.0020	0.0227	N.S.
Fertiliser	1	0.0204	0.2315	N.S.
Water x Pruning	1	0.0880	1.0000	N.S.
Water x Fertiliser	1	0.0080	0.0910	N.S.
Pruning x Fertiliser	1	0.0580	0.6580	N.S.
Water x Pruning x Fertiliser	1	0.0514	0.583	N.S.
Error	16	0.0882		

split into two groups, those involving edaphic factors and those endogenous factors that influence the growth of the tree itself.

Perhaps the principle edaphic factor that could affect the trees response to nutrient amendment is the nutrient reserves within the soil itself. Although mineralisable nitrogen was not measured in the experimental soil used, total nitrogen was measured being 435 +/- 10 ppm which compares with 1027 ppm for a good garden soil or 480 ppm on a typical urban site (Dutton & Bradshaw,1982). It was assumed prior to planting that the site was relatively nutrient poor, as growth responses had been observed in the past by another worker (Capel, 1980). However the site had been an agricultural field and although total nitrogen was low, mineralisable nitrogen may have been high and adequate for tree growth.

A further edaphic factor that could influence the response of the trees to fertiliser addition is the water status of the soil (Kramer & Kozlowski, 1979). Summer droughts, have been shown to limit growth so seriously that little or no growth can be obtained by applying fertiliser (Goode,1974). This was the reason for including an irrigation treatment in section 6.5. However no interaction between irrigation and nutrient addition was observed. The reasons for drought affecting the response of the tree to nutrient amendment appear obvious, as plant roots absorb nutrients from the soil solution and the composition of the soil solution depends on the moisture content of the soil (Russell,1988). Hence Mason (1958) showed that *Malus domestica* absorbed more of the five major nutrients when the soil was maintained in a moist condition than when it was allowed to dry out. Root factors such as morphology and extension growth may be involved, but in addition the translocation of nutrients in the soil towards the root surface is known to be severely impeded under droughted conditions (Wiersum,1969).

Any factor that leads to injury of the root system can also seriously affect mineral absorption and therefore the response of the tree to nutrient addition. Hence other edaphic factors, such as waterlogging of the soil (Bernatzky,1978), attacks by nematodes or pathogenic fungi (Harris,1983) or soil compaction which leads to a reduction in the mean pore size of the soil, and changes in aeration and water status (Craul,1985) can all affect the trees response to nutrient addition. These factors can generally be disregarded as explanations for the different responses observed during these investigations, as the experiments were conducted in an uncompacted, freely draining, sandy loam soil. There was no evidence of pathogenic attack either during the growing season or when the plants were harvested.

Weed competition has also been demonstrated to significantly affect the trees responses to nutrient addition and this is discussed in detail in chapter 7. It would not have operated in these nutrient experiments because weed control was carried out.

Turning to the endogenous factors of the tree itself that could affect the response to nutrient amendment, these include the size of the root system and the importance of stored nitrogen.

It has been demonstrated in a previous experiment (Chapter 4) that the size of the root system has an important influence upon the volume of water available to the tree, and therefore presumably, also the amount of nutrients. A number of reports suggest that the size of the root system is of importance in determining the effects of fertiliser amendment on tree growth (eg. Van de Werker & Warmrod, 1961 and Patch, Binns & Fourt, 1984). Indeed the latter authors go so far as to suggest that the roots of a transplant are likely to be so restricted following transplanting that they are incapable of taking up applied nutrients for up to a year after planting. Yet from the number of reports detailing enhanced growth with newly planted trees after fertiliser application this must be regarded with some scepticism (eg. Capel,1980; Krohn,1981; Dutton & Bradshaw,1982; Walters,1982; Gilbertson *et al.*,1987). Capel (1980) suggests that whilst young trees are capable of responding to nutrient addition in their first year, with larger trees response to fertilisation is often only apparent in the second year. However, no growth responses were observed for either *F.excelsior* or *A.pseudoplatanus* following two years of nutrient addition.

There are a number of reports detailing the physiological importance of stored nitrogen in support of tree growth in early spring. Thus fertilisation of the trees whilst in the nursery could have important repercussions on the growth of the tree following transplanting. For example, Taylor & May (1967) and Taylor & Van den Ende (1969) found a highly positive correlation between the level of storage nitrogen in *Prunus persica* and the new shoot growth in the following spring, if the current nitrogen application was low. Indeed, Tromp (1983) found that nitrogen applied in autumn was absorbed and stored in *Malus domestica* roots and could determine the amount of spring growth, supplying at least half of the total nitrogen required by the new leaves in spring and summer.

Direct comparison of the results from each investigation in this series is inappropriate, as not only were different species used, but also different types of fertiliser and different intensities of fertiliser application. Each of these factors has been demonstrated to have significant effects on the growth responses of trees to nutrient addition. But again no effects were observed in the present experiments.

Ponder (1980) investigating three fertiliser application methods on the growth of *Juglans nigra* found that there was superior growth of seedlings growing in plots where the fertiliser had been mixed with the soil than in plots where the fertiliser had been broadcast or placed in holes. The explanation given was that mixing with the soil gave a better distribution of fertiliser and improved aeration. Investigation 6.3 demonstrated that there was no significant response by *A.pseudoplatanus* to either a surface dressing of 'Osmocote' or sub-surface application as 'Growstix'. Coleman, Mock & Furuta (1978) investigating the placement of 'Osmocote' found that a surface application, or placing the 'Osmocote' as a single mass under the transplant or mixing with the complete volume of soil had little effect on plant growth. Capel (1980) found that the effects of sub-surface placement or broadcasting of fertiliser was species dependent but in general there were negligible differences between the two methods.

A single large fertiliser application can have a different effect on nutrient uptake than repeated fertiliser applications throughout the year (Capel 1980). Miyasaka (1984) investigating the growth responses of *Eucalyptus* species to fertiliser applications reported that seedlings fertilised twice per year over a two year period with a soluble fertiliser were taller and had greater diameters than those given one application per year of the soluble fertiliser or one application per year of three different brands of slow release fertilisers. But again this was not found in the present experiments.

A major aim of the experiments was to see how far fertilising the tree at planting would supply it with sufficient nutrients to restore the pre-transplanting shoot:root ratio rapidly. However none of the investigations demonstrated any significant response of root growth to nutrient addition. The reported effects of nutrient addition on root growth tend to be contradictory. Phosphorus and potassium fertilisation is sometimes recommended to enhance the root growth of trees under urban conditions (Bernatzky,1978; Pirone,1978). However, Harris (1983) reports that there is no experimental evidence to show that a deficiency or excess of phosphorus or potassium will affect root growth more than a deficiency or excess of any other nutrients. Gilbertson *et al.*(1987) demonstrated on very poor substrates (china clay waste) that root growth is as responsive as shoot growth to nitrogen fertilisation. However Nambiar (1981) reported that nutrient deficiency had considerably less effect on root configuration than on shoot growth. Root development measured in terms of size, spread and number of roots was increased by three to five times after fertilisation of *Pseudotsuga menziesii* (Gessel & Walker,1956). Van den Driessche (1983) found that for the same species fertilisation increased root growth capacity. Hamilton *et al.* (1981) demonstrated that root growth of *Cotoneaster sp.* was not significantly affected by either nitrogen or phosphorus application. Ritchie & Dunlap (1980) report that the effects of fertiliser addition on root growth potential has not been investigated in any great detail and the published reports detail conflicting results.

The only significant response to fertiliser addition (investigation 6.5) was an increase in shoot extension. Indeed, it is a common presumption that high levels of nutrient supply can increase shoot growth relative to root growth. For example, Tattar (1978) advises against fertilising declining trees with nitrogen because it primarily stimulates foliage production at the expense of root growth. Kozlowski & Kramer (1979) suggest that excessive fertilisation of seedlings leads to excessive shoot growth, producing a high shoot:root ratio, which often results in poor survival after outplanting. Nambiar (1980) found high levels of nutrients in the nursery, nearly doubled the shoot:root ratio of *Pinus radiata*.

Cannell (1985) discusses the effects of nutrition on shoot/root interactions in terms of assimilate partitioning. Linder & Axelsson (1982) report that after supplying a nutrient solution on a daily basis during the growing season, for 6 years, to *Pinus sylvestris*, the treated trees were over twice as large as the untreated trees. Yet, the treated trees partitioned only about 31% of assimilates to the roots, compared with 59% in the untreated trees. Maggs (1961) reported that addition of nitrogen to *Malus domestica*, increased above ground dry matter production by 5.9%, yet the total annual dry matter production per tree was increased by only 1.3%. Other evidence for the effects of nutrition on partitioning of assimilates comes from Keyes & Grier (1981) who investigated the growth of 40 year old *Pseudotsuga menziesii* stands on fertile and infertile soil and found that trees grown on fertile soil produced only 17% more total dry matter than the trees grown on the infertile soil, yet the former were producing about 88% more dry matter above ground.

No statistically significant differences in response to nutrient additions at different times of the year were observed during investigation 6.4. Reports on the effects of timing of nutrient addition do lead to a confusing picture. Smith (1978) recommends autumn application, although offers no evidence to substantiate this. Lipas & Levula (1980) also found autumn or late winter applications of nitrogen better than spring applications. Taylor (1987) examining the response of *Picea sitchensis* to nitrogen application at different times of the year at two locations in upland Britain found no differences, as with this investigation, between application dates at either site. Summer nitrogen applications were found to be most effective in terms of shoot growth for apple trees (Delap,1967). Salonen (1983) found May application to be best whilst Ballard (1981) suggests spring or autumn applications are preferable. Again it must be emphasised that comparisons between between such pieces of work is difficult because of different experimental material and sites.

One of the major problems with regard to nutrient addition and tree growth is that many of the investigations where responses have been reported, have been carried out in a 'no soil' situation. For example some of the investigations have used solution culture (see eg. Ingestadt & Lund,1979) or waste materials as the substrate eg. china clay waste (Gilbertson *et al.*,1987) or brick rubble (Capel,1980). These can be relevant to physiological understanding or growth on extremely poor materials, but they may not be applicable to growth in less extreme situations.

Although the results presented here have shown a general lack of response to nutrient amendment, it is difficult to extrapolate the results to other situations, as the response only relates to the growing conditions at the experimental site and during the years that the experiments were conducted (Russell,1988). It is possible that the site chosen was more fertile than the sort of urban situations investigated by Capel (1980), for instance. In terms of tree planting practice it is therefore difficult to know how to interpret the results. Whilst no detrimental response to nutrient addition has been observed, the general practice of fertilising on planting should surely be retained and encouraged. However at the same time it is suggested that the specific nutrient status of the substrate at the planting site be analysed and deficiencies corrected by particular nutrient amendments.

Chapter 7

The Effects of Weed Competition on Tree Establishment

7.1 Introduction

The dominant component of the urban landscape is grassland. The reasons for this include the inexpensive cost of establishment and maintenance, the resilience to maltreatment and the fact that it will usually gradually improve itself (Dutton & Bradshaw,1982). To the landscape architect reclamation of derelict sites requires immediate establishment of this permanent vegetative cover of grass. Trees are then often planted into, and are required to compete successfully with, this dense cover of grass.

Foresters and fruit growers through research and field observations, over some 30 years, have recognised the competitive effects of grass swards on the growth of trees. Depending upon the size of the tree there are three environmental resources, light, water and nutrients that will be partitioned between the tree and the grass sward. Although grass will be the principle component of the sward other broad leaved weed species and woody weeds may also be present (Megginson,1984).

There are many reports indicating that herbaceous sward competition can severely affect the survival of seedlings and transplants. Philo *et al.* (1983) found that survival of *Juglans nigra* seedlings on mine waste was reduced by over 60% when weed competition was not controlled. *Pinus radiata* seedling survival was only 18% where weed control was not carried out, compared to survival rates of 94-100% with various weed control measures (Balneaves,1984). Davies (1988b) noted that the effects of weed competition was severe where poor planting stock was used, all *Quercus robur* transplants perished where no weed control was practised compared to up to 63% survival with various weed control measures. Even where good planting stock was used, *Castanea sativa* and *Acer pseudoplatanus* survival was only 35% and 33% respectively in unweeded plots. Brown (1980) investigating the effects of weed competition on *Abies fraseri* and *Pinus sylvestris* found survival where no weed control had been practised was 47% and 60% after 3 years respectively compared to control survival rates of 93% and 87%. Davison & Bailey (1980) found survival of both *Prunus laurocerasus* rooted cuttings and *Chamaecyparis lawsoniana* seedlings were significantly reduced by weed competition.

Subsequent growth of the tree can also be severely impaired if surrounding weed competition is not controlled, and the reduction in growth can be dramatic. For example, shoot weight of *Pinus ponderosa* was reduced by a factor of six if weed growth was not suppressed (Larson & Schubert,1969). Similar observations have been reported by a number of workers for a wide range of species (eg. Balneaves,1984; Lund-Hoie, 1984; Philo *et al.*, 1983; Buckley *et al.*, 1981; McIntosh,1980). Root growth has also been demonstrated to be sensitive to weed competition and a doubling or trebling of root growth following weed suppression have been reported (Parfitt & Stott,1984; Buckley *et al.*,1981). Davies (1987a) has demonstrated that root growth is as responsive to weed suppression as shoot growth.

The importance of eliminating competition from weed roots can be emphasised when the nature of the growth of grass and tree roots are compared. McDonald (1986) cites an example of a single 4 month old *Secale cereale* plant, which had a root surface area of 237m² and a total length of 623km, which was many times larger than that of a conifer seedling. Similarly Sutton (1969) states that it is generally true that grasses have an enormously greater number of root tips per unit volume of surface soil than have forest trees. Also the grass roots are located in the soil layer first to be warmed in the spring, first to receive precipitation, and first to receive nutrients from precipitation or litter and often begin root growth before trees (McDonald, 1986).

The following investigations examine the responses of newly planted trees to weed competition. Different types of weed control treatments and any interaction with fertiliser application are examined. Finally the effect of weed growth on the water relations of the tree is discussed.

7.2 The effects of different weed control measures and fertiliser addition on the growth of *Acer pseudoplatanus*.

7.2.1 Introduction

There are numerous methods of weed control but to be effective they must eliminate competition from weed roots. Thus, as convincingly shown by Davies (1984), mowing is ineffective. Some methods are extremely labour intensive, such as hand weeding (Rupp & Anderson,1985) and hoeing, but are very effective. Height growth of *Fagus sylvatica* and *Fraxinus excelsior* was doubled following weed control by hoeing (Wood & Nimmo, 1962; Davies 1987b). For practical reasons however herbicides are the most frequently used method of sward control involving both residual and non residual herbicides (Insley,1982; McCavish & Insley,1981). Herbicides certainly provide the cheapest form of weed control, but many people who have used herbicides are sceptical of their safety. Other methods of weed control are therefore sometimes preferred, involving the placement of a mulch on the surface of the ground around the tree (Litzow & Pellett,1983). Black polythene sheeting is used for weed control in many parts of the world but it has not found favour in the UK (Davison, 1976). Loose mulches such as bark mulch can be effective (Davies, 1984), but they have the disadvantage of being bulky and expensive to transport and spread and that often supplementary hoeing or herbicide application may be needed to maintain high standards of weed control.

The effectiveness of some of these weed control treatments namely, herbicide application and mulching using either chopped bark or black polythene on the growth of shoots and roots of *Acer pseudoplatanus* was therefore examined in the following investigation. Since major interactions have been shown between weed control and fertliser addition on the growth of newly planted trees (Kendle, 1988), fertiliser treatments were included in the experimental design.

7.2.2 Materials and methods

Two hundred and forty *Acer pseudoplatanus (1+1)* transplants were planted in December 1987 into a grass lawn comprising principally of *Festuca rubra, Holcus lanatus* and *Dactylis glomerata*. The trees were planted in a replicated block design, in groups of 5 trees with 12 treatments per replicate block. There were four blocks. The treatments consisted of four weed control measures coupled with three fertiliser treatments. The weed control treatments were: a black polythene sheet, bark mulch, herbicide (paraquat) as 1 application and a control. The area of ground covered around each transplant was 0.5 x 0.5m. The fertiliser treatments included a surface dressing of 70g of 8-9 month release 17:10:10 'Osmocote', sub-surface application using 'Growstix' (see chapter 6) and a control.

The trees were harvested during January 1989, using the water jet method (method 2 of chapter 2). Growth parameters were assessed as dry weights after drying in an oven at 90°C.

7.2.3 Results

The benefits of weed control to tree survival are clearly demonstrated from this experiment (Figure 7.2.1, Table 7.2.1). Disregarding the fertiliser treatments, only 66% of the trees survived in the unweeded plots, 88% survived in the bark and polythene mulched plots, and 100% survival in herbicide treated plots.

At the same time where weed competition was not controlled, addition of fertilisers to the tree considerbly exacerbated the deleterious effects of weed competition. With all the weed control methods, apart from the herbicide treatment, survival rates were reduced when nutrients were added in the form of a surface dressing of 'Osmocote'. However, this was not the case where nutrients were sub-surface applied as 'Growstix'. Where weed control was not practised,

Figure 7.2.1 The effects of different weed control measures and fertiliser addition, on the survival of *Acer pseudoplatanus*

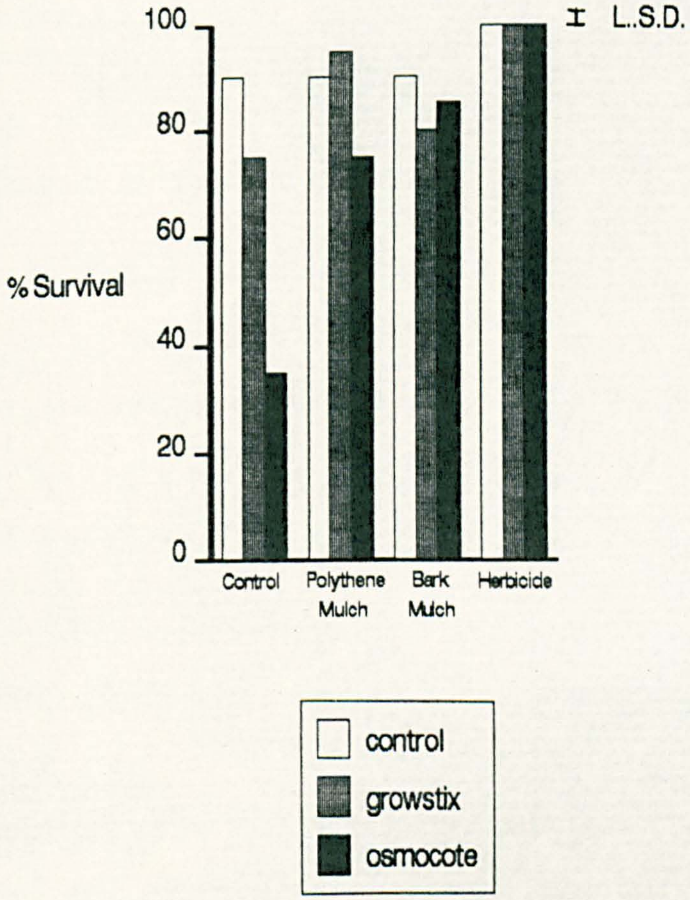


Table 7.2.1

ANOVA for the survival rate of Acer pseudoplatanus after different weed control and fertiliser treatments.

Item	D.F.	M.S.	F	P
Total	47			
Weed Control	3	5.74	7.45	<0.01
Fertiliser	2	4.15	5.38	<0.01
Weed Control x Fertiliser	6	1.70	2.21	N.S.
Error	36	0.77		

application of nutrients in the form of 'Osmocote' and 'Growstix' reduced tree survival to only 35% and 75% respectively, compared to a survival rate of 90% where no fertilisers were added.

All the weed control measures investigated enhanced subsequent growth of the trees with varying degrees of success, ranking from high to low in the following order: herbicide, bark mulch and black polythene mulch (Figure 7.2.2, Table 7.2.2).

Only the herbicide treated plots remained clear of weeds for the duration of the experiment. There was some re-invasion by weeds of the bark mulch, whilst weed growth was never fully controlled by the plastic mulch, as weeds grew through the slits made for the stem of the tree and any holes that had been made by animals.

This investigation demonstrates clearly that root growth is reduced to a considerably greater extent than shoot growth when weed growth is permitted, i.e. shoot:root ratios increased in the presence of weed growth despite a decrease in extension growth. The degree of suppression was remarkable, by a factor of 2 in the absence of fertiliser, and by a factor of 6 in its presence.

No statistically significant growth responses were observed as a result of fertiliser addition (Figure 7.2.2, Table 7.2.2). However a trend was observable for the trees grown without any weed control, where the addition of nutrients led to a reduction in shoot and root growth, this effect being greatest where nutrients were surface applied in the form of 'Osmocote' compared to a sub surface application as 'Growstix'.

Figure 7.2.2

The Effects of Different Weed Control Measures and Fertiliser Addition on the Growth of *Acer pseudoplatanus*

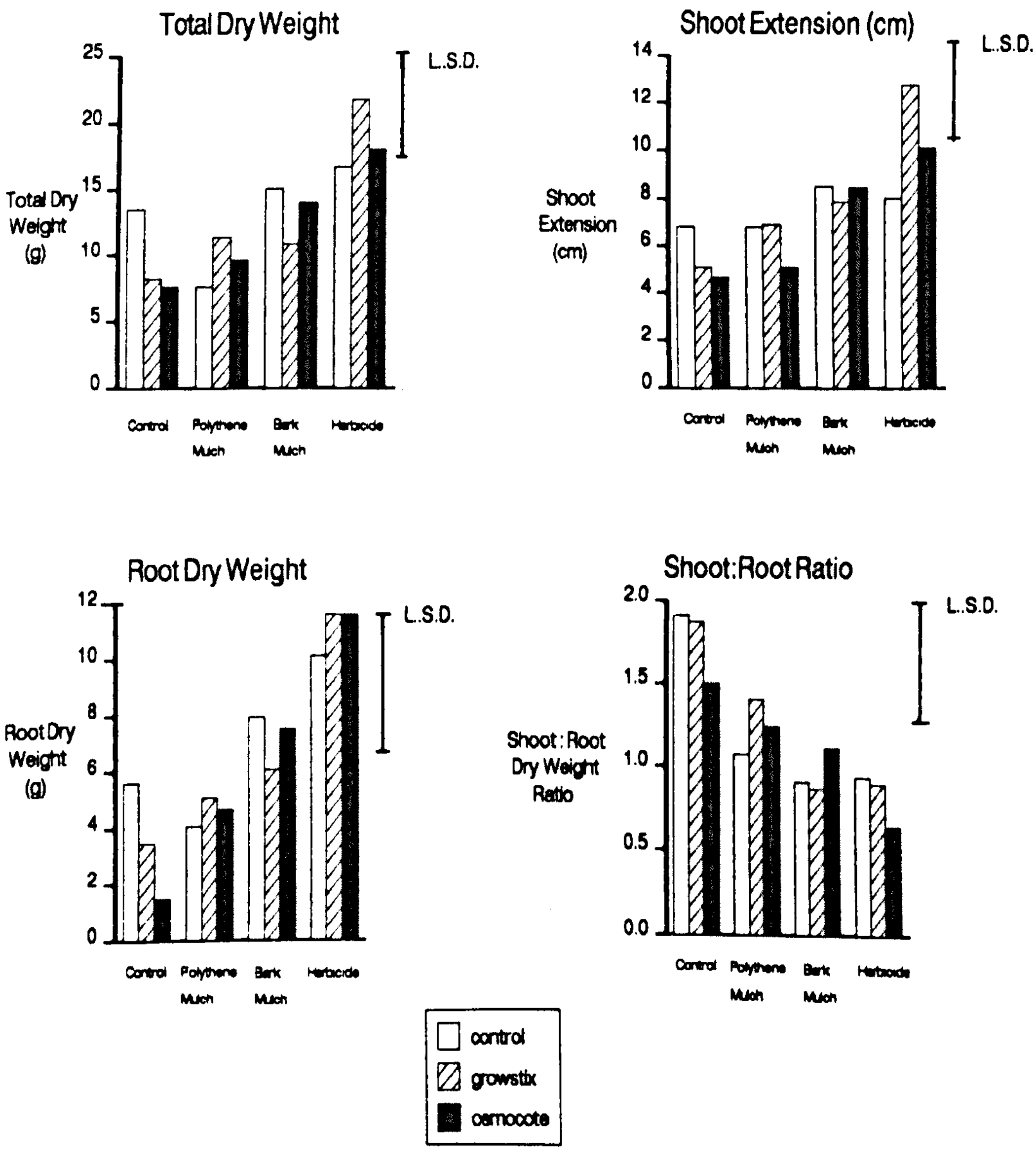


Table 7.2.2

ANOVA of the effects of different weed control and fertiliser treatments on the growth of *Acer pseudoplatanus*.

Total Weight

Item	D.F.	M.S.	F	P
Total	47			
Weed Control	3	224.84	12.05	<0.01
Fertiliser	2	4.02	0.22	N.S.
Weed Control x Fertiliser	6	32.76	1.76	N.S.
Error	36	18.66		

Shoot Extension

Item	D.F.	M.S.	F	P
Total	47			
Weed Control	3	55.46	5.63	<0.05
Fertiliser	2	4.56	0.46	N.S.
Weed Control x Fertiliser	6	9.25	0.94	N.S.
Error	36	9.85		

Root Weight

Item	D.F.	M.S.	F	P
Total	47			
Weed Control	3	136.37	16.85	<0.01
Fertiliser	2	1.60	0.20	N.S.
Weed Control x Fertiliser	6	7.70	0.95	N.S.
Error	36	8.10		

Shoot:Root Ratio

Item	D.F.	M.S.	F	P
Total	47			
Weed Control	3	2.06	9.85	<0.01
Fertiliser	2	0.07	0.33	N.S.
Weed Control x Fertiliser	6	0.14	0.65	N.S.
Error	36	0.21		

7.2.4 Discussion

Numerous other reports detail benefits of weed control on survival of a number of species: Cellier & Stephens (1980) - *Pinus radiata*, Barber (1984) - *Pseudotsuga menziesii*, South, Gjerstad & White (1978) - *Pinus taeda*, Lund-Hoie (1984) - *Picea abies*, Larson & Schubert (1969) - *Pinus ponderosa*, *Erdmann (1967)* - *Liriodendron tulipifera* and *Fraxinus americana* and Davies (1985) - *Acer pseudoplatanus*.

However it should be noted that not all reports detail such benefits, a number reporting no observed effects of weed control on tree survival eg. Todhunter & Beineke (1979) - *Juglans nigra*, Erdmann (1967) - *Quercus rubra* and *Juglans nigra*, Dickmann, Heligmann & Gottschalk (1977) and Parfitt & Stott (1984)- *Populus spp.*, and McIntosh (1980) - *Picea sitchensis*.

Similar findings as to the deleterious effects of fertiliser addition on tree survival, when weed growth is not controlled have been reported. Addition of fertiliser to *Pinus radiata* in the absence of weed control resulted in a 25% increase in weed mass and resulted in a decline in tree survival (Balneaves, 1984). Survival rates of *Pinus radiata* in plots receiving nitrogen was reduced by 20% compared to plots receiving a no nitrogen treatment, where weed growth was not controlled (Cellier & Stephens, 1980). In the absence of weed control, fertilisation reduced survival and growth of planted *Juglans nigra* seedlings (Williams, 1974).

It has been shown that the different weed control measures investigated enhanced the growth of the trees to varying degrees of success, ranking from high to low in the following order: herbicide, bark mulch and black polythene mulch. This ranking differs from many others reports, where in general, a black polythene mulch appears to be superior to either a herbicide or an organic mulch treatment (Bredell & Barnard,1974; Davison & Bailey,1979; Buckley, Chilton & Devonald,1981; Parfitt, Stinchcombe & Stott,1980; Parfitt & Stott,1984 and Davies,1987a). For example, Davison & Bailey (1979) reported that newly planted *Malus domestica* mulched with black polythene made up to 30% more extension growth than trees mulched with straw, which in turn made 10% more growth than trees grown in soil with a herbicide treatment. Davison (1976) suggests that the use of a black polythene mulch can increase the value of *Acer platanoides* and *Chamaecyparis lawsoniana* by 33% and 13% respectively, above the value obtained by the use of herbicides. There are however, other reports in the literature concurring that mulch treatments are less effective than a herbicide treatment (Buckley *et al.*,1981). Davies (1988a & b) investigating the effect of different sizes of black polythene mulch and herbicide treatments concluded that herbicide spots were generally better than polythene mats when the area treated was less than $1m^2$ per tree, but not so good when larger areas were treated: this was attributed to weeds rooting under the mulches.

Reduction in the evaporation rate of soil moisture together with increased soil temperatures are often quoted as the principal reasons why trees grown with black polythene mulches grow better than trees where other sward management regimes have been used (Liptay & Tiessen, 1970; Bredell & Barnard,1974; Litzow & Pellett,1983; Parfitt & Stott, 1984). However, Davies (1984,1985) has demonstrated that most soil moisture is lost by transpiration with relatively little being lost by evaporation from bare soil. Buckley *et al.*(1981) suggest that the immediate kill imposed by a herbicide treatment may in fact be more beneficial, especially in years of reduced rainfall, by allowing rapid infiltration of water.

It has been discussed that only the herbicide treated plots remained free of weeds and that weeds grew through the slits in the polythene which had either been made for the tree stem or by animals. This has important implications as it has been shown that polythene mulches tend to concentrate soil moisture in the surface 75mm of the soil (Parfitt & Stott,1984), the horizon that contains the majority of the weed roots. Thus it would appear that although the polythene mulch is capable of conserving soil moisture, if weed growth is not completely controlled, the soil moisture will be utilised by the weeds to the detriment of the tree.

It is a consequence of the majority of research into the effects of weed growth upon trees, disseminating from an interest in forestry, that very few reports detail the effects upon root growth.Those workers that have reported on this subject found that shoot and root growth were affected to a similar extent when weed growth was controlled Davies (1987a) and Buckley *et al.*(1981).

Whilst there was no overall response of the trees to fertiliser addition, a trend was observable for the trees grown without any weed control, where addition of nutrients either in the form of 'Osmocote' or 'Growstix' led to a reduction in all parameters measured.

This is in general agreement with the findings of other workers. Gilbertson *et al.*,(1987) demonstrated a negative effect of fertiliser addition in the presence of weeds. Root volume of *Betula pendula* transplants was reduced from 29ml with weed control and fertiliser addition to only 3mls with fertiliser addition but lacking weed control. Likewise growth of *Quercus petraea* was improved by fertiliser addition only where weed growth was suppressed (Davies,1987b). McIntosh (1980) also reports that fertiliser application to *Picea sitchensis* had little effect on growth unless accompanied by a herbicide treatment.

A limitation of this experiment, is that the most common method of weed control practised in the urban landscape i.e. mowing of the grass sward, was not included. Davies (1987a) states that due to mechanical damage by mowing machines, cutting swards is likely to be more detrimental that helpful to the growth of the tree, nor does mowing satisfy the requirements discussed by Davies (1984) and Messenger (1976) that to be effective weed control must eliminate competition from weed roots. The reported effects of grass mowing on tree growth are contentious. Buckley *et al.*(1981) found that the growth of *Fraxinus excelsior* transplants and whips was increased by 20% and 62% respectively when the surrounding sward was mown compared to the unmown sward. For *Fraxinus excelsior*, height improvements of over 66% have been recorded when the surrounding sward was mown (Insley & Buckley,1980). Yet Davies (1984) reported that regular cutting of grass swards increased the grasses transpirational soil drying ability, resulting in the poorer growth of *Prunus avium*. Bould, Hughes & Gunn (1972) and Crabtree & Westwood (1976) conclude that even well mown swards have a marked detrimental effect on tree growth. Similar results were also reported by Lord & Vlach (1972), who also noted that the effect of mowing was also to reduce the nitrogen content of the tree.

A further limitation of these experiments is that no attempt was made to determine the optimum ground area around the tree, that should be kept weed free. Apart from the elegant work of the Forestry Commission (Davies,1984, 1987a & b, 1988b) very few reports exist on this subject. Davies (1987) showed that as a general rule, an area of at least 1m diameter at the base of transplants and 1.5m diameter for standards should be kept weed free to maximise growth over a three year period. Yet Insley & Buckley (1980) demonstrate that the area kept weed free of growth around *Fraxinus excelsior* seedlings and transplants need not be large, with basal treatments of 30 x 30 cm being effective again over a three year period. However, Devonald (1986) found a herbicide treatment of $0.6m^2$ failed to improve survival of *Fagus sylvatica* transplants, whilst total sward removal was successful. In forestry practice the area treated around transplants ranges from 0.1 to 0.8 m^2 per tree (Aldhous, 1973). Buckley *et al.* (1981) demonstrated that by increasing the size of area treated, growth of *Acer platanoides* transplants was enhanced. Root growth was particularly affected, increasing by 54% when the area treated was enlarged from $0.06m^2$ to $0.25m^2$.

Nevertheless, despite the incomplete design of this experiment, the practical implications of the results are quite clear. In order to aid the newly planted tree to restore as quickly as possible the pre-transplanting shoot/root balance, proper weed control must become part of the general management procedure. It appears that weed control measures that completely destroy the sward will be most beneficial. In practice this means the use of a herbicide either alone or in combination with a mulch treatment. Chopped bark mulch has been shown to be more beneficial than a black polythene mulch perhaps because weed growth could continue through slits in the polythene. Where proper sward management is not carried out, under no circumstances should additional fertiliser be given to the trees as this will greatly exacerbate the deleterious effects of the sward competition.

7.3 The effect of weed competition on the growth and water relations of *Acer pseudoplatanus*.

7.3.1 Introduction

The principal mechanism by which the presence of weeds affects the growth of the tree is considered to be by competition for soil water reserves (eg. Newton & Preest,1988; Sands & Nambiar,1983; Brown,1980). Thus nutrient addition in the presence of weeds has a negative effect, which must be by increasing the vigour of weed growth thereby exacerbating the already deleterious effect of weed competition on water supply. However, there is only one report in the literature that demonstrates that weed competition can affect the trees potential for nutrient uptake (Parfitt & Stott,1984).

In view of the previously described experiments on the water relations of newly planted trees the following investigation was therefore set up to examine the effects of weed growth on the water relations of newly planted trees as affected by nutrient addition and in particular to assess the potential of weed growth to deplete the soil water reserves around the root system of a newly planted tree.

7.3.2 Materials and Methods

Forty *Acer pseudoplatanus* (1+2) transplants were planted into 24 litre pots containing a 2:1 peat:coarse sand substrate, 20 of the pots had been amended with 8-9 month release 18-11-10 'Osmocote' at a rate of 3 kg m^{-3} fertiliser. The substrate had also been amended with 1 kg m^{-3} of ground limestone and ground magnesium limestone. Ten of the pots containing the nutrient amended and unamended substrates were then sown with a grass mix of 50:50 *Festuca rubra* and *Lolium perenne* at a rate of 15 g m^{-2}. Thus there were four experimental treatments consisting of:

1) + Grass + Nutrients
2) + Grass - Nutrients
3) - Grass + Nutrients
4) - Grass -Nutrients

The trees were then divided into 2 groups so that each group contained 5 replicates of single trees of the 4 treatments. All the trees were then watered and continued to receive water regularly until all had leafed out. The experiment was conducted inside a a well ventilated polythene tunnel house, to provide protection from rain.

Water was then withheld from one group of trees, these were weighed to determine overall water loss from the tree/grass/soil system, at least once a week when stomatal resistances were also measured. The other group of trees continued to receive water on a regularly. A 'Crump' Diffusive Porometer was utilised to measure stomatal resistances, on each occasion, 3 readings were made on the lower surface of the youngest expanded leaf of the tree, the last recording being accepted as the stable value. Measurements were taken at 10 am. This treatment was continued until the first signs of stomatal closure was observed, whereupon the trees were re-watered to field capacity and allowed to recover for 1 week before the procedure was repeated for a second time. The maximum stomatal resistance that the porometer could measure was 16 sec cm^{-1}. By the time this value was measured, visible signs of wilting were apparent. Above this upper limit it was assumed that stomatal closure had occurred. At the end of the third cycle the droughting treatment was continued until all the trees had ceased transpiring and wilted, at which point the trees were harvested. Growth parameters of the trees and grass were ascertained as dry weights after drying in an oven at 90°C.

In order to assess the evapotranspiration from pots containing bare soil and the grass mixture only, 5 pots of bare substrate and 5 pots of each of the fertiliser amended and unamended substrate sown with the grass mixture were also included in the droughting sequence.

7.3.3 Results and Discussion

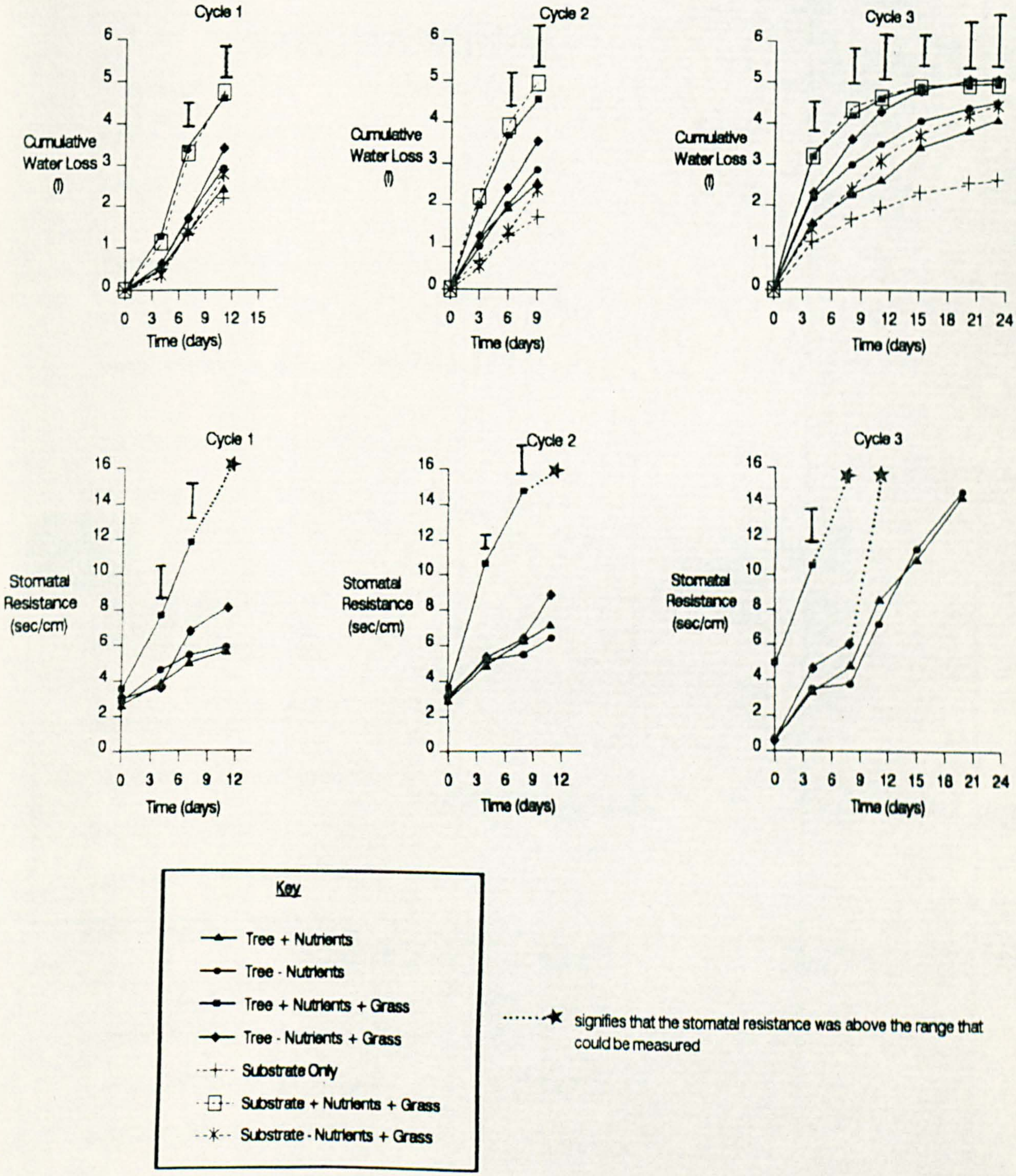
i) Water Loss

The deleterious effects of grass competition on soil moisture depletion has clearly been demonstrated in this experiment (Figure 7.3.1). The pattern of water loss from the pots containing the trees ranking from high to low in the following order: Grass+nutrients > Grass-nutrients > Substrate-nutrients > Substrate+nutrients. The respective pattern for the pots without trees was Grass+nutrients > Grass-nutrients > Substrate only.

During cycle 1, stomatal closure had occurred in the trees grown with grass and additional nutrients by day 11, water loss from the

Figure 7.3.1

The effects of grass competition on the water relations of *Acer pseudoplatanus*.



pots amounting to 4.61. By this time the trees grown without grass competition but with additional nutrients had lost 47% less water. During cycle 2, stomatal closure had occurred by day 9 with water loss from the pots amounting to 4.61, with the trees growing without the grass competition but with additional nutrients, losing 45% less water. With cycle 3, stomatal closure had occurred by day 8 in the trees grown with grass and additional nutrients, water loss from the pots amounted to 4.251, with the trees growing without grass competition but with additional nutrients, losing 44% less water.

Stomatal closure in the trees grown without grass competition occurred by day 23, of cycle 3. Figure 7.3.2 shows the effect of weed competition on tree growth by the end of cycle 3.

Water loss from pots where there was grass competition, but without additional nutrients was significantly less, 26%, 23% and 34%, for cycles 1, 2 and 3 respectively, than from the pots where additional nutrients had been supplied, by the time stomatal closure had occurred.

These findings are in broad agreement with those of other workers. Barrett & Youngberg (1965) reported a 45% greater use of water in a sapling stand of *Pinus ponderosa* with an understory than in one without an understory. Larson & Schubert (1969) have demonstrated that two grasses *Festuca arizonica* and *Muhlenbergia montana* depleted soil moisture faster and to lower levels than *Pinus ponderosa*. Newton & Preest (1988) found that *Pseudotsuga menziesii* maintained in weed free plots experienced less water stress during establishment. Similar results have also been discussed by Davies (1984,1985,1987a), Carter *et al.* (1984), Sands & Nambiar

Figure 7.3.2

The effects of grass competition and nutrient amendment on the growth of *Acer pseudoplatanus* transplants, 23 days since last being watered. From left to right: Substrate only + nutrients, grass-nutrients and grass+nutrients.

(1983), Brown (1980), Preest (1977) and Lambert, Boyle & Gardner (1972) for a number of different tree species.

During all of the 3 cycles, water loss from either the grass only or tree+grass pots was of the same magnitude, showing that very little water was available to the tree. Without grass competition, the amount of water transpired by the tree amounted to over 1.5l, over the period of cycle 3 (calculated by subtracting total water loss from the substrate only treatment from the value obtained for water loss of the tree+nutrient treatment).

ii) <u>Growth of the grass</u>

The potential competitive power of the grass is very clear from its shoot and root weight determined at the end of the experiment (Figure 7.3.3, Table 7.3.1). Given water and nutrients these were 125 and 145g respectively compared with 65 and 35g for the trees.

Root growth was unaffected by nutrient addition when water was limiting, but was increased by a factor of 3 when water was available. Shoot growth was significantly affected by nutrient addition, regardless of the water status of the substrate, with increases of magnitude of 4.6 and 5.6 being observed for the droughted and watered pots respectively.

iii) <u>Growth of the trees</u>

Total and root dry weights as well as shoot extension were all substantially and significantly reduced when the trees had been grown in the presence of grass (Figure 7.3.4, Table 7.3.2). The effect of droughting the trees also led, as might be expected, to significant reductions in these parameters. Significant interactions between water and grass were also apparent indicating that the

Figure 7.3.3 The growth of the grass sward

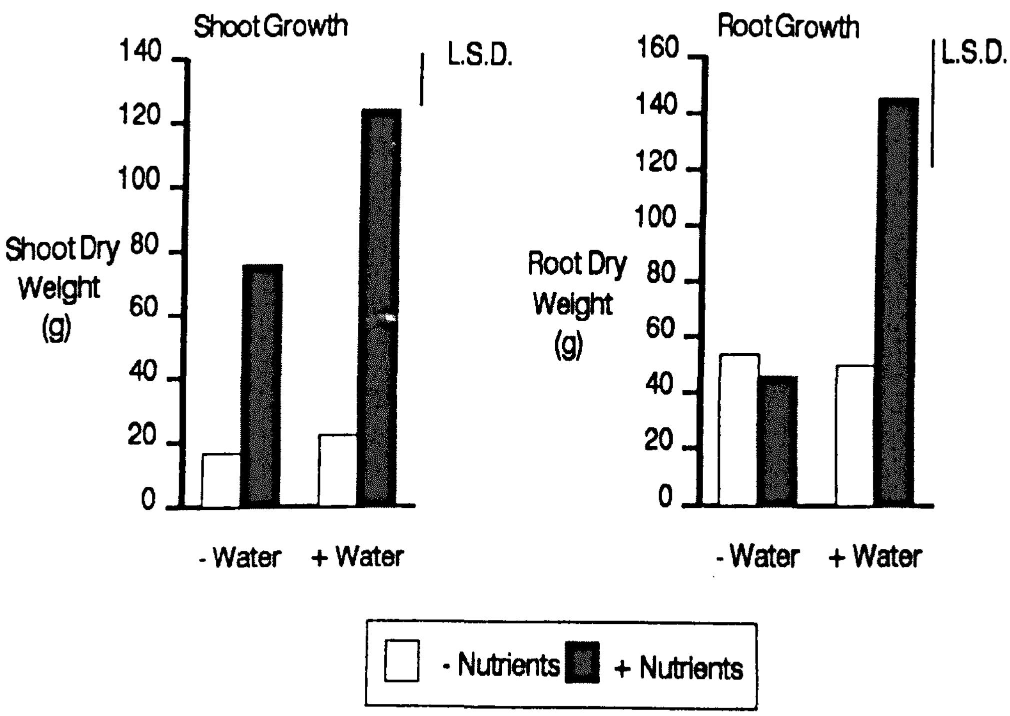


Table 7.3.1 ANOVA for the growth data of the grass sward.

Shoot Weight

Item	D.F.	MS	F	P
Total	19			
Fertiliser	1	32441.51	591.03	<0.01
Water	1	3658.51	66.65	<0.01
Fertiliser x Water	1	2253.57	41.06	<0.01
Error	16	54.89		

Root Weight

Item	D.F.	MS	F	P
Total	19			
Fertiliser	1	9741.70	15.39	<0.01
Water	1	11529.60	18.21	<0.01
Fertiliser x Water	1	13488.82	21.30	<0.01
Error	16	633.16		

Figure 7.3.4

The growth data of *Acer pseudoplatanus* grown with or without grass competition, fertiliser or irrigation.

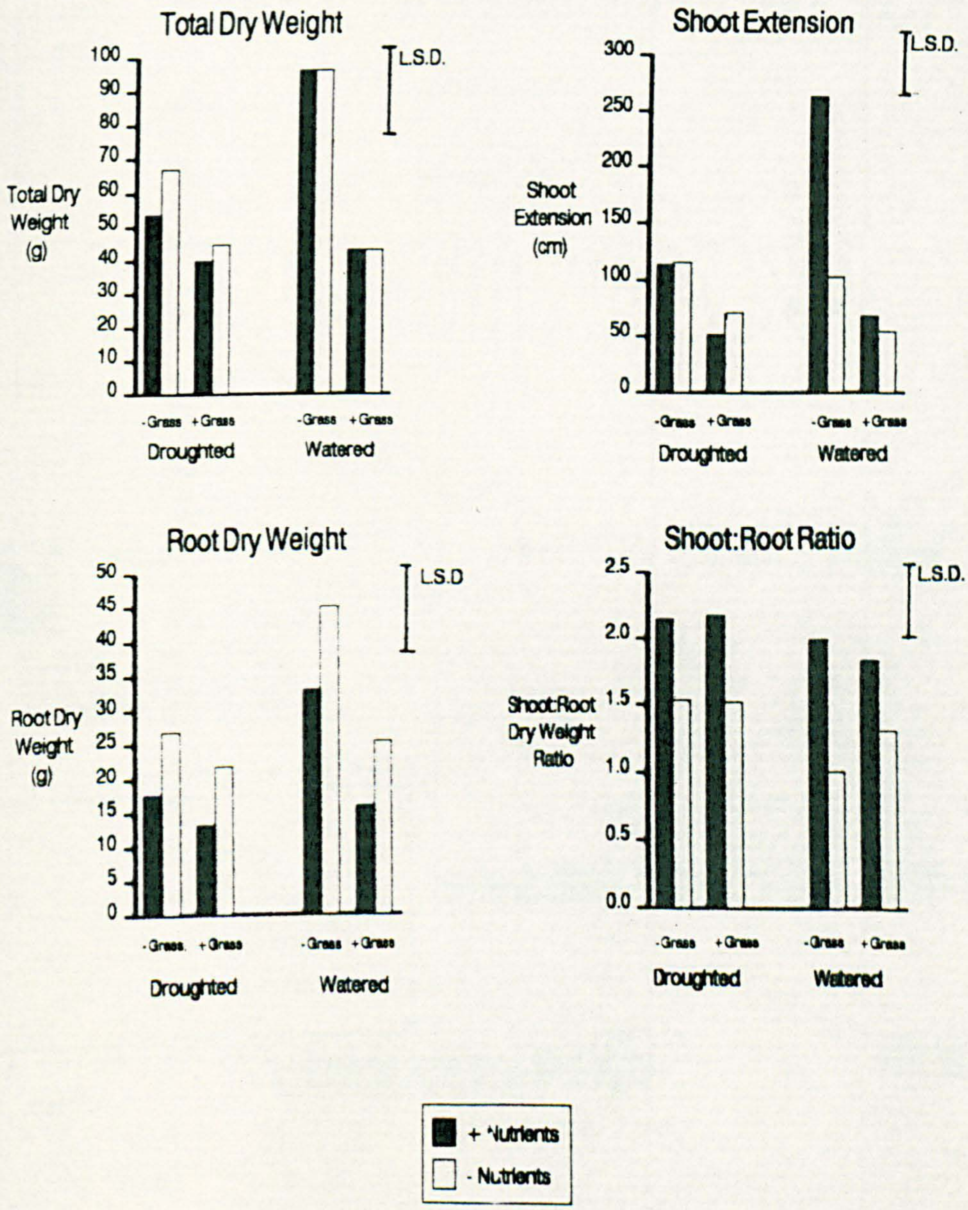


Table 7.3.2

ANOVA of the effects of grass competition, fertiliser application or irrigation on the growth of *Acer pseudoplatanus*.

Total Weight

Item	D.F.	MS	F	P
Total	39			
Water	1	3219.15	8.99	<0.01
Grass	1	7337.59	20.50	<0.01
Fertiliser	1	743.90	2.08	N.S.
Water x Grass	1	1881.29	5.26	<0.05
Water x Fertiliser	1	252.51	0.71	N.S.
Grass x Fertiliser	1	379.83	1.06	N.S.
Water x Grass x Fertiliser	1	335.36	0.94	N.S.
Error	32	357.96		

Shoot Extension

Item	D.F.	MS	F	P
Total	39			
Water	1	11696.40	6.79	<0.05
Grass	1	76038.40	44.17	<0.01
Fertiliser	1	14288.40	8.30	<0.01
Water x Grass	1	11628.10	6.75	<0.05
Water x Fertiliser	1	23716.90	13.78	<0.01
Grass x Fertiliser	1	16892.10	9.81	<0.01
Water x Grass x Fertiliser	1	10368.40	6.02	<0.05
Error	32	1721.51		

Table 7.3.2 continued

ANOVA of the effects of grass competition, fertiliser application or irrigation on the growth of *Acer pseudoplatanus*.

Root Weight

Item	D.F.	MS	F	P
Total	39			
Water	1	1005.01	12.14	<0.01
Grass	1	1321.35	15.96	<0.01
Fertiliser	1	979.11	11.83	<0.01
Water x Grass	1	469.91	5.68	<0.05
Water x Fertiliser	1	8.74	0.11	N.S.
Grass x Fertiliser	1	5.85	0.07	N.S.
Water x Grass x Fertiliser	1	3.19	0.04	N.S.
Error	32	82.80		

Shoot:Root Ratio

Item	D.F.	MS	F	P
Total	39			
Water	1	0.93	4.89	<0.05
Grass	1	0.01	0.05	N.S.
Fertiliser	1	4.64	24.42	<0.01
Water x Grass	1	0.02	0.11	N.S.
Water x Fertiliser	1	0.03	0.16	N.S.
Grass x Fertiliser	1	0.22	1.16	N.S.
Water x Grass x Fertiliser	1	0.16	0.84	N.S.
Error	32	0.19		

effects of grass growth on total weight, root weight and shoot extension of the trees was dependent upon the water status of the substrate. In fact the effects of the grass were greater in the watered treatments. This must be due in some part to the enhanced shoot and root growth of the grass and the subsequent invigoration of competition for the limited volume of water and nutrient reserves.

The effects of nutrient amendment on shoot extension depended upon the water status of the substrate (shown by the first order interaction). With the irrigated trees, nutrient amendment enhanced shoot extension, yet with the droughted there was a slight repression of shoot extension. However this interaction was also dependent upon the presence or absence of grass (shown by the significance of the second order interaction). Thus the best response in terms of shoot extension was observed with the -grass/watered/+nutrient treatment and the worst observed with the +grass/droughted/+nutrient treatment. Thus it would appear that the effect of the grass treatment has a similar effect as drought, on the growth of the tree.

Dramatic shoot growth reductions in trees are often a consequence of lack of proper weed control. McIntosh (1980) reported that height growth of *Picea sitchensis* could be up to 50% greater where weed growth had been controlled, six years after planting. Similar levels of growth enhancement following weed control have been reported for *Pinus sylvestris* and *Abies fraseri* (Brown,1980) and for *Juglans nigra* seedling stem height (Philo *et al*.1983). Larson & Schubert (1969) have demonstrated that shoot weight of *Pinus ponderosa* was increased six fold where weed growth had been controlled. *Picea abies* apical growth and radial growth following five years of weed control were two and three times greater than control trees (Lund-Hoie,1984). Buckley *et al.* (1981) showed shoot growth increases of over 200% in *Fraxinus excelsior* and *Acer platanoides* following weed management compared to the control. Long term effects of weed control can be even more dramatic, Balneaves (1984) has reported that following only 15 months weed control after planting, height growth of *Pinus radiata*, 10 years later was increased from a control height of 10.9m to 13.5m.

Richardson (1953) studied the effect of the presence of *Lolium perenne* on root development of *Acer pseudoplatanus*. The presence of the grass depressed root growth rate, reduced the density of root hairs and restricted both rooting depth and the lateral spread of roots. Documented evidence exists as to the positive effects of weed control on root growth. Parfitt & Stott (1984) report that root growth of *Salix alba* and *Populus tacamahaca x trichocarpa* cuttings was 2.5 and 3.5 times greater where weed control was used. A four fold increase in root weight of *Pinus ponderosa* following weed control has been demonstrated by Larson & Schubert (1969). Buckley *et al.* (1981) indicate that root volume of *Acer platanoides* transplants can be increased by up to 228% following weed control for two years. Davies (1987b) demonstrated that root growth of *Acer pseudoplatanus* and *Quercus petraea* were reduced to the same degree as shoot growth by weed competition.

Shoot:root ratios were unaffected by the grass treatment but were significantly increased by the droughting treatment. Fertiliser addition to the substrate also led to significant increases in the shoot:root ratios of the trees regardless of grass or water treatments. This was a result of not only increased shoot growth but also to a repression of root growth. These results are very different to the effect of fertilisation shown in the experiment on fertiliser addition and irrigation which was discussed in section 6.5. Whether this result was due to the optimum conditions found in the tunnel house or perhaps the low nutrient status of the peat/sand substrate is not known. For a more detailed discussion of the responses of trees to nutrient addition refer to Chapter 6.

Parfitt & Stott (1984) concluded that enhanced shoot growth of *Salix alba* and *Populus tacamahaca x trichocarpa* cuttings after weed suppression was due not only to an adequate water supply but also enhanced potential for nutrient uptake. This is in general agreement with this investigation where it was found that there was an interaction between all 3 factors of weed competition, water supply and nutrient supply.

It would appear from this investigation that the antagonistic effects of a grass sward on tree growth is clearly related to competition for water. However, even where water and nutrient supply were not limiting, the presence of grass severely restricted all the growth parameters measured. One possible explanation for this is allelopathic toxicity, which has been proposed as a mechanism by which weed species can affect the growth of trees (McDonald,1986).

Jarvis (1964) reported the presence in *Deschampsia flexuosa* humus of a substance inhibitory to the growth of *Betula verrucosa* and *Quercus petraea* roots. Horowitz (1973) described inhibitory effects of three perennial weeds, *Cynodon dactylon*, *Cyperus rotundus* and *Sorghum* *halepense* on the growth of *Citrus aurantium* seedlings, concluding these effects resulted from not only competition for moisture and nutrients but also by phytotoxic substances produced by the weeds. The classic example is the juglone toxin produced by *Juglans nigra* and *Juglans cinerea*, instances of juglone toxicity have been reported by von Althen (1968) and Brooks (1951) where growth of *Pinus resinosa* and *Quercus rubra* have been affected when growing in proximity to *Juglans nigra*. Allelopathy is however still an extremely controversial subject, the difficulty being the separation of effects which might have been caused by competition for water nutrients or light and those resulting from toxic inhibitors. Harper (1961,1977) argues that it is often easy to extract substances from plants that might prove phytotoxic, but it is more difficult to prove that these substances are liberated in the field and more over, evolution of resistance to such toxins might have been evolved by higher plants making allelopathy an uncommon phenomenon.

Perhaps a failing of this experiment was that the trees were harvested at the end of June i.e. only half way through the growing season. Nevertheless significant growth differences were apparent by this stage, and the primary objective of the investigation was to assess the effects of weed competition on the water relations of the tree and this was accomplished.

7.4 Conclusions

These experiments have confirmed the need for weed control around newly planted amenity trees. It has been demonstrated that to be effective weed control must completely eliminate competition and in practice this means the use of a herbicide either alone or in combination with a mulch treatment. Perhaps the most significant effect that has been demonstrated, is the effect that weed competition has on the water relations of the newly planted tree. It has been shown that grass growth can deplete the water reserves of a given volume of soil, twice as quickly as the tree alone. If this is taken with the evidence from chapter 4, which has demonstrated that the only water available to the tree is that contained within the volume of soil directly surrounding the roots, then the case for weed control becomes overwhelming. This not only has a direct effect on growth but a particular effect on root growth which will not only affect the current seasons growth, but also growth in subsequent years.

Chapter 8

Discussion

This series of investigations has examined the hypothesis that the high failure rate and poor growth of newly planted amenity trees are a direct consequence of the process of transplantation. To test this, firstly the demands of the newly planted tree in terms of water and nutrient supply were determined and then cultural practices that could be used to manage these resources were investigated.

That a period of reduced vigour exists directly following transplanting has been discussed by Watson *et al.* (1986). These workers concluded that this period might extend for up to 5 years for a standard tree, with shoot extension being reduced to between 22% and 38% of the mean before transplanting. Similar results have been discussed by Ferree (1976) where the total shoot growth made by a transplanted *Malus domestica* was 32% less than an untransplanted tree.

During these investigations first year shoot extension growth has been found to be particularly low. For example, following pruning and staking treatments of *Platanus x hispanica* (section 5.3) total shoot extension during the first year amounted to 5.17m, whilst for the second year 12.4 m was recorded. With smaller stock, the difference was even more dramatic. Total shoot extension of *F.excelsior* during an investigation on the effects of nutrient addition was 0.27 m during the first year but had increased to 1.78 m after the second year.

Root Growth

The principal mechanism by which the growth of the tree is affected following transplanting, is the loss of a large part of the root system. It was found, by measuring the root stock of the material used for the investigations, that for a 4m high standard tree, the rooting volume was only $0.18m^3$. Assuming that transplanting practices mean that only 5% of the original root system is moved along with the tree (Watson & Himelick,1982; Gilman,1988) then the pre-transplanting rooting volume would have been $3.6m^3$. The repercussions of this, in terms of water supply to the tree, is dramatic.

It was demonstrated that the only water available to the newly planted tree was effectively that contained within the volume of soil directly surrounding the roots. If it is assumed that the available water capacity of the soil is 15%, which is typical for urban soils (Gilbertson *et al.*,1987) and that the soil is at field capacity, this would provide only 23 days water supply, assuming that the tree has a transpiration demand of approximately $1.2\ l\ day^{-1}$, as was found for a newly planted *P.x hispanica* (4m) standard. If the guidelines set by BS 4043 for planting semi-mature trees were extrapolated to include standard trees, the diameter of the root system of these trees should have been approximately 1m, which translates into a rooting volume of $0.58m^3$, and an available water supply for up to 73 days, which would be more than adequate to support tree growth.

The significance of the size of the root system in alleviating the stress caused to the tree was demonstrated, as increased shoot vigour, in section 4.2. Under partially droughted conditions, the total shoot extension of a tree with a root system which occupied a volume of approximately 0.18m^3 amounted to 4.21m, whilst for a tree having a rooting volume of approximately 1m^3, the total shoot extension was 12.38m.

Kopinga (1985) and Gilbertson *et al.*(1987) have discussed the dimensions of the root system in terms of nitrogen supply to the tree. As with the water requirements of the tree, the dimensions of the root system will have a profound influence on the amount of nutrients available. However from the investigations on the effects of increasing the nutrient supply to the rooting zone of the tree (chapter 6), it would appear that either the amount of nutrients available to the tree, or the nutrient reserves of the tree, are adequate to support growth at least for the first two years following transplanting. Even on such a nutrient poor substrate as peat and sand, with no additional nutrients a whip could put on over 1m of shoot extension (section 7.3).

In terms of establishment success, the principal requirement is the restoration of the pre-transplanting shoot:root ratio. To achieve this it is necessary to understand some of the processes that control root growth. This study has demonstrated that a significant amount of endogenous control of root growth resides within the shoot. The dependence of root growth on the production of current photosynthate was demonstrated in chapter 3, where total defoliation completely inhibited root growth until new leaf buds began to open. The shoot system acts as an effective sink for not only current photosynthate but also stored carbohydrate, as demonstrated by section 5.2, where summer pruning severely restricted root development. It is postulated that the control of the distribution of photosynthate and carbohydrate reserves is under hormonal control.

Such findings throw light on the lack of useful effects of pruning in assisting establishment. Whilst dormant pruning does not disturb root growth, the tree very rapidly establishes a new crown and leaf area greater than in unpruned trees. However there are indications that dormant pruning may result in reduced leaf area during the early part of the growing season, when the rooting volume of the tree will be at a minimum. Summer pruning has such a profound effect on root growth that its total effect is negative.

Where standard trees were used as experimental material for the pruning investigations, shoot:root ratios were not ascertained, as the stem forms of the trees were so variable that any growth differences in response to pruning treatments would have been masked. However, as before, moderate pruning treatments had no effect on root growth. Responses to severe pruning treatments appeared to be species dependent, with an increase in root growth being observed for *T.cordata* but reductions noted for *F.excelsior* and *A.platanoides*. Although differences were not statistically significant, it is believed this was due to the low number of replicates used (3 per pruning treatment).

This study has also examined what other cultural practices can be used to shift the shoot:root ratio. The practices investigated were; irrigation, the use of a soil polymer, nutrient addition and weed control.

Where irrigation had been included as an experimental treatment (sections 3.1, 4.2, 5.2, 6.5, 7.3), despite enhanced shoot and overall growth, shoot:root ratios remained relatively constant. However, root growth has been demonstrated to be very responsive to polymer amendment. Even in the presence of enhanced shoot growth, shoot:root ratios were reduced following polymer amendment. The exact reason for this effect of polymer amendment could not be investigated. But it is known that irrigation can provide only temporary alleviation of water stress (the available water capacity can be exhausted between waterings) whereas the polymer radically increases the available water capacity reserves and provides a continuous water supply to the newly planted tree.

As has already been discussed there was a general lack of response to nutrient addition under field conditions. However under controlled environmental conditions it was demonstrated that addition of nutrients to a peat:sand substrate led to an increase in the shoot:root ratio i.e. a relative decrease in root growth. Similar results were discussed by Linder & Axelsson (1982) who ascribe this to an alteration in assimilate partitioning within the tree. The evidence as to the effects of nutrient addition on the growth of newly planted trees is conflicting. Some workers have reported enhanced root growth following nutrient amendment, however many of the investigations have being carried out on substrates that are known to have an extremely low nutrient status eg. china clay waste (Kendle,1988; Capel, 1980).

Weeds are an important factor that can influence the establishment of a newly planted tree. They have a major negative effect on all aspects of growth (including that of roots; Davies,1987a). In the present experiments weed growth significantly increased the shoot:root ratio despite enhanced shoot growth. In other words, weeds had a disproportionate negative effect on root growth. From the experiments where water loss was measured, the antagonistic effects of the presence of weeds would seem to be due to competition for water resources, although allelopathic toxicity can not be discounted.

All the investigations described have assessed the shoot:root ratio of the tree at the end of the growing season. Yet it is known that the shoot|root ratio constantly changes throughout the growing season, depending on the periodicity of both shoot and root growth. Lyr & Hoffmann (1967) discussed that only general rules apply to root growth in a temperate climate. Being that maximal root growth in most tree species occurs in the early summer and that seedlings with early termination of shoot growth often exhibit strong root growth in midsummer. Winter growth of roots has been observed in areas with mild winters, although to a much reduced extent. The duration of shoot growth varies between species (Kramer & Kozlowski,1979) and can be grouped into four categories:

1) a single flush of terminal growth followed by formation of a resting bud

2) recurrent flushes of terminal growth with terminal bud formation at the end of each flush

3) a flush of growth followed by shoot tip abortion

4) a sustained flush of growth extending late formed leaves prior to terminal bud formation

Of the cultural factors examined it would appear that all the successful practices which reduce the shoot:root ratio (use of polymers, weed control and possibly pruning) and those that do not adversely affect the ratio (irrigation) are either directly or indirectly connected with the water supply to the tree.

Practical Implications

The overall problem for the newly planted tree is that of water supply. This could be overcome either by ensuring that the soil can supply sufficient water or that the root system is sufficiently extensive to obtain it. The improvement of the water holding capacity of the backfill material or inclusion of some method of irrigation into the rooting zone are therefore important considerations. The former can easily be accomplished, and has been done in practice by the use of an imported backfill material of high available water capacity. This can be purchased as specific tree planting composts. However objections have been voiced over this practice, as the interface between the two contrasting soil types may become a barrier to air and water movement (Patterson 1985). As a result the soil that is most porous will tend to saturate first and water will not migrate into the next most permeable soil until the first approaches total saturation.

The benefits of using cross-linked polyacrylamide polymers during planting, not only on the growth but also on the water relations of tree has been clearly demonstrated. Although the costs of such polymers is relatively high (approximately £4 per kg), this still compares very favourably with the costs of a watering contract (£8 per tree, based on 1984 prices). In addition polymers are light weight and unlike other backfill amendments such as peat, are not bulky. Thus to amend a planting pit of $0.58m^3$ in size , with 25% v/v peat or 0.4% v/v polymer ('Aquastore') would require 145l of peat but only 2.32l of polymer. But the use of these polymers perhaps has a greater potential in the production of nursery stock. It was noted that root penetration into the gel particles and aggregation around the expanded polymer occurs (Figure 8.1). This effectively provides a buffer against desiccation during the lifting, transporting and planting procedures. Perhaps more importantly, the consequences of having a poor root-soil contact, with air gaps at the interface, which results in a large resistance to water flow in the soil-plant continuum, are reduced.

The alternative to improving the rooting medium is to improve the amount of root system carried over with the nursery stock. Root undercutting is practised during the production of nursery stock (Gilman & Yeager,1988; Watson & Snydor,1987; Giesler & Ferree,1984) in order to lower the shoot:root ratio and to produce a compact and fibrous root system. Research on the subject has tended to be directed at forestry transplants (eg. Mullin,1966; Sterling & Lane,1975; Bacon & Hawkins,1979; Gilman & Yeager,1988) with the intention of providing information on the suitability of the technique for improving survival after transplanting. One piece of research indicates the potential benefits of root undercutting (Watson & Snydor,1987) where root undercutting of *Picea pungens* led to an increase in the percentage of the whole root system contained within the root ball from 5.8% in undisturbed stock to 11.8%, but the size of the root ball was not increased. It has been shown from the present investigation that it is the root volume that is the determining factor in the water supply to the tree and not root density.

The present investigations have demonstrated that it is essential

<u>Figure 8.1</u>

Root aggregation around expanded polymer particles.

that weed growth around the newly planted tree is suppressed. Three methods of weed control were investigated, a herbicide treatment, bark mulch or a black polythene mulch. Herbicide application was the only measure that completely suppressed weed growth, which was shown to be of importance in terms of tree survival and growth.

Methodology

Although this investigation has been limited to examining the response of bare root transplanted trees, many of the findings also apply to trees transplanted with a ball of soil. There is always a drastic reduction in rooting volume and the root system can experience desiccation as the soil ball dries (Himelick,1981). Even with containerised stock, the problem of restricted rooting volume is apparent, coupled with the often observed problems of root deformation (see eg. Grene,1978; Laiche, Kilby & Overcash,1983). The contradictory results as to the benefits or otherwise of using containerised stock (Okafo & Hanover,1978; Hunt, 1980; Laiche *et al.*,1983; Pilz & Znerold,1986) become understandable as a result of the present work, as containers will have done nothing to improve rooting volume. The majority of this research has been conducted using seedlings. Whether there are any merits to producing larger tree stock under a containerised system, in terms of survival and growth after planting is a further area where research ought to be directed but it will be essential to look at rooting volume.

All the experiments that were conducted inside the polythene tunnel houses had a degree of artificiality. It could be argued that none were sufficiently close to natural conditions to adequately reflect the effects of the various treatments investigated on the growth of the trees under natural conditions. Indeed it has been shown that maximum treatment effects were obtained from the tunnel house experiments. However for all those factors investigated in both the field and tunnel house, with the exception of nutrient addition, all the responses observed from the tunnel house investigations were reproducible under field conditions.

It would have been valuable if the experiments could have been conducted under similar conditions to those in which amenity trees are normally planted i.e. the urban environment. However this posed a considerable number of problems. From the outset of the investigation it had been decided to isolate single factors, whether that be water or nutrients and to examine the effects of each in turn, upon the growth of the tree. Due to the heterogeneity of the urban environment, this would have proved extremely difficult. This would also have necessitated the involvement of local authorities which in itself would have caused difficulties. The field situation at the University of Liverpool's Botanic Gardens provided fairly homogeneous edaphic and climatic conditions, which allowed each of the factors to be examined in isolation and which proved free from disruptions such as vandalism. In retrospect it is only the investigations examining the effects of nutrient addition on the growth of the trees which would have benefited from being carried out in the urban environment. However Capel (1980) obtained responses to nutrient additions on the same site as was used during these investigations.

Difficulties arise with any work concerned with the growth of trees, not only because of the cost of the experimental material, but also due to the amount of time and labour required to evaluate the growth of the experimental material. This is reason that it was not possible to use standard trees throughout the investigation. But it is the case that the whole range of tree sizes is planted for amenity purposes, and there is no reason to suppose that the underlying principles will not be the same, not only between different size classes but also between species.

In terms of methodology, the use of the glass sided boxes has proved an invaluable tool for investigating the responses of the trees in terms of root growth. By allowing for continuous monitoring of root growth, immediate effects of treatments could be followed. Any study that involves examining root growth poses considerable problems, especially where trees are involved. Excavation of roots in the field, inevitably results in some loss of fine roots, although the sandy conditions at the study site diminished this problem. The use of pots placed a finite limit on the rooting volume both in terms of horizontal spread and depth of penetration, yet the root system could be harvested in its entirety.

It could be argued that root weight was not the best criterion to evaluate, as it is not a parameter that characterises the absorbing amounts of roots in a soil (Bohm,1979), which was of particular interest where rooting volume was being investigated. No attempt was made to differentiate between roots of different diameters, root length or root number as this would have drastically reduced the number of replications that were possible, because of the time necessary to make these determinations. Nevertheless, root weight allowed changes in total underground productivity to be evaluated.

Other Investigations

One important factor that could influence root regeneration after transplanting and that was not investigated, was time of planting. The accepted period for planting deciduous trees is during the dormant period and all investigations discussed in this thesis have involved dormant planted stock. There are numerous reports suggesting that autumn planting is preferable to spring planting, resulting in increased root proliferation by bud break, a situation existing well into the growing season (Hensley, Khatamian & Gibbons,1984; Hinesley,1986; Gilbertson *et al.*,1987) but many of the investigations have concerned coniferous species. However any practice that results in autumn defoliation will detrimentally affect tree growth. Defoliation of trees even as late as the middle of October when leaves were beginning to senesce naturally, results in reduced growth the following spring (Larson,1975;1978). Spring planting is recommended for a number of coniferous species in preference to autumn planting (Cram & Thompson,1981).

A number of workers have demonstrated that root growth can be stimulated by spraying or implanting with auxins, indole-3-butyric acid and napthaleneacetic acid (Magley & Struve,1983; Prager & Lumis,1983; Struve & Moser,1984). However although auxins have been shown to be capable of promoting initiation, they have also been demonstrated to inhibit root elongation. This is an area where further work is justified and should be directed, to elucidate whether the widespread use of growth hormones would be justified.

It has been demonstrated that staking can have a profound influence upon both stem and root growth. The common practice that has evolved is to stake the tree rigidly and secure with tree ties. However this can lead to problems such as the trunk being damaged by rubbing, tree ties may girdle the trunk (Figure 8.2) and the tree top may be lost if the stake or tree ties break (Gilbertson & Bradshaw, 1985). Evelyn (1678) discussed problems related to staking of newly planted trees noting his disapproval of the single staking method:

> ".. secure it abundantly without the choking or frilling,to which trees are obnoxious that are only single staked and bushed, as the vulgar manner is."

Evelyn (1678) goes on to detail his preferred method of stabilising the transplanted tree:

> "I find a good piece of rope, tyed fast about the neck of the trees upon a wisp of straw to preserve it from galling, and the other end tightly strein'd to a hook or peg in the ground.....sufficiently stabilises my trees against the western blasts without more trouble."

The present work shows that with the very restricted root system, some form of support is necessary to stabilise the newly planted tree. But the methods of staking presently used, either a short or tall single stake with tree ties, can result if not correctly monitored, in the loss of the tree. It is suggested that further work be directed into investigating alternative methods of support, such as guying or the underground pegging of the root system.

Whilst this investigation has been limited to the initial period of establishment, which is certainly the most important in terms of tree survival, further work should include the later part of the establishment phase (years 3-5). During this period it is necessary to ensure that root development has occurred beyond the confines of the planting pit. It is probably during this phase that the success

Figure 8.2

Tie strangulation.

or failure of the landscape scheme will be determined. Adverse edaphic conditions certainly in the urban environment are often found outside the planting pit. Further work should therefore be directed towards managing the whole planting site rather than just the planting pit. Areas such as continuous planting spaces (Patterson,1985; Hammerschlag & Sherald,1985) and creative design of planting sites (Kuhns,1985; Kopinga,1985; Patterson,1985) are worthy of investigation.

One area of interest that could have a profound effect on amenity tree schemes is the suitability of certain species. Unlike forestry, there has been virtually no selection for performance or adaptation to urban conditions (Review Group on Arboriculture,1988). It is also not known if there are intraspecific differences in response to establishment pressures. This is an important area which justifies further research.

The implications of this piece of research extend to other areas such as forestry and orchard management. Today the scale of tree planting is increasing not only in this country, where community forests have been planned (Johnson,1989), but world-wide where extremely ambitious tree planting schemes have been discussed. Australia provides one such example, where it is planned to plant by the end of the century up to 1 billion trees at a cost of £150 billion (Anon,1989). Forestry will of course remain an important industry and amenity tree planting schemes will undoubtedly increase as their value to society is recognised.

Conclusion

It would appear that 'transplant shock' manifested as reduced vigour of the shoot system is an inevitable feature of the transplanting process. The reason appears to be a very simple matter of water relations and in particular the inability of the very reduced root system to provide sufficient water to supply the transpiration demands of the tree.

This series of investigations has demonstrated that there are basically two simple operations that can be carried out at either the nursery or the planting site to reduce the magnitude of the 'transplant shock'. These include:

a) increasing the amount of root system moved with the tree when it is transplanted.

b) increasing the water supply to the rooting zone of the newly planted tree either by irrigation or the use of a soil polymer.

Whilst the benefits of transplanting a tree with a larger root system have been clearly demonstrated, there is a need for further work to be carried out to produce a standard specification for the amount of root system that should be moved with different sizes of tree stock on transplanting.

Similarly whilst clear benefits of irrigation on tree growth have been demonstrated there is a need for further work to investigate different methods and rates of application.

The evidence presented suggests that the use of a cross-linked polyacrylamide polymer both in the nursery and at the planting site could have excellent benefits on both survival and growth of the newly planted tree. However there is a need for further information, and work should be conducted to assess the effects of the polymer on not only 1) different species but also 2) uses in the nursery 3) uses in the urban environment and 4) the effects of different types of polymer on tree growth.

Whilst the evidence from this investigation demonstrates that some form of 'planting check' is an inevitable feature of the process of transplanting, the high fatality rate is not a direct consequence of transplantation and results from a lack of proper maintenance. The most important factor that must be controlled is weed competition which has been demonstrated to have dramatic consequences on not only tree survival but also subsequent growth.

Clearly the benefits of this type of work can only be accomplished if there is good information transfer between all sectors of the arboricultural industry, from research, nursery practice, and both to and from the practitioners themselves.

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Appendix

Scientific Name	Common Name
Abies amabilis Forbes.	Pacific silver fir
Abies balsamea Mill.	Balsam fir
Abies fraseri (Pursh) Poir.	Fraser fir
Acer negundo L.	Boxelder
Acer platanoides L.	Norway maple
Acer pseudoplatanus L.	Sycamore
Acer rubrum L.	Red maple
Acer saccharinum L.	Silver maple
Acer saccharum Marsh.	Sugar maple
Betula pendula Roth.	Siver birch
Camellia sinensis (L.) Ktze.	Tea
Castanea sativa (Mill.)	Sweet chestnut
Carya illionensis (Wangenh.) K. Koch	Pecan
Cercis canadensis L.	Eastern redbud
Chaemaecyparis lawsoniana (A.Murr.) Parl.	Lawson cypress
Citrus aurantium L.	Sour orange
Citrus sinensis Osbeck	Sweet orange
Cornus florida L.	Flowering dogwood
Cotoneaster sp.	Cotoneaster
Cynodon dactylon (L.) Pers.	Bermudagrass
Cyperus rotundus L.	Nutsedge
Dactylis glomerata L.	Cocksfoot
Deschampsia flexuosa (L.) Trin.	Wavy hair-grass
Eucalyptus saligna	Saligna eucalyptus
Fagus sylvatica L.	Common beech

Festuca arizonica Vas.	Arizona fescue
Festuca rubra L.	Red fescue
Fraxinus americana L.	White ash
Fraxinus excelsior L.	Common ash
Fraxinus pennsylvatica Marsh.	Green ash
Gleditsia triancanthos L.	Honey locust
Holcus lanatus L.	Yorkshire fog
Hordeum vulgare L.	Four-rowed barley
Ilex crenata	Holly cultivar
Juglans cinerea L.	Butternut
Juglans nigra L.	Black walnut
Lactuca sativa L.	Lettuce
Libocedrus decurrens (Torr.) Florin	Incense cedar
Liriodendron tulipifera L.	Tulip tree
Lolium perenne L.	Perennial rye-grass
Lycopersicum esculentum L.	Tomato
Malus domestica Mill.	Common apple
Malus pumila Mill.	Common apple
Malus sargentii	Sargent crabapple
Muhlenbergia montana (Nutt.) Hitchc.	Mountain muhly
Nasturtium officinale R.Br.	Green water-cress
Picea abies (L.) Karst.	Norway spruce
Picea glauca (Moench) Voss	White spruce
Picea pungens Engelm	Colarado spruce
Picea sitchensis (Bomgard) Carr.	Sitka spruce
Pinus contorta Loud.	Lodgepole pine
Pinus elliotii Engelm.	Slash pine
Pinus ponderosa Laws.	Western yellow pine
Pinus radiata D. Don	Monterey pine

Pinus resinosa Ait.	Red pine
Pinus strobus L.	White pine
Pinus sylvestris L.	Scots pine
Pinus taeda L.	Loblolly pine
Pinus virginiana Mill.	Scrub pine
Platanus x acerifolia (Ait.) Willd.	London plane
Platanus x hispanica Muenchh.	London plane
Platanus occidentalis L.	American sycamore
Populus generosa	Poplar Cultivar
Populus tacamahaca x trichocarpa	Poplar Cultivar
Populus tremula L.	Aspen
Prunus amygdalus Batsch	Almond
Prunus avium L.	Gean
Prunus cerasifera Ehrh.	Cherry plum
Prunus laurocerasus L.	Cherry laurel
Prunus persica (L.) Batsch	Peach
Prunus serrulata Lindl.	Japanese cherry
Pseudotsuga menziesii (Mirb.) Franco	Blue douglas fir
Pyrus calleryana L.	Bradford pear
Pyrus communis L.	Common pear
Quercus alba L.	White oak
Quercus coccinea Muenchh.	Scarlet oak
Quercus palustris Muenchh.	Pin oak
Quercus petraea (Mattuschka) Lieblein	Sessile oak
Quercus robur L.	English oak
Quercus rubra L.	Red oak
Quercus stellata Wang.	Post oak
Quercus velutina Lam.	Black oak

Raphanus sativa L.	Radish
Rhododendron ponticum	Rhododendron cultivar
Salix alba L.	White willow
Secale cereale L.	Rye
Sorbus aria (L.) Crantz.	Whitebeam
Sorghum halapense (L.) Pers.	Johnsongrass
Tilia cordata Mill.	Small leaved lime