ROOT DEVELOPMENT OF *P. PATULA*

By

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Declaration

I the undersigned hereby declare that the work contained in this thesis project is my own original work and has not previously in its entirety or in any part been submitted at any university for a degree.

Signature:

Date:

Summary

Pinus patula is one of the most important softwood species planted in South Africa for fibre and timber production and also the main species to be planted in the North Eastern Cape managed by Mondi Forests. *Pinus patula* is an exotic species to South Africa and therefore only commercially exists in man made plantations. Transplants are being grown in containerised nurseries and flowing from this regime are root alterations with potential root deformity risks. Current difficulties include poor root development and instability. The so-called old land syndrome also occurs in old agricultural soils.

In this study my objective was to investigate the extent of this problem and whether the problem could be solved by better silvicultural practises. Literature indicated that bad root development occurs within the period in which transplants are kept in the nursery. Old land soils have numerous possible variables that could be investigated and tested. Trials were conducted where different dimensions of transplants, cuttings and seed were planted under different soil, climate and chemical conditions. Root development, root weight, root growth potential, shoot growth and survival were measured in order to establish the ideal containerised seedling dimension for optimum survival and growth. Ideal growth conditions for optimal transplant and later tree development in old land soils were also determined.

It was evident that smaller seedlings had better chances of survival and growth. The effects of container volume and dimension on root development were unfortunately not tested. My results indicated it a very important factor in root development. Taproots should not be pruned and the laterals should not start to grow in a horizontal circular direction, as it will cause an altered root development.

Old lands do not have a single individual factor causing bad survival and growth but rather a combination of factors. Weed competition weakens the transplants and other detrimental factors such as pathogens, soil structure deterioration, sub standard transplants, toxins and soil nematodes aggravate matters.

Opsomming

Pinus patula is van die mees belangrike sagtehout spesies tans aangeplant in Suid Afrika vir vesel en saaghout doeleindes. Genoemde spesie is die hoofspesie geplant in die studie area naamlik die Noord Oos Kaap bestuur deur Mondi forests. *Pinus patula* is 'n uitheemse spesie en kom kommersieel slegs in plantasievorm voor. Saailinge word in houer kwekerye gekweek en wortel misvorming kan hieruit voortvloei. Swak wortel ontwikkeling en onstabiliteit is twee van die hoofprobleme wat met laasgenoemde ondervind kan word. Die sogenaamde oulandsindroom word in 'n erge graad in die studie area ondervind

My studie poog om die omvang van genoemde probleme te ondersoek en of die probleme opgelos kan word deur verbeterde boskultuurpraktyke al dan nie. Literatuur dui daarop dat die wortelmisvormingsprobleem hoofsaaklik spruit uit die tydperk waar die saailing in die kwekery deurbring. Die oorsaak van mortaliteit in oulande is ook ondersoek.

Eksperimente is uitgelê waar verskillende dimensies van saailinge, steggies en saad geplant en getoets is in verskillende grond, en klimaats toestande. Wortel ontwikkeling, wortel gewig, wortel groeipotensiaal, lootgroei en oorlewing is gemeet ten einde die ideale saailing dimensie en groeitoestande vir optimum oorlewing en groei vas te stel.

Saailinge met 'n kleiner dimensie het 'n groter kans tot normale oorlewing en groei. Houerdimensie en volume is nie in hierdie studie getoets nie. Hierdie studie dui daarop dat houerdimensie en volume 'n belangrike faktor is in die ontwikkeling van wortels. Die studie dui ook daarop dat dit belangrik is om nie in 'n praktyk te verval waar die penwortel gesnoei word en laterale wortels horisontaal sirkelvormig begin groei nie. Genoemde sal wortel vervorming tot gevolg hê.

Geen enkel faktor kon vir die swak groei en hoë mortaliteit in oulande verantwoordelik gehou word nie maar wel 'n kombinasie van kompeteerders. Onkruid kompetisie het wel die saailinge onderdruk en gevoelig gemaak vir ander ouland beperkings soos patogene, grondstruktuurverval, lae standaard saailinge, toksiene en grondnematode.

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Frances my wife.

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1. Root development of *Pinus patula*: A literature review

1.1 Introduction

"The nature and practice of forest management is an adventure into the world of a gambler" (Hite, 1978). Current investment in soil preparation and planting of trees is enormous. A total of 30 011 hectares (Department of Water Affairs and Forestry, 1993/4) of South African State owned pine plantations were planted at a direct cost of R1214.27/ha (Rusk *et al.*, 1995) in 1994. These plantings (end 1996) add up to a total of 844 603 ha planted pine plantations in South Africa (Rusk *et al.*, 1996). These efforts can be nullified by planting incorrect plant material resulting in poor survival, growth and development. Prepared soils can puddle and fertilisers can leach out before plants can utilise the added nutrients. The South African forest industry had a capital turnover of R1 279 172 K and a total expenditure of R1 183 158 K in 1996. Losses due to incorrect silvicultural practices can therefore not be afforded due to the huge investments in young plantations (Rusk *et al.*, 1996).

Effective rooting depth (ERD) and soil moisture content are two very important factors affecting establishment and growth (Eis, 1970). A tree depends on its roots to absorb water, and minerals and for anchorage (Mason, 1985). Root systems of newly planted trees provide access to a limited volume of soil. The establishment success of trees depends on the speed with which they put out new roots, resulting in an improved nutrient and water uptake ability (Burdett *et al.*, 1983). The competitiveness and survival of a tree depends to a large extent on the size, shape, type and efficiency of the root system (Eis, 1978). The weight of the root system influences a trees stability, the heavier the root system the better the stability (Edwards *et al.*, 1963).

The form of root development affects plantation stability and yield (Mason, 1985). Grene (1978) stresses the fact that root deformations will reduce root growth throughout the life of the stand and that they lead to poor stability but will not harm field performance, such as stability in the first decade after planting. Root deformities may therefore be a hidden hazard to planted plantations. Lindgren and Orlander (1978) found a strong positive correlation between root area and stability of trees, as well as between increased height growth and a healthy root form. The effect of root development on tree growth could also influence plantation performance and the trees ability to contend with competing vegetation (Burdett *et al.*, 1983). Work done on *Picea mariana* by McClain (1978) showed that root deformations negatively affect growth and stability as well as decrease resistance to *Armillaria mellea* attack. *Pinus* species lack the ability as in the case of *Abies* species to produce adventitious roots, as a means to improve a root system that is inadequate at the time of planting (Håkansson and Lindström, 1995). Container and bare root culture (planted trees) will affect several root system characteristics (Stein, 1978). Burdett (1978) experienced tree instability for at least the first few years in planted pine plantations.

Control of the form and physiological condition of forest planting stock to promote satisfactory root development after planting provides an effective tool to improve seedling survival and productivity (Burdett *et al.*, 1983). Balneaves and De La Mare (1989) found in *Pinus radiata* that the straighter the taproot and the deeper its penetration, the less stem deviation occurs, and Mason (1985) documented that early stand stability depends on good taproot development. The quantity and quality of root development determines stability (Eccher, 1975 ex Grene, 1978; Stone and Norberg, 1978; Mason, 1985). Mexal and Burton (1978), in contrast, found no correlation between taproot deformation and seedling growth. As efforts in tree improvement increase and succeed, so will there be an increase in the need to change species and genotypes on the growing site. Natural regeneration can become uneconomical and even impossible. Some imported and locally produced seed is too expensive to waste and cost effective seedling nurseries is the only alternative (Tinus, 1978).

Kopparfors (complete reference not available, ex Tinus, 1978) experienced no negative results in planted trees with malformed roots. Entangled roots grow together and create new functional roots (Kopparfors, complete reference not available, ex Tinus, 1978; Hagner, 1978; Grene, 1978). Hagner (1978) reports that in the early years the central core of the root system may form a swelling that will disappear when overgrown by a continuous cambium layer. A newly planted tree may have a reduced resistibility to lateral pressure but regains normal stability very soon (Hagner, 1978; Van Eerden, 1978). Burdett (1978), in contrast, remarks that *P. contorta* seedlings tend to become less stable as they increase in size. According to Stefánsson (1978) young pine trees with entangled roots are easily pushed over. He further noted that in the next year the trees show a definite improvement in firmness, but it is apparent that an increase in initial pressure can cause root fractures. Stefánsson (1978) explained this phenomenon by examining sectioned root systems. With time, the curled and tangled roots become absorbed by fewer dominating roots and result in an even stronger rooting system. Until the mentioned deformities have been corrected, nutrient translocation is disrupted, and root fractures may lead to infection by decaying fungi and render the seedling susceptible to instability (Stefánsson, 1978).

Previous studies on root development relating to stem failure fall into the following three groups (Mason, 1985).

- Roots of toppled trees were investigated but not those of stable trees (e.g. Huuri, 1978).
- The forces required to pull over several different types of stock were measured (e.g. Lindgren and Orlander, 1978; Håkansson and Lindström, 1995).
- Stable and unstable trees growing in the same environment were excavated and measured (e.g. Edwards *et al.*, 1963; Droomer, Area manager N.E.C.F., pers. comm., 1994).

In undertaking this literature review I had problems with the definition of bare rooted and containerised seedlings. The reason for this is that researchers have different definitions for such seedlings. For example Owston and Stein (1978) transplanted bare rooted seedlings into containers and referred to them as containerised seedlings. Some authors (e.g. Van Eerden, 1978; Sloan *et al.*, 1987) define the age of seedlings but not the season in which grown, dimensions of seedlings or containers and fertiliser regimes, which are essential for comparison purposes. Another problem experienced is that some authors only refer to trees and do not mention the specific species. Where species were given, they are mentioned in this review, otherwise they are not. When comparing different seedlings, the definition and description should include certain quantitative and qualitative parameters (Chavasse, 1978; Rose *et al.,* 1990 ; Donald *et al.*, 1994).

In investigating such a topic, questions to be answered include:

- What does a normal root system look like?
- How do containers alter this ideal root system?
- Is there a compromised ideal artificial seedling?
- What are the effects of poor root form on survival, stability and growth?

1.2 What does a normal root system look like?

There are three main parts to any root system:

- The large structural roots, which are responsible for anchorage, stability and water uptake.
- The long exploratory fine roots, which also serve as anchorage and nutrient uptake (diameter 1-2 mm).
- The short and fine roots, also known as feeder roots (Davey, 1990).

1.3 Artificial alterations on root systems and factors influencing root configuration

When planting a transplant into the field a degree of root disturbance or alteration takes place. The effect and influence of these alterations should be investigated and analysed.

1.3.1 Containerised nursery systems

Containerisation takes place when a seed is planted and a seedling raised in any kind of containment to be planted into the field at a later stage.

1.3.1.1 History of container planting

Hundreds of years ago, pine were planted in central Europe with their roots in a clump of earth. The use of bare root seedlings dates from the beginning of the 19 th century when G. L. Hartig published his results. Interest in the use of containers arose again in the 1950's. Research done on other biological and technical fields was applied to add new dimensions and significance to this work. In the early 1960's, several new types of containers were developed for use in forestry operations. The reason for this development was the increasing need for forest regeneration and it was argued that this would be cheaper and more reliable than open rooted seedlings. Many problems were encountered when containerized plants were introduced on a large scale (Räsänen, 1981). Foresters who commit totally to a container programme, because it is supposedly a sure cure for all afforestation ills, will be disillusioned and disappointed after a short experience with controlled environment systems, because much research and experience is still needed in the use of containers (Hite, 1978). When looking at the results of this investigation and the amount of work currently in process on this topic this issue is still under severe scrutiny.

1.3.1.2 Containers

"Choice of container type depends as much on sentiment as it does on practicality" (Edwards and Huber, 1981). This quote indicates that Edwards and Huber (1981) were convinced that some foresters do not realise the importance of containers in the production of trees with healthy root and shoot development. Stone and Norberg (1978) reported that when root spiralling in container-grown seedlings is left uncorrected prior to transplanting, many of the transplants produce malformed roots. In severe cases, root malformation can result in structural failure near the root crown or in a one sided root system incapable of providing stability later in the life of the tree (Stone and Norberg, 1978). Root girdling can constrict the root's vascular system and therefore shortens the lifespan of a tree (Appleton, 1993).

Tinus (1976) lists the advantages of containerised seedling production compared to bare root production. Most obvious advantages are the opportunity to accelerate seedling growth in a greenhouse environment, optimising photoperiod, temperature, plant nutrition and pest control. Containerised seedlings have a higher survival and growth rate in the field than bare root seedlings (Owston and Stein, 1978; Hahn and Hutchison, 1978; Sloan *et al.*, 1987), and they can be held in the containers until planting conditions are suitable (Brisette, 1981). Containerised *P. ponderosa* seedlings outperform bare rooted seedlings, especially on harsh sites. On better sites the difference is less significant (Sloan *et al.*, 1987). Containerised seedlings suffer little transplant shock because little root disturbance occurs (Kinghorn, 1972 ex Romero *et al.*, 1986). Unlimited opportunities to control seedling growth, form, hardiness and physiological condition are obtained enabling the nursery manager to extend the planting season beyond bare root nursery seedling ability (Romero *et al.*, 1986). Hite (1978) mentions the cost advantage of containerisation in the northern Rockies which is 18% less than bare root seedlings. However, Chavasse and Balneaves (1971 ex Mason, 1979) and Lindgren and Orlander (1977) found that the occurrence of toppling was greater in tubed stock than in bare root stock.

Van Eerden (1981) observed that use of containers cause root deformations, which may lead to instability, basal sweep and toppling in some of the pines. Containerised rooting systems show the dominant influence that container design has on root morphology (Van Eerden, 1978). Hait and Tinus (1974 ex Tinus, 1981) experienced the problem of roots striking the container wall during development, resulting in malformed roots. Kopparfors (complete reference not available, ex Tinus, 1978) found that seedlings grown in trays with firm walls have less difficulty in growing into the neighbouring soil after planting than open rooted seedlings. According to him these roots develop better because they are in close contact with the soil. Containers with stiff, impermeable-walls, vertical ribs or grooves, lack of sharp horizontal corners, and a hole at the bottom for air pruning are used to produce seedlings with untangled roots (Stefánsson, 1978; Tinus, 1981). Unfortunately, most of the new roots grow from the bottom of the plug, leaving the seedling with an inadequate root system that may lead to swaying and toppling of older trees (Tinus, 1981). Harrington *et al.* (1986) reported that planted containerised *P. echinata* seedlings lack a tap root in 30% of the cases compared to a taproot absence of 15% in natural regenerated seedlings. Seedlings with vertical taproots exhibit greater height growth than trees with deformed root systems and are generally more stable.

Pine taproot development is also influenced by containerisation. Menzies (1974 ex Mason, 1979) observed that 50% of stable trees, but only 25% of toppled trees have taproots. Lateral root development of 67% of toppled stems are in one horizontal direction while only 43% of the stable trees have such a root configuration. Mason (1979) found a positive correlation between toppling and the state of taproots. The better the taproot development the better tree stability.

he container determines the size and shape of the root system. In Sweden, Lindgren and Orlander (1976 ex Mason, 1979) compared different sizes of containers. Many containers restrict root development and cause spiralling and strangulation. This is often accompanied by a slight increase in above ground portions and such trees are more likely to topple. Container volume determines seedling size and shape and is important in the production of an untangled root system that will promote field establishment and wind firmness (Tinus, 1981). Although container volume can affect seedling growth, growing density and thus competition for light is a more important factor influencing growth of seedlings in containerised nurseries (Simpson, 1991). This will also affect growth and survival after planting. Hunt (1990) found smaller shoots and heavier roots in *Pseudotsuga menziesii* and *Abies* spp. seedlings in smaller seedling containers (50 to 60 ml). This can be an aid to limiting height growth in nurseries. Copper treatment of nursery containers has little effect on the shoot growth of pines but root fibrousity and mycorrhizal development (*Thelephora terrestris*) will increase. Larger containers are promoted until enough research has been done on smaller containers (Tinus, 1981).

Owston (1990) found no difference in survival between seedlings produced in containers, bare root seedbeds and seedlings that were transplanted into containers. The prescribed sizes and dimensions of seedlings from different production methods and container sizes differ considerably. Jansson (1971) reports that plants with root spin/strangulation have a greater average height than plants without root spin/strangulation. According Jansson, 1971; Grene, 1978; Hagner, 1978, root strangulation and root malformation cannot cause instability and plant losses

1.3.1.2.1 Air pruning

The question of whether or not to prune roots is a rather difficult one to answer. In the literature there are sound research reports confirming both opinions. These conflicting opinions are probably due to differences in species, container shapes and sizes, and transplant size. Air pruning involves a container design, with opening, in the side of the plugs, so that when a root comes into contact with an opening, it forms a dormant bud. After planting, when it comes in contact with the soil, the bud will flush quickly. This method is becoming more popular, especially in countries with strict environmental regulations. Aiking (1995) and Håkansson and Lindström (1995) recommend air or copper pruning for species with poor adventitious root formation.

Air pruned seedlings have root systems with active tips not just at the bottom of the plug but also along the sides. These active root tips assist the plants in overcoming transplant shock, thus improving survival and growth. The reason for this improvement in root development can be ascribed to improved oxygen availability to the roots. Disadvantages of this system are the higher water consumption and the more pronounced edge effects. The benefits, such as the improved seedling and the cost effectiveness of the system, outweigh the disadvantages according to Aiking (Director of Marketing BCC, pers. comm., 1995).

Privett and Hummel (1992 ex Appleton, 1993) found that a porous-walled container with pin hole perforations randomly distributed along the container wall produced roots superior to non-porous smooth and ribbed containers.

1.3.1.2.2 Chemical pruning

To eliminate the effect of containers on root form, thereby improving stability after planting, can be done by means of chemical root pruning (Bell, 1978; Burdett, 1981; Gordon and Hayes, 1994). This technique involves the use of seedling containers treated with cupric carbonate. There are however concerns regarding the environmental and safety impact of copper products. The use of these products must comply with all the relevant safety regulations on its use (Regan *et al.*, 1993). Roots will cease to elongate when in contact with the container wall resulting in a tree with a box pruned system with a root configuration comparable to a naturally regenerated system (Burdett, 1981). Chemically pruned roots will resume radial growth after the container is removed (Burdett, 1978; McDonald *et al.*, 1981; Burdett *et al.*, 1983). Root growth is influenced by the amount of auxin in the root tip, a stunted root tip will end up branching. Chemical root pruning is actually a form of copper toxicity (Regan *et al.*, 1993). Chemically pruned *P. contorta* stock grows faster in the field than unpruned stock. The difference in growth rate is associated with a difference in root form. Mechanical stability by promoting lateral root development straight from the taproot close to the soil surface is achieved with chemical root pruning (Burdett *et al.*, 1983; Regan *et al.*, 1993). Absence of root spiralling and other root deformations are reported after work done on chemical pruning by McDonald *et al.* (1984 ex Romero, 1986) and Gordon and Hayes (1994), resulting in greater seedling stability and resistance to windthrow. In contrast, root growth in seedlings from untreated containers are largely restricted to elongation of laterals growing downwards against the container wall (Burdett, 1978).

Chemical root pruning on *P. contorta* is only effective in small containers. In the larger containers a fair amount of second order lateral root growth takes place (after pruning of the first order lateral root) before lifting is possible. This will result in a large amount of laterals growing downwards after planting. This root growth dominance will prevent seedlings from growing laterals perpendicular to the taproot (Burdett, 1981). The effect of nursery treatments and planting on root form diminishes with time, however, and the same can be expected of chemical root pruning (Armson, 1978).

1.3.1.2.3 Biodegradable pots

The requirements for biodegradable paper pots are a thin layer of material incorporating both biologically degradable components and components resistant to attack (Sugden and Scarratt, 1981). The advantages of paper pots are firstly the biodegradability of the pots and secondly allowing free growth through the walls. Salem (1978) promotes the paper pot as one of the only containers which offers excellent opportunity for mechanisation. In contrast, Tinus (1978) experienced problems with paper pots, especially when they were not moist enough. He found root spiralling on seedlings after planting, especially on dry sites. Salem (1978) found that the permeability of the walls is not enough for lateral root penetration. Grene (1978) noted root spiralling due to the resistance of paper pots to decomposition even after 3-5 years in the soil.

Kraft paper tubes were one of the earliest container materials tested. These tubes are thick walled and decompose slowly in sandy soils. Light kraft paper tubes fold easily for shipment but planting is difficult because of rapid degradation of the tubes. Both the heavy and the lighter kraft tubes cause seedling chlorosis from nitrogen utilisation during the degradation process (Barnett and McGilvray, 1981).

Walters' planting gun and plastic bullet technique was developed and used in the early 1960's in Canada (Walters, 1961 ex Barnett and McGilvray, 1981). This technique opens the way for planting the seedling without removing the container, but has a negative effect on the effectiveness of planting and root development in heavier soils.

The Japanese paper pot contains plastic fibres and chemicals to increase durability and to resist soil micro-organisms. Tubes degrade slowly, disallowing the roots to grow freely through the pot wall and only a few roots manage to get through, resulting in low survival and growth (Barnett and McGilvray, 1981).

Conwed tubes consist of a plastic netlike material and can be manufactured in several lengths. Tubes are not biodegradable and roots become severely constricted, when attempting to grow through the netlike container wall, eliminating these tubes as an option (Barnett and McGilvray, 1981).

Biodegradable plastic tubes are manufactured from an aliphatic polyester, polycaprolactone and are susceptible to attack and assimilation by microorganisms (Potts *et al.*, 1972 ex Barnett and McGilvray, 1981). Degradation rate can be controlled by wall thickness. Survival is better than in paper tubes. These tubes have a number of unique and promising characteristics but the relatively high cost of material discouraged complete development of this system (Barnett and McGilvray, 1981).

Seedlings can also be grown in blocks manufactured from a synthetic or organic medium (Polyloam and Gro blocks), and planted in the field in these blocks. Problems such as bad survival, growth and the inability of blocks to retain moisture, disqualify this option (Barnett and McGilvray, 1981). Kys tree starts, is a block and consists of a blend of sphagnum peat moss, vermiculite, cellulose fibres and nutrients. This block outperformed or equalled the other containers in terms of field survival and growth in work done by Barnett and McGilvray (1981). As problems with containerisation increase, options like the Kys tree starts should become more popular.

1.3.1.3 Size and shape of containers

Container volume determines seedling size and shape and is important in the production of an untangled root system that will promote field establishment and wind firmness (Tinus, 1981). *P. caribaea* and *P. oocarpa* seedlings grown in large diameter containers (65 mm diameter) were smaller but had a higher survival rate and better height increment in the field than plants raised in smaller diameter containers (32 mm diameter) (Solberg, 1978). With rooting volume held constant, root growth responds more to container diameter than length (Boudoux, 1972 ex Romero, 1986). The root collar diameter is largest in the largest tube diameter and smallest in the smallest tube diameter (Berger and Lysholm, 1978). Tube size 65 mm x 10 mm x 10 mm (volume 329 ml) gives a survival rate as good as tubes of 49 mm x 20 mm x 20 mm (volume 369 ml), in spite of less soil volume. Differences in tube length do not result in different height growth up to 4 months after sowing, but the survival rate increases with increasing tube length. High seedling density (affected by tube diameter) in a nursery bed will stimulate height growth. (Solberg, 1978). The influence of tube length on field survival is not as distinct as with tube diameter (Solberg, 1978). Survival as a function of tube volume (up to a limit) expresses a good correlation. Very little has been achieved by exceeding a volume of 277 ml (survival 86.6%).

Romero *et al.* (1986) report that root dry weight, shoot dry weight and shoot length of 20 week old *P. contorta* seedlings increased significantly as rooting volume increased from 10 to 524 ml. Seedlings grown in the largest containers weighed 10 times more than those grown in the smallest containers. Rooting volume became limiting over time beginning with the smallest container. Rooting volume did not become limiting until 14 weeks in the largest container. In contrast, container size does not significantly affect survival of *P. monticola* seedlings planted on a marginal site (Miller and Schaefer, 1984).

1.3.1.4 Stock type designations

A stock type designation identifies seedling age and method of production. Generally, little is reported on size and physiological condition of seedlings (Owston, 1990). Both physiological and morphological parameters should be included in the records in order to improve the value of information. Stock type designations are valuable when deciding on ideal transplant characteristics for problem areas because it is correlated with survival and growth on a specific site type.

1.3.1.5 Container loading and seeding

In the late seventies, Hellum (1978) expressed the need for research on container medium. He ascribed the lack of root egress out of the medium into the soil to the type of medium used in the nursery. Goodricke (1992) warned the nurseryman against buying cheap growing media. The best way to go is in using a tried and tested growing medium and to develop some method of testing new batches. Important variables include particle size, distribution and air filled porosity. Quality of irrigation water is of utmost importance and can nullify all other nursery treatments. All irrigation water should be tested regularly and if necessary, appropriate action should be taken to correct any imbalances (Goodricke, 1992).

Compaction of medium after tray filling is very important. If a growing medium mix of peat:vermiculite (3:1 by volume) is used, an optimum compaction of 0.11g/ml is prescribed. Usable compactions may vary between 0.08g/ml to 0.13g/ml. Values above 0.14g/ml will result in difficult lifting. Container cavities should be tamped to a depth of 5mm and covered after sowing (Matthews, 1981).

1.3.1.6 Pathogens

Any agent causing a disease is called a pathogen. Pathogens may be either biotic such as fungi or abiotic such as air pollution. Some pathogens are parasites, but not all parasites are pathogens (Manion, 1981). Unlike tree diseases in natural forests, diseases are more amplified in uniform age plantations and in the reduced genetic diversity found in plantations. Diseases are one of the greatest threats to plantation forestry and have become progressively more important in recent years (Wingfield and Kemp, 1994). Root deformations can affect development and growth of young stands resulting in a stressed tree with a root system more susceptible to fungal attacks (Håkansson and Lindström, 1995). Once the tree's vitality is reduced, the stem also becomes more vulnerable to fungal attack. (Manion, 1981)

Incorrect forestry practices such as overstocking, soil compaction and off site plantings may accentuate the effects of diseases. In low resistant pathogen plantations, the probability of experiencing huge losses is great.

Therefore, management of diseases, developing an integrated forest protection plan and the implementation of a better quarantine and detection system is essential. This can be achieved by encouraging co-operation between forest protection specialists and forest managers. Good silviculture practices, such as greater species and genetic diversity, minimise stress and can thus reduce the susceptibility to pathogen attack (Wingfield, 1994).

1.3.1.7 Nursery nutrition

Care must be taken in interpreting nursery nutritional results of other forestry regions where seedlings may require special treatment to withstand specific stress factors. Nurserymen commonly use nitrogen in the first stages of seedling production to obtain maximum shoot growth. A decrease in nitrogen and an increase in phosphorus to obtain a “hardened” seedling follow this. According to Nelson (1992), root dieback may result from such a fertiliser regime. He suggests a general fertiliser regime of N:P:K:Ca:Mg:S in the ratio of 3:1:5:3:1:1 as a means of producing acceptable seedlings.

Application of N fertilisers at a later stage of the nursery phase increases stored N in plants but no new succulent growth will form. This can increase root growth capacity and initial survival (Donald, 1988). It was further found that increasing nitrogen supply can reduce drought resistance. Van den Driessche (1991) in contrast found that increasing nitrogen levels in deficient soils improves drought resistance after planting.

Donald (1988) found that an optimum *P. radiata* seedling can be obtained if 0.05 g N and 0.067 g P per tree are applied forty days before planting.

High soil fertility can lead to lush growth of tree tops, resulting in a high susceptibility to toppling (Chavasse, 1978; Hirvelä and Hynynen, 1990). Root elongation is positively affected by an increase in phosphate levels and soil temperatures (Bowen, 1969). Sustained phosphate uptake at lower temperatures does not compensate for greater root growth at higher temperatures, because P content is much higher in seedlings grown at 27°C than in seedlings grown at 15°C. There is no significant difference in growth between high and low phosphate levels at 27°C.

Results from a Sappi field trial indicated that "hard" and "soft" *P. patula* transplants produced for better survival showed no significant difference in survival (Morris, 1993a; Bayley, 1995). Seedlings stressed with lack of nutrients to harden them off are likely to lead to high mortality rates because of their lack of vigour. Similarly, seedlings oversupplied with nutrients, especially nitrogen, tend to be soft, weak and prone to diseases and wilting. A balance is therefore needed to ensure a transplant able to survive and grow well under all planting conditions (Nelson, 1992).

Container size is a very important consideration when devising a fertilisation regime. Seedlings can be damaged and mycorrhizal formation negatively affected by over-fertilisation (Langlois and Fortin, 1981). Care must be taken not to confuse factors such as waterlogging, poor aeration and low temperatures, which reduce root absorption ability, with nutrient deficiencies (Nelson, 1992).

1.3.1.8 Mycorrhizae

The physiological activity of the root is to provide the plant with water and nutrients. Mycorrhizal fungi assist roots in the above-mentioned functions by means of a symbiotic association. The main role of mycorrhizal fungi is the conversion of minerals in the soil and decaying organic material to an accessible form to the host plant. The host in turn supplies carbohydrates to the fungus (Esau, 1977).

An ectomycorrhizal fungus association is essential in many tree species, including *Pinus* species for normal growth and development in the field. Mycorrhizae can thus be a biological tool to improve survival and growth of pines on both poor and good sites (Marx *et al.*, 1984; Pate, 1994). Copper-mycorrhizal treatments are very effective in increasing the number of short roots as well as the percentage of mycorrhizal roots in *P. ponderosa* (Mc Donald *et al.*, 1981).

It is important to inoculate forest tree seedlings with selected mycorrhizal fungi before planting in the field to enable the beneficial fungi to colonise the root systems before competition with other microbes start. Marx *et al.* (1984) showed that the most effective inoculum has abundant hyphae inside the growing medium, pH (water) between 4.5 and 6.0, low amount of microbial contaminants and low amount of residual glucose as a consequence of leaching the inoculum before drying.

1.3.1.9 Defective nursery practices

Nänni (1960) compared roots of planted and naturally regenerated *P. patula* trees and found excellent root systems in the naturally regenerated trees, which may be due to protection of the seedlings from wind, or to the fact that these trees are not disturbed. Pricked-out seedlings taken from nursery boxes have many distorted roots.

Van Eerden (1981) lists four don'ts in the nursery:

- Damage to roots
- Pot-binding
- Root growth into container walls or into adjacent cavities
- Contamination

According to Mason (1979) and Sutton (1979), rough handling of stock during lifting and transport can lead to broken and deformed rooting systems. This will result in less stable roots than undamaged root systems. Seedlings grown in nurseries under climatic conditions different to those in the field will perform poorly in the field (Sutton, 1979). Field stability will decrease if the seedling is kept too long in the nursery, even if grown in containers with guide bars (Håkansson and Lindström, 1995).

1.3.2 Bad planting and method of planting

"Quite probably the only means of preventing mechanical instability in planted pine is to use planting methods which do not cause any persistent modification to the natural pattern of root morphogenesis" (Burdett, 1978). Foresters recognised many years ago that bare root planted seedlings, showing poor growth after planting, are the result of root disorders. These problems can often be related to incorrect planting techniques (Hait, 1978; Burdett, 1978; Hite, 1978). To ensure optimum planting, Blake (19??) recommends that a set of planting specifications must be developed as well as a system to ensure that these specifications are achieved by the planters. Planting technique and quality can be improved by optimising the planting pit, proper filling of pit after planting, preventing root disturbances, mulching, using super-absorbents where necessary and planting on ideal planting days (Theron, 1994). Storage period and time of day when planted play a role in survival after planting (Morris, 1993). Many people over-emphasise establishment costs, but ignore the unit cost of the end product.

Nänni (1960) found no bad planting in the field in his Cathederal Peak windfall studies. The trees were planted with their roots buried straight down to somewhat more than their full depth, earth added, and the transplants then lifted slightly to straighten any root distortion. The transplants had only a taproot and two or three feathery lateral roots, which were unable to properly anchor the transplants.

It was found by Shultz (1973) that trees with deformed roots at time of planting have better stem growth up to at least the 15th year. Shultz (1973) states that root deformation at planting does not appear detrimental to tree growth.

Ritchie and Tanaka (1990), in contrast, found that root growth potential (RGP) is negatively affected by bad planting. According to Mexal (1991), poor planting can result in a reduction of growth, yield and survival, thus necessitating a complete replanting of the site. Examinations of root systems by Stoszek (1978) indicate that reduced growth and survival can be ascribed to root deformities administered by the planting tools. Parts of these root systems are often dead and infected by *Armillaria mellea*. He also calls attention to the correlation between regeneration, pests (insects and diseases) and nutritional characteristics of trees. If a tree looses its ability to develop roots, thereby impairing nutrition uptake, additional insect and disease problems can be expected. Slit planting deforms the root systems of *P. elliottii* and is the cause of some windfalls in young pines (Shultz, 1973).

Klawitter (1969) found that bad planting affects the growth and development of tree seedlings, as well as their susceptibility to wind damage. The first signs of incorrect planting methods are early mortality. Root disturbance at planting may have a negative effect on survival. Mason (1985) excavated trees that had snapped below ground level and found that all these trees displayed the same constriction of lateral roots growing around the bole. This so-called "Ball and Socketing" is ascribed to bad planting of open-rooted seedlings by Mason (1985). However, it is also caused by constricted root systems of seedlings kept in nursery containers far too long. Tanaka *et al.* (1976, ex Tinus, 1978) stress the fact that seedling roots must get into the planting slit with no or as little as possible disturbance, preventing many of the problems that developed in the past. Transplanting stress and slow recovery are induced by poor root to soil contact (Sands, 1984 ex Nambiar, 1984).

Morris (1993a) found a decrease from 48% to 13% in mortality when planting *P. patula* correctly. He prescribes the use of a fresh pit combined with deep planting. Where the upper soil horizons are subject to drying, deeper rooted plants will presumably obtain more water (Burdett, 1990). Ellis (Soil scientist U.S., pers. comm., 1996) recommends a planting hole deep enough enabling planting without any root disturbance. In the case of shallow soil limitations the planting pit must eliminate the limitation (Louw, Asst. Director, Soil Sciences, Nietvoorbij, pers. comm., 1996). A square planting pit with loosened walls is optimal (Ellis, Soil Scientist U.S., pers. comm., 1996; Louw, Nietvoorbij Director, Soil Sciences, pers. comm., 1996).

1.3.3 Silvicultural practices

Silviculture is the cultivation of forest trees (Hawkins, 1988). All activities man undertakes on forest land should take place in the most responsible and productive manner. All actions and activities should be scrutinised and evaluated before implementation to determine whether it is optimum or not (Frahm-Arp, Resource manager, Sappi Forests, pers. comm., 1998).

1.3.3.1 Soil characteristics and soil types

The below ground environment is highly variable with major changes over short distances in the composition of soil particles and pores, water and nutrient content and physical structure. It often consists of a mosaic of micro sites (Atkinson and Last, 1994). Nel and Bennie (1992) found on citrus that soil strength, at a depth of 100-200 mm, and the air capacity of the lower subsoil the most statistically significant factors influencing top growth and root development. With a soil strength above 0.5 MPa, tree volume and root penetration decrease significantly. Nänni (1960) mentions the detrimental effect that expansion and contraction of soil cracks (e.g. vertic soil properties) have on root development and growth of *P. patula*, it can even be injurious to roots. The absence of trees in parts of Mpumalanga is mainly ascribed to these actions.

Haigh (1990) ascribes effective rooting depth (ERD) as one of the major factors influencing the growth and development of roots. The deeper the soil, the more volume of soil will be available, and thus the higher the available nutrients as well as the moisture holding capacity of the soil. Different soil types have different effects on root development and configuration (Eis, 1970). *P. patula* has a critical rooting depth demand of at least 600 mm (Haigh, 1990). Effective rooting depth is determined by the following factors (Chavasse, 1978; Yen *et al.*, 1978; Donald, 1988; Haigh, 1990):

- Hard rock

  Continuously hard layer of rock that cannot be penetrated by roots and cannot be cut by a spade when wet.
- Soft fissured rock

  Weathering bedrock with affinities and characteristics with underlying parent rock.
- Stone lines or layers

  Hard to very hard non-continuous rock layers or lines.
- Dense clay

  Horizon or layer that is considerably less permeable and more clayey than the overlaying material.
- Soil moisture

  Both too high and too low soil moisture contents will affect root development and growth negatively. Roots will either die of drought or waterlogging in mentioned extremes.
- Soil depth

  Soil depth is the area in which roots can effectively grow and develop. All above-mentioned factors will have an influence on soil depth.
- Texture

  The ratio sand to clay to loam determines the texture of soils. Soils with a very high clay content for example will impede root development and growth.
- Bulk density

  Soil bulk density can be defined as the mass of dry soil per unit bulk volume. High bulk densities will have the ability to impede roots to develop freely.
- Soil strength

  High strength soils will have the ability to resist soil deformation. Roots deform soil in order to develop and grow and could be inhibited in soils with a high strength.

- Aeration

  Aerated soils have soil air replaced by atmospheric gasses and could improve the rooting ability in such soils.
- Depth to water table

- Aeration

  Aerated soils have soil air replaced by atmospheric gasses and could improve the rooting ability in such soils.
- Depth to water table

  As in the case of soil moisture content, the water table is also largely inaccessible for root development.
- Nutrient content

  Roots will develop towards an area with high soil fertility. Fertile soils will positively influence root and shoot development.

Fraser and Gardiner (1967) investigated the root development of *Picea sitchensis* on four different soil types. The impeding factors for root development are: *Armillaria mellea*, soil compaction, rock layers, hard setting and wetness. Root grafting takes place in soils with impeded drainage and in mineral soils. These trees will pull other trees over when windfall occurs. Root development will improve when waterlogged soils are drained. High rates of toppling have been noted on fertile farmland sites (Chavasse, 1969 ex Mason, 1985). Fertile soils usually encourage root production, but Nambiar (1980) found that the increase in root production can not keep up with above ground production.

1.3.3.2 Soil preparation

Soil preparation is the manipulation of the soil environment surrounding the roots to make the conditions for root development as ideal as possible. The choice of soil preparation method depends on physical and chemical barriers, residues from previous rotations and terrain. Improvement of soils is essential and care must be taken not to weaken the soil with the soil preparation method (Ellis, 1994). Restrictive layers such as hard rock (but still breakable), soft fissured rock, stone layers, plough-pans or compacted (strong) soils can be rectified by using mechanical soil preparation methods such as ripping or deep ploughing. Wet soils can be drained by ripping with the drainage direction, or ridging can be used. Deep clay layers can be left untouched by only cultivating the material above by using implements such as a shift or a wing plough (Lambrechts, 1994).

Taproot penetration of *Pinus radiata* in deep ripped soils (100 cm) is deeper (up to 153 cm) and has less root distortion (Menzies' scoring system) than those from shallow-ripped soils (60 cm) (Mason, 1979; Mason, 1985; Balneaves and De La Mare, 1989). According to Yeatman (1955), intensive site preparation tends to change the micro topography and drainage patterns. This also greatly influences the form and development of root systems.

Ripping can reduce toppling propensity by encouraging vertical root development. Bedding in contrast can, at least in Andisols and Humic soils, increase the likelihood of toppling (Mason, 1979; Edwards *et al.*, 1963). *P. contorta* seedlings planted by Håkansson and Lindström (1995) on ploughed sites are more stable than trees planted on mounds. Cultivation with discs or rotary hoes tends to induce or aggravate toppling, and winged rippers are possibly a better option (Chavasse, 1978). Average lateral root lengths of *P. elliottii* were 28 cm in furrows (1 m wide and 7-12 cm deep), and 61 cm in beds (1.1 m wide and 30 cm high) in a trial done by Shultz (1973). He found that taproot length is significantly longer in the beds than in furrows, probably because bedded trees are further from the water table. Mason (1979) found that taproot elongation will cease when reaching the compacted pumice layer beneath the mounds and toppling is significantly more frequent in the bedded treatments, because roots are confined to the loosened soil. Likewise, in a comparison of Mason (1985) of a ripped block and a ripped and bedded block, more trees tended to topple in the ripped and bedded block.

Single line rip results in orientation of primary and secondary lateral roots in the rip line and can influence wind firmness (Klawitter, 1969; Mason, 1979; Balneaves and De La Mare, 1989). This confinement in the rip line will become more pronounced in the secondary lateral roots. Toppling perpendicular to rip line takes place as well as in rip lines in loose soils (Mason, 1985). Root development in deep rip lines increases anchorage, but will result in a tendency towards stem failure rather than uprooting. Unripped treatments have fewer trees with sinuous stem form (Mason, 1979; Balneaves and De La Mare, 1989).

Plants planted in planting holes with glazed clay walls will tend to have a circle or girdled root configuration. The clay walls restrict natural root development into the neighbouring soil. Roots may even circle on the outside of the medium in container grown trees (Appleton, 1993).

Tree size and soil strength varies within one soil preparation method. Trees in cultivated soils are larger and toppling can also be influenced by tree size, not only by soil preparation method. Soil preparation can increase the likelihood of toppling in loose and sandy soils but prevent toppling in hard compacted soils (Mason, 1985).

1.3.3.3 Spacing

Fraser and Gardiner (1967) investigated the effect of spacing on root development and found that widely spaced trees have a root plate diameter less than the espacement resulting in root systems that do not touch each other. Sinker roots develop from under the stump with smaller sinkers growing down from lateral roots. On the closely spaced trees the root plate diameter is greater than the espacement. Sinker roots are concentrated under the stumps. Spacing in containerised nurseries cannot be manipulated in the same manner as in open rooted nurseries, thereby excluding spacing to a greater extent as a tool in manipulating root configuration.

1.3.3.4 Genetics

Regardless of the phenotypic characteristics of the mother tree, associated progeny will exhibit a range in seedling development related to distribution of permanent first order lateral roots. (Kormanik and Muse, 1986 ex Kormanik, 1988). Eis (1970) reports on the difference between root development of different trees. This complicates the whole issue because the literature often only refers to trees, without mentioning species, and therefore assuming no variability between or within species. Lavender *et al.* (1993, ex Atkinson and Last, 1994) compared the root systems of 30 different *Betula pendula* clones and found a marked difference in the total mass of the roots, total length of white and woody roots, root distribution and root to shoot ratios. Variations in the anatomical structure of roots have also been identified. It is therefore possible to select trees for a well-developed rooting system enabling habitat matching or site specific planting (Atkinson and Last, 1994). Genetic factors, seedling morphology and physiology, and site factors influence seedling quality and survival (Brisette, 1984). Tree selection on the basis of first order lateral root (FOLR) development can be done as a standard nursery procedure, because the number of FOLR's influences survival and growth (Kormanik *et al.*, 1990). This characteristic appears to be under direct genetic control (Kormanik, 1987).

1.3.4 Drought and other environmental factors

Although environmental factors influencing seedling survival and growthare largely out of mankind's control, these factors can be predicted, avoided and managed.

1.3.4.1 Drought

Newly planted seedlings can be exposed to drought through limited soil moisture and high evaporative demand conditions of the atmosphere. Drought causes plant water stress by restricting water uptake from the soil and by insufficient stomatal control as evaporative demand increases, resulting in growth reduction (Grossnickle and Folk, 1993) and increased seedling shock (Haase and Rose, 1993). Stressed seedlings have reduced leaf conductance and photosynthesis. A reduction of reserve carbohydrates and currently available photosynthate occurs, the latter of which is considered to be the primary energy source for root growth in some species (Van den Driessche, 1987).

Stock quality improvement can alleviate the stress transplants experience on afforestation and re-afforestation sites. Increased root volume may enable open rooted Douglas fir seedlings to avoid shock following outplanting (Haase and Rose, 1993). A programme defining a transplants' functional integrity could determine whether it has the capability to survive under the unfavourable conditions. Functional integrity indicates whether a transplant is, or is not, damaged to the point of limiting primary physiological processes (Grossnickle and Folk, 1993). Haase and Rose (1990) found that new shoot growth will decrease and days to budbreak will increase with an increase in moisture stress. This effect is most pronounced in the high root volume seedlings.

In studies undertaken by Balneaves and De La Mare (1989), more primary lateral roots developed in the leeward quadrants of the stem which is in contrast to other findings that heavier lateral root development occurs on the windward side of trees. A possible explanation for this rooting pattern is a rain shadow on the leeward side of trees where rain occurs in windy storms. Observations by Fraser and Gardiner (1967) do not reveal any tendency for more or bigger roots to develop on any side, even on the lee-side of the prevailing winds.

1.3.4.2 Wind

Chavasse (1978; 1979) reports that shelter is considered to be important in wind exposed nurseries. Wind can have a detrimental effect on seedlings resulting in abrasion by soil particles in extreme cases. Le Roux (1955 ex Nänni, 1960) eliminates the possibility of wind damaging young *P. patula* trees. "It can be said with certainty that the immature stand of *P. patula* is immune to wind damage". Wind can therefore only be responsible for the final breakage of weakened trees.

Young trees may create circular holes around their stems from swaying in prevailing winds, this is called socketing. Significantly ($p<0.01$) more socketed *P. radiata* trees planted in New Zealand were toppled than unaffected trees (Mason, 1985). Tree swaying will constantly damage new developing roots and compaction around the root plug can also occur. Planting transplants deeper, thus reducing plant sway can reduce this problem. Abnormal root systems can result in pronounced bow or crook in the stem as a result of bad anchorage in windy conditions. Naturally regenerated trees have excellent root systems and can be ascribed to undisturbed root growth or protection of seedlings against the wind. Nänni (1960) recommends that soil should not be loosened when pitting. Only a small hole large enough to accommodate the roots is efficient. When the seedlings are pricked out, it is recommended to plant them in conical tarred paper cups to avoid disturbance or damage. This resulted in a years' growth gain in *Eucalyptus saligna* (Nänni, 1960).

A windfall assessment done by Versfeld (1980) indicated that wet soils tend to be more susceptible to windfall than the same soil in a drier season. Increased rooting resistance on drier sites is responsible for the lower windfall counts but these better-anchored trees tend to break (Mason, 1979; Versfeld, 1980). Versfeld states that improper previous management practices, e.g. delayed thinning and exposed sites, contribute to the high windfall occurrence. Soil type is eliminated as a possible contributing factor because trees on shallower and sandy soils adjacent to damaged areas are not affected.

1.3.4.3 Ground slope

Fraser and Gardiner (1967) found a tendency for lateral roots to concentrate on the downhill side, and the sinker roots to grow on the uphill side.

1.3.4.4 Temperature extremes

The beginning of rapid root growth after planting relies on a favourable soil temperature. This begins when soil temperatures exceed 10°C (Carlson, 1986). Soil temperatures can however easily exceed 30°C, 10 cm below ground level. Such temperatures, coupled with adequate soil moisture, can result in root death in the first season after planting (Balneaves and De La Mare, 1989). Marshall and Waring (1985) found a starch depletion in *Pseudotsuga menziesii* seedlings at soil temperatures exceeding 20°C. The previously deposited starch is used to maintain older roots. Root mortality closely follows the exhaustion of starch and sugar reserves. Roots grow faster as temperature increase up to 25°C but root decay starts at higher temperatures (Lyford and Wilson, 1966). The optimum temperature for root growth in *P. menziesii* seems to be about 12-15°C.

Bowen (1969), in contrast, found that *Pinus radiata* has a suppressed root growth at low (11°C), which has a negative influence on nutrient uptake. Borland (1994) found that soil temperatures of 7.2°C-12.8°C can be detrimental to root growth and will damage roots. Freezing temperatures can cause frost damage and reduced gas exchange capability in newly planted seedlings. Water uptake capability can decline, resulting in water stress (Nambiar, 1984; Grossnickle *et al.*, 1991 ex Grossnickle and Folk, 1993). To protect containerised seedlings against too low soil temperatures, the containers can be moved closely together. This results in a large container effect. Container colour, material from which the container is made and container aeration can also affect plug temperatures. Cold climatic field conditions can damage root systems of juniper seedlings while the trunk, branches and stems are untouched. Such trees will die in the new growing season. In the past, all tree growers have relied on literature listings on the lowest winter temperatures a given species can survive. Very little information is available on survival temperatures for roots (Borland, 1994).

1.4 The ideal "artificial" root system ensuring optimum growth, tree stability and survival

It is clear from the above stated literature that silvicultural practices influence the state and nature of root systems of containerised seedlings. Fortunately, when operating within certain responsible and measured guidelines, stable and healthy trees can be produced.

1.4.1 Seedling quality

Physiological and morphological seedling characteristics that can be linked to afforestation and re-afforestation success in terms of survival and growth (Rose *et al.*, 1990; Donald, 1992; Grossnickle and Folk, 1993) define the ideal seedling concept. The intent of defining a quality seedling is to cull mediocre seedlings, thereby ensuring better survival and growth (Donald, 1992; Grossnickle and Folk, 1993). The ideal seedling must be measured in terms of morphological targets such as stem diameter, height and root:shoot ratio (Menzies *et al.*, 1985). The importance of parameters other than height and diameter to define seedling quality have only recently been realised (Rose *et al.*, 1990).

Using a single test or criteria is dangerous because seedlings have a wide array of physiological processes that continually respond to environmental conditions (Grossnickle and Folk, 1993).

1.4.1.1 Morphological targets

Edwards and Huber (1981) state that every nursery has its own method and idea of monitoring stock. Nurseries mostly monitor shoot height, stem diameter, shoot dry weight and root dry weight throughout the growing season. Some nurseries do not monitor consistently. Hinze (1994) prescribes the ideal seedling in terms of shoot dimensions. Lopushinsky and Beebe (1976) and Kormanik (1987) believe that visual root quality is a very strong performance-predicting tool. Toumey and Korstian (1947, ex Kormanik, 1988) concluded that "in judging quality of nursery stock, much greater emphasis should be placed on number, size, extend and condition of roots than on appearance of stock above ground."

The vertical development of a root system is more important in maintaining tree stability than lateral root development of 2-3 year old trees. Menzies' taproot score favours straight grained taproots over kinked or bent taproots. From a mechanical point of view this makes sense because a straight root will sustain stress over a greater portion of its length than a bent root, which will often fail at the bend. All lateral roots have a bend at the point where they are attached to the bole. To reduce the likelihood of toppling, management practices should be adopted to encourage straight grained vertical roots (Edwards *et al.*, 1963; Mason, 1979; Mason, 1985). Pfeifer (1982, ex Mason, 1985) stresses the importance of lateral root development on tree stability when the taproot is absent. Seedlings with fewer lateral roots will be less competitive in a forest environment (Kormanik and Muse, 1986 ex Kormanik, 1988).

Kormanik (1988) found that *P. taeda* seedlings with less than four first order lateral roots have poor stem and root characteristics compared to seedlings with four or more first order lateral roots. The number of first order lateral roots is therefore a good indicator of a seedling's competitive ability. The loss of some first order lateral roots at planting result in the increase of seedling shock and cause a higher water stress throughout the first growing season (Nambiar, 1984). Nambiar (1984) states that there is a close positive relationship between the number and vigour of first order lateral roots at planting, the root production after planting and the ability of transplants to grow and survive. Kormanik (1988) further found an increase in survival with an increase in the number of first order lateral roots on *Liquidambar styraciflua*. After five growing seasons, Kormanik (1988) found a striking improvement in yield in *L. styraciflua* trees with high first order lateral root counts. Although this work has been done on open rooted seedlings, it should also applicable to containerised seedlings. Strangely, very little literature is available on the ideal root characteristics of the ideal seedling. The degree of taproot deformation and stem deflection are both significantly negatively correlated with depth of taproot penetration according to Balneaves and De La Mare (1989). It is therefore important to have a vertical downward root development to ensure that at least a portion of the seedling root system is in moist soil (Carlson and Miller, 1990).

Donald *et al.* (1994) characterise an ideal containerised seedling as follows:

- Are they healthy and free from disease?
- When extracting the seedling, does the plug remove easily from the cavity?
- Is the plug firm, without air pockets and the root system well developed, without kinks and J-roots?
- Is the seedling positioned in the centre of the plug?
- Is the ratio of height (mm) to collar diameter (mm) less than 60:1?
- Are the plants hardened without soft, succulent new shoot growth?

If the answers to all these questions are positive, then the seedlings will perform well on most sites.

1.4.1.2 Physiological targets

Container production provides greater flexibility but requires more planning and foresight. Synchronisation of seedling physiology with natural conditions before planting is a major issue (Brissette, 1984). Barnett (1991) stresses the importance of incorporating root growth potential and dormancy release index as physiological characteristics in the target or ideal seedling concept.

1.4.1.2.1 Root growth potential (RGP)

RGP is defined as a seedling's ability to grow roots when placed in an environment which is highly favourable for root growth (Ritchie and Tanaka, 1990). Seedling RGP seems to assess both food reserves and health of the root system (Menzies *et al.*, 1985).

Stone (1970 and 1971, ex Ritchie and Tanaka, 1990) developed the idea of RGP as a measure of physiological grade. His research showed that potentially poor performing seedling batches could often be identified beforehand by their weak performance in RGP tests. Seedlings of high root volume have superior RGP, resulting in higher water uptake ability. Soil temperature also has a dramatic influence on RGP (Carlson, 1986). Many forest organisations now use RGP in screening nursery stock before planting (Sutton, 1990). Along with this surge of interest comes confusion and abuse of the technique. As with all other measurements, care must be taken not to over-emphasise this technique and a common sense understanding of what RGP tests can and cannot do must be developed

(Ritchie and Tanaka, 1990). A further source of confusion in using this technique is the seasonal periodicity in root growth potential (Stone and Norberg, 1978).

RGP is distinctly different from root growth in the field because of the following reasons:

- This ability is developed in a seedling while under controlled conditions in a nursery. These conditions, e.g. time of lifting, root pruning to stimulate root fibrousity (Deans *et al.*, 1990, ex Ritchie, 1990), fertilisation, irrigation, top pruning and cold storage will influence the RGP of the tested stock (Ritchie and Tanaka, 1990).
- RGP is expressed after planting but this expression rarely matches the potential for root growth. RGP is very strongly affected by environmental and soil conditions such as soil and air temperature, soil moisture as well as handling and planting quality. The best time to do RGP tests is just before the stock is to be planted (Ritchie and Tanaka, 1990).

The obvious question to ask is whether RGP works or not?

Ritchie and Tanaka (1990) state that seedlings are rarely planted in soils warm enough for root growth. In such cold soils RGP tests are often very good predictors of survival. RGP testing in general is a very good seedling quality indicator but only a fair predictor of survival (Ritchie and Tanaka, 1990). Simpson (1994) suggests that RGP is a good predictor of both performance potential (controlled environment) and field performance. Burdett *et al.* (1983) provide unequivocal evidence that RGP can affect shoot growth independently of its effect on survival. Barnett (1991) states that rapid early root growth (thus high RGP) helps to prevent seedling death or growth loss caused by water stress. Burdett *et al.* (1983) accounted for most of the variation in survival and growth of seedlings after planting in the field with RGP tests under standard conditions. Other physiological predictors can supplement RGP tests.

1.4.1.2.2 Oregon State University vigour test

A seedling's subsequent survival after exposure to a controlled stress event is measured. The stress is applied for 15 minutes at a temperature of 15°C and 30% relative humidity (Lavender and Duryea, 1982; Grossnickle and Folk, 1993).

1.4.1.2.3 Shoot/seedling water potential

Shoot water potential of potted trees after a set time is an indication of the ability of a root system to absorb water and maintain proper water levels in the shoot. Water potential less than -5.0 MPa is probably lethal for most seedlings (Cleary and Zaerr, 1980 ex Menzies *et al.*, 1985).

1.4.1.2.4 Needle conductance and transpiration

Needle conductance and transpiration indicate the water movement capability of needles and are indirect measures of a root's capability to absorb moisture and the xylem's capability to transport water to the needles (Lindgren and Orlander, 1978).

1.4.1.2.5 Infrared thermography

Foliage heat exchange can be measured which results from transpiration. This is an indirect measure of a root system's capability to absorb water and the xylem's capability to transport it (Lindgren and Orlander, 1978).

1.4.1.2.6 Root system water loss capability

Root system water loss capability is measured under positive pressure and is an indirect measure of root system integrity (Ritchie *et al.*, 1990).

Some other measurements, for example fine root electrolyte leakage, variable chlorophyll fluorescence, mitotic index, phytogram, stress-induced volatile emissions (Grossnickle and Folk, 1993) and level of food reserves (Menzies *et al.*, 1985), can also be used to define seedling quality. Some of these tests are however far out of the reach of South-African foresters (Herman, 1992).

1.4.1.3 Field testing

The mechanical, meteorological, biological and other factors affecting growth and survival of plants certainly have physiological effects, often of a complex nature. All these factors may be controlled or excluded in controlled environment laboratories but the final evaluation must always be the performance of the plants in the forest (Chavasse, 1979). Survival, stress and tree stability must be evaluated as well as stress effects such as exposure, storage, delayed planting, time of year and site conditions (Chavasse, 1979).

1.4.2 Timing of planting

"Current work done with tubed stock of Radiata pine and eucalyptus shows that planting date must be strictly related to the size of the container." This quote from Chavasse (1978) stresses the importance of the correct planting date.

Berger and Lysholm (1978) found that 6-month-old *P. caribaea* seedlings in 49-mm diameter tubes seem to be lagging behind the seedlings produced in the same tubes kept in the nursery from 12 to 15 months. The reason for this is that these trees were kept too long in the nursery which had a detrimental effect on increment on trees from small tubes. Williams *et al*., (1988) found that *P. taeda* seedlings with an average shoot length of 26.5 mm and diameter of 4.89 mm have worse RGP's than larger seedlings (26.4 mm length, 5.34 mm diameter). Shoot growth is however better in the smaller seedlings. Tuttle *et al*. (1988) found an increase of 53% in survival when planting 16 cm tall open rooted *P. taeda* seedlings instead of 23 cm seedlings. The use of shorter seedlings can reduce the cost of blanking by increased survival, because they have less foliage. South and Mason (1993) found in work done on (assumably open rooted stock) *P. sitchensis* that 30 cm tall stock grew better than 20 cm stock. These gains in height are achieved in the first 6 years of establishment. If root pruning is not available in a nursery, Aiking (1995) prefers a loose plug with a small calliper above a strong firm plug. The most probable reason behind stability problems in the field is that seedlings are kept in the nursery too long. Small sized containers compact roots, increasing the risk of fungal attacks such as *Armillaria* spp. The use of larger or aerated containers can alleviate this problem (Håkansson and Lindström, 1995). Bayley (1995b) reports that seedling age and planting period have an impact on survival of *P. patula* seedlings. Morris (1993a) compared seedling survival of hard and soft *P. patula* seedlings, with ages ranging from six to nine months, planted in different depths in old and fresh pits. He experienced a weak trend for the younger and shorter plants to have better survival although this effect had less of an impact than those of planting method and selection process. Cleary *et al*. (1978, ex Miller and Schaefer, 1984) found that small stems are more susceptible than bigger stems to girdling by high temperatures at the soil surface. Larger seedlings have more insulating tissue to shield sensitive cambium cells.

Bayley (1995) and Morris (1993) stated that seedling survival could be significantly improved by identifying the best time of year and conditions for planting. Stock quality improvement should also be included. Seedlings were planted by Bayley (1995a) in the dry winter months on two sites. Stockosorb was added in the planting hole resulting in an improvement in both growth and survival.

Nursery seedlings can be stored under cold, dark conditions for several months prior to planting. Losses of reserves (starch and sugar) during storage have been reported and can be responsible for poor root regeneration and poor seedling survival after planting (Ritchie, 1982).

1.5 Effects of root deformations on tree growth and survival and the importance in commercial forestry

"It is unacceptable to prepare soils, plant seedlings, fertilise and weed them on sound researched information and knowledge then ending up with useless four year old pine compartments with 70% or more of the stand consisting of unstable trees. The financial implications of such failures is disastrous" (Droomer, Area Manager N.E.C.F., pers. comm., 1994).

1.5.1 Toppling and windthrow

Wind damage can be divided into two distinct categories: toppling and windthrow. Mason (1979) states that toppling occurs between the ages of two and six years (the tree starts leaning) and windthrow (the tree breaks at ground level) usually when the stands are much older. Toppling is a gradual weakening of the root fibres caused by tree sway and is often preceded by socketing. In severe winds these roots will break. Toppling is generally confined to transplant planted plantations, while windthrow can also occur in natural regenerated stands. Windthrow is accompanied by a failure of the stem at the root collar or roots being pulled out of the soil (Atterson *et al.*, 1963; Mason, 1979; Mason, 1985; Håkansson and Lindström, 1995).

Improving container design can reduce the risk of toppling (Tinus, 1981). The underlying cause of toppling is thus the transplanting of a seedling into a new growing medium and therefore altering the natural root development pattern (Mason, 1979). Various opinions for the cause of this phenomenon have been offered, including poor quality of tree stock, method of planting, soil and site conditions, low fertility, low root:shoot ratios, exposure, weed competition and low stocking (Mason, 1985).

1.5.2 Nutrient content of trees

Nitrogen and phosphorus concentrations in open rooted *P. radiata* seedlings will drop with a decrease in number of first order lateral roots (Nambiar, 1984). Phosphorus and potassium are less affected by number of roots and root treatment. Nambiar (1984) found that the combination of low weed control and limited root length, result in low nutrient concentrations compared to high values found in intensive weed control treatments.

1.5.3 Growth and survival

A healthy root system ensures effective water and mineral absorption and anchorage (Mason, 1985). Establishment success depends on root growth, resulting in an improved nutrient and water uptake ability (Burdett *et al.*, 1983). Seedling survival in a habitat depends to a large extent on the size, shape, type and efficiency of the root system (Eis, 1978).

Root quality and quantity determine stability and survival (Eccher, 1975 ex Grene, 1978; Stone and Norberg, 1978; Mason, 1985). The structure and development of root systems is essential for the understanding of the ecological and physiological requirements of forest tree species. Such understanding is a necessary base for silvicultural decisions (Eis, 1978).

1.6 Conclusion

The complexity of understanding root development is highlighted in the literature. There are as many and contrasting opinions regarding root development and its importance in the growing of trees than there are publications.

It is generally agreed that root development and configuration are of the better predicting tools for seedling survival and development in the field. Tree stability, nutrient and water uptake, tree form, growth, disease tolerance, morphology and physiology are some of the more disputed factors.

It is thus clear that there is great diversity in opinion amongst knowledgeable researchers. Further investigations are therefore necessary, as knowledge of the structure and development of root systems is essential for the understanding of the ecological and physiological requirements of forest tree species. Such knowledge is a necessary base for silvicultural decisions (Eis, 1978). Root deformation, malformation and all the other descriptive terms used for poor root systems must be qualified and quantified.

2. The normal root configuration and the containerised root configuration tested against the Menzies' scoring system

Synopsis

Roots of fifty-seven natural regenerated and fifty-two planted containerised *P. patula* trees were dug out and washed to determine the spatial development of their roots. Root development was measured in terms of spatial taproot and lateral root development. The Menzies' scoring system was used to determine the topple index (Mason, 1979; Mason, 1985). Topple index predicts the likelihood of a tree to be unstable, with a score of 1.8 being ideal and 1.2 being unacceptable. Both taproot and lateral root development is being incorporated in this scoring system. Natural regenerated trees had a significantly better average topple index of 1.83 with planted trees able to score only 1.32. The natural regenerated trees outscored the planted trees in terms of taproot development as well as lateral root development. The Menzies' scoring system is thus a good predictor of tree stability if assumed that the natural regenerated tree is ideal in terms of root development and stability.

2.1 Introduction

There is widespread evidence that naturally regenerated trees develop a strong taproot and several main laterals, which are generally distributed to all points of the compass, provided the soils allow this (Chavasse, 1978; Burdett, 1978). Haigh (1966) found a well-developed taproot system in *Pinus* spp. in the Zululand sandy soils with lateral roots largely restricted to the topsoil. Stein (1978) found the average taproot of naturally regenerated conifer seedlings to be almost six times longer than the shoot after two growing seasons. Taproots of *P. ponderosa* seedlings exceeded 30 cm after six weeks in controlled environment tests done by Hite (1978). Naturally regenerated *P. contorta* trees have an open root configuration, with strong and well distributed roots, without root strangulation (Van Eerden, 1978), in contrast to the bushy weak roots of planted trees. Bilan *et al.* (1978) state that the superiority of a dominant root to develop until reaching a soil depth of unfavourable growing conditions is genetically driven. In the absence of a taproot some lateral roots will develop as taproots. Root development and root structure of *P. taeda* differ on different sites. Trees grown on the drier sites include early development of larger, more branched and deeper root systems. All the sites investigated have dominant main roots when undisturbed. Root disturbance breaks taproot dominance and may result in strong sinker root development (Bilan *et al.*, 1978). Seedlings of drought tolerant provenances survive better than seedlings of wetter provenances (Zobel and Goddard, 1955 ex Bilan *et al.,* 1978).

Fine roots or feeder roots are responsible for most of nutrient and water uptake by trees (Marshall and Waring, 1985; Marshall, 1986). Atkinson (1985) observed that primary fine roots of young fruit trees have a lifespan of 3-5 weeks. Approximately 75% of these roots will die while the balance are "recruited" to the woody portions of root systems. Although fine roots may constitute less than 1% of the total biomass of the tree, they may account for as much as 66% of annual biomass production. This is very important because biomass production below ground determines production above ground (Grier *et al.*, 1980 ex Marshall and Waring, 1985). Field data accumulated by Blake (19??) show that root quality in terms of the amount of fibrous roots is very closely related to survival.

Container and bare root culture affect several root system characteristics, including symmetry, balance, constriction, coiling, taproot development, and root system deformities caused by planting. Coiling and root constriction are more prevalent in container grown trees (Stein, 1978). Sloan *et al.* (1987) found that container size and shape largely affect root form and development. One of the major differences between planted and naturally regenerated trees, according to Burdett (1978), is the angle of the laterals with respect to the taproot. Naturally regenerated trees have laterals growing at approximately ninety degrees from the taproot, whereas in planted containerised trees the laterals tend to grow parallel with taproots for the first 10 to 15 cm. The methods of growing seedlings and planting them should allow the root system to develop a form as close as possible to that of naturally regenerated trees (Chavasse, 1978). Hellum (1978) concludes his study, where he compared planted *Abies alba* trees with naturally regenerated trees, that neither containerised nor open rooted seedlings can compete in growth rate with natural regenerated seedlings. Straight grained well-developed taproots and sinker roots occur in most naturally regenerated trees and will reduce the likelihood of trees to topple (Chavasse, 1978; Mason, 1985). Van Eerden (1978) stresses the fact that growing and planting methods will leave an imprint on juvenile root systems.

Tinus (1976) is of the opinion that containerised seedlings will outperform open rooted seedlings. Healthy actively growing seedlings without root disturbance can thus be planted. Containerised seedlings have a higher survival and growth (Sloan *et al.*, 1987). In contrast van Eerden (1981) experienced root deformities in containerised seedlings. Containers can therefore determine the size and shape of root systems. This in turn might influence the stability of standing trees (Lindgren and Orlander, 1976 ex Mason, 1979).

Improving container design and root pruning can probably reduce the risk of toppling. Thrown trees usually have very shallow root systems and very rarely exhibit directional root formation (Edwards *et al.*, 1963). The underlying cause of toppling is thus the transplanting of a seedling into a new growing medium and therefore altering the natural root development pattern (Mason, 1979). Various opinions for the cause of this phenomenon have been offered, including quality of tree stock, method of planting, soil and site conditions, fertility, low root:shoot ratios, exposure, weed competition and low stocking (Mason, 1985).

The state of the taproot and the number of sinkers are two of the more important variables related to toppling propensity. Mason (1985) reported that stable trees have better vertical root form than toppled trees. Another significant factor, but not highly correlated with the taproot score, is the number of sinker roots (Mason, 1985). Toppled trees can recover in some instances with some degree of butt sweep or sinuosity of the lower bole, with large quantities of compression wood (Mason, 1979; Mason, 1985). A discriminant function, which only uses Menzies' taproot score and the number of sinkers to define the two states of toppled and stable trees is as follows:

Topple index = 1.844 - 0.07032 (Menzies' Taproot score) + 0.01827 (number of sinkers) (Mason, 1979; Mason, 1985).

The index ranges between 1.8 for a stable tree and 1.2 for an unstable tree. This index will give the quality of a root system from a stability point of view (Mason, 1979; Mason, 1985).

The tendency to topple is a result of a combination of factors. A simple root score cannot predict toppling with any accuracy and a much more reliable and complex model is needed. The Topple Index can however be used as an indicator for toppling probability (Mason, 1979). Chavasse (1978) reminds us that other factors can also increase a tree's susceptibility to toppling such as irregular canopy surfaces. The risk of windthrow after incorrect thinning is increased as wind turbulence in the stand will increase. The most important factor relating thinning is the timing of such an operation in relation to the height of trees at risk. Thinning must be done early and heavily to promote root and diameter growth (Chavasse, 1978).

2.2 Materials and methods

The trial area was located on the Chillingly Estate on an easterly slope (Trial area marked "A" on map A). These plantations are located in the North Eastern Cape and managed by Mondi Forests. Natural regenerated and planted trees were dug out from old agricultural lands. Soils were of the Griffin form, characterised by an orthic topsoil, a yellow-brown apedal B-horison and a red apedal subsoil (Soil Classification Working Group, 1991). A ploughpan 50 mm thick at a depth of 300 mm was visually observed and noted.

Fifty-seven two year old natural regenerated and fifty-two planted containerised *P. patula* trees were dug out. Containerised trees were grown in the Unigro 128 seedling tray. The timespan of being in the nursery is unknown. Holes were dug according to the profile wall method (Ellis, pers. comm., 1994), one-meter from the stem. This method measures and counts all roots protruding from two soil walls dug at 90% from each other. High-pressure water was used to wash away the soil, enabling the documentation of spatial root development. Direction of root growth and number of roots were noted. Root systems were then washed out in total to be measured quantitatively as well as qualitatively.

Taproot presence was noted and length measured. Containerization results in a lateral root taking over the taproot function. In such cases that root was measured. Number of laterals per 100 mm taproot were counted and measured. Root systems were then qualitatively judged, using the Menzies' scoring system.

Figure 2.2 (A-N) is a visual presentation of the Menzies' scoring system (Mason, 1979; Mason, 1985). It was necessary to adjust the Menzies' taproot scoring system to accommodate container-raised trees. The reason for this is that the taproot of containerised trees gets air pruned in the nursery. In some of the cases one or more lateral roots take over the taproot function. An additional score of five and seven is included in the Menzies' taproot score. The Menzies' lateral scoring system was used unchanged. These taproot and lateral root scores were used to determine topple index. This index is a prediction of tree stability and likelihood to topple.

2.3 Results

Table 2.3.1 shows the mean taproot scores, lateral root scores and topple indexes. Trees regenerated naturally outscored planted trees significantly ($p<0.001$) on all the evaluation criteria. Table 2.3.2 is the ANOVA table for the response variables and table 2.3.3 presents the minimum, mean and maximum values.

Naturally regenerated trees had a mean taproot score of 0.33 where 0 is seen as ideal. Planted trees scored 7.37 with a score of 10 being unacceptable. The lateral root score also favoured naturally regenerated trees, i.e. 1.44 (ideal = 0) vs a score of 4.12 (poor =10) for the planted trees.

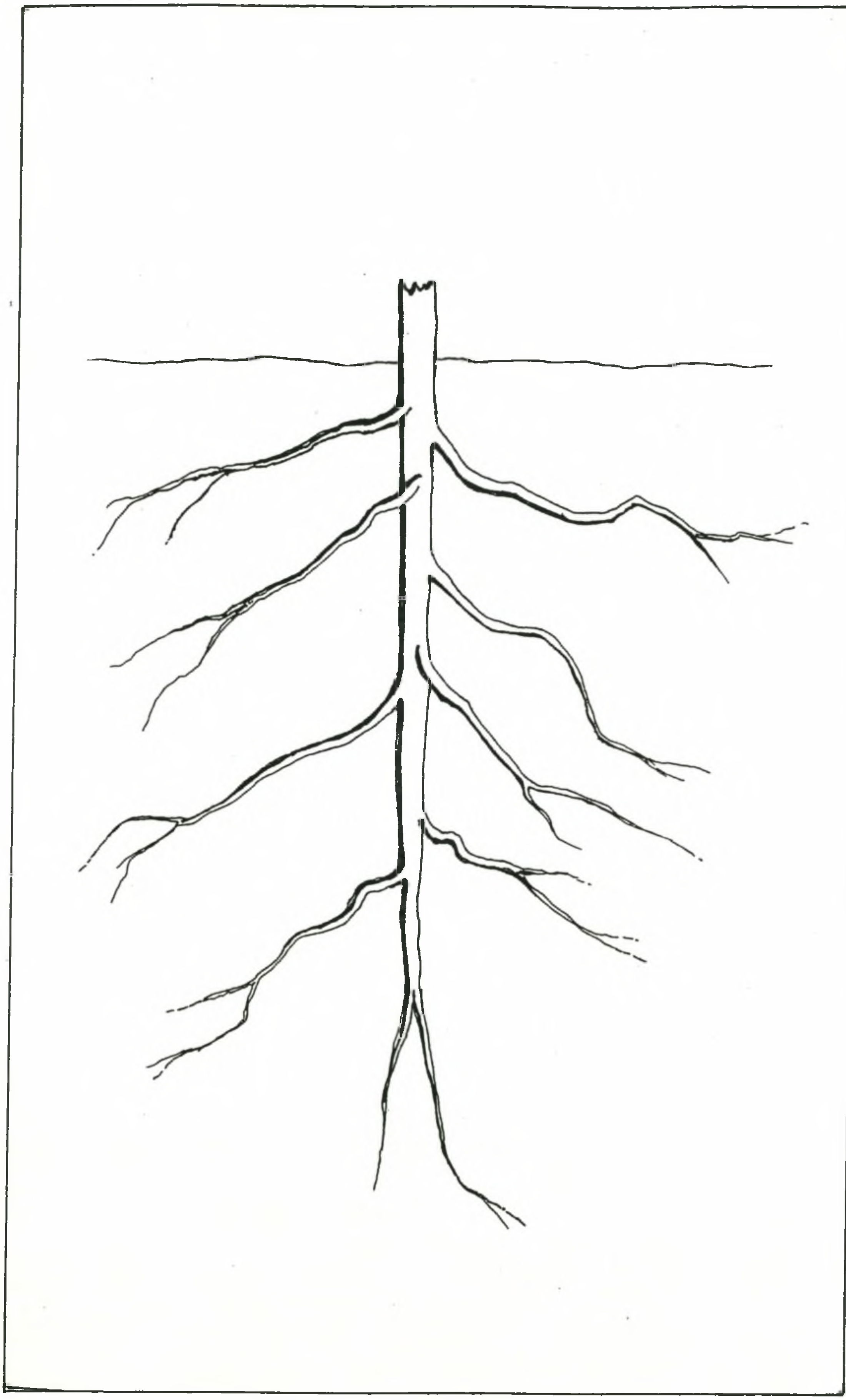

Figure 2.2 A: Menzies 0 taproot score (M1)
Strong dominant well developed taproot

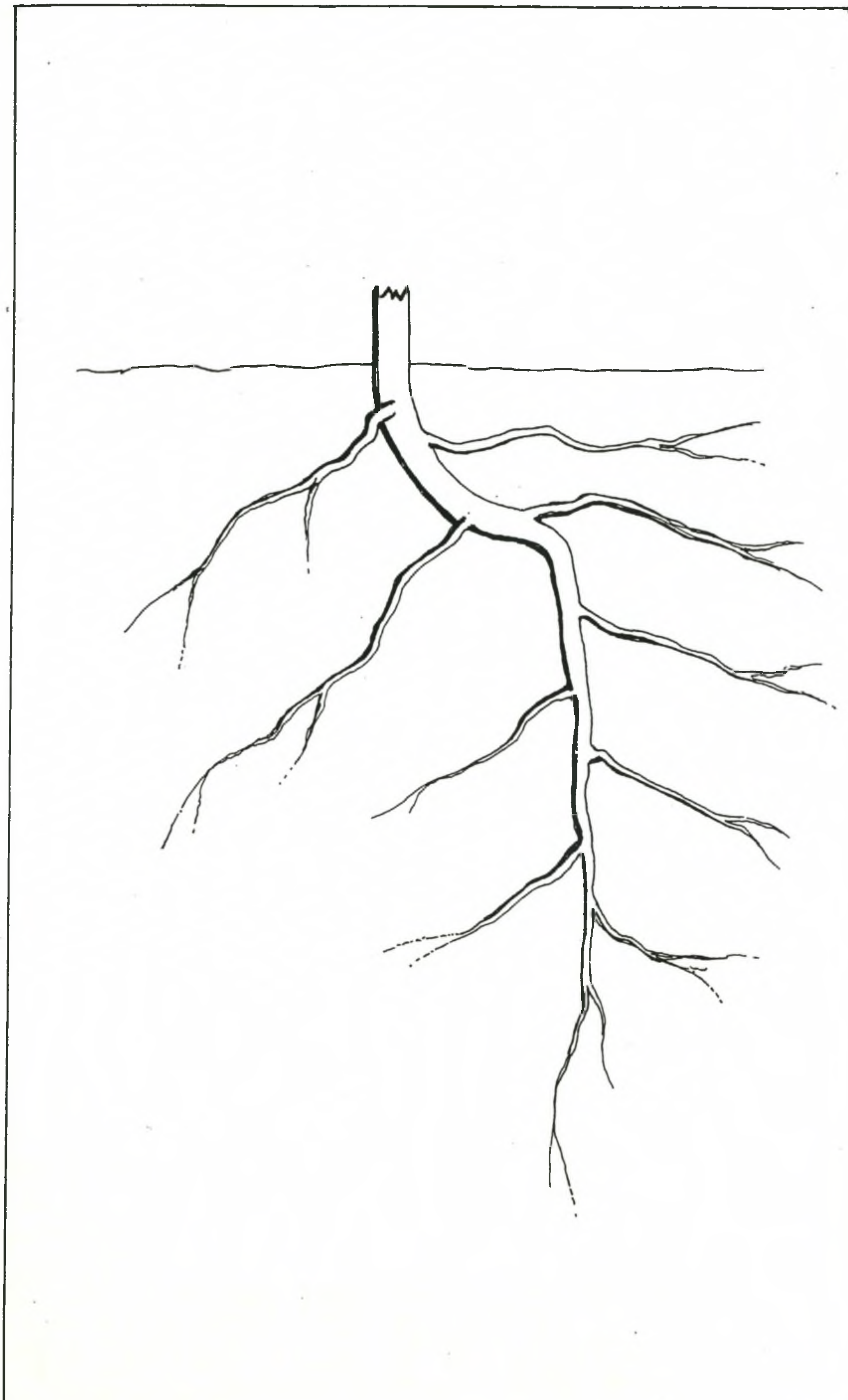

Figure 2.2 B: Menzies 2 taproot score (M1)
Stunted slightly deformed taproot but still a definite taproot

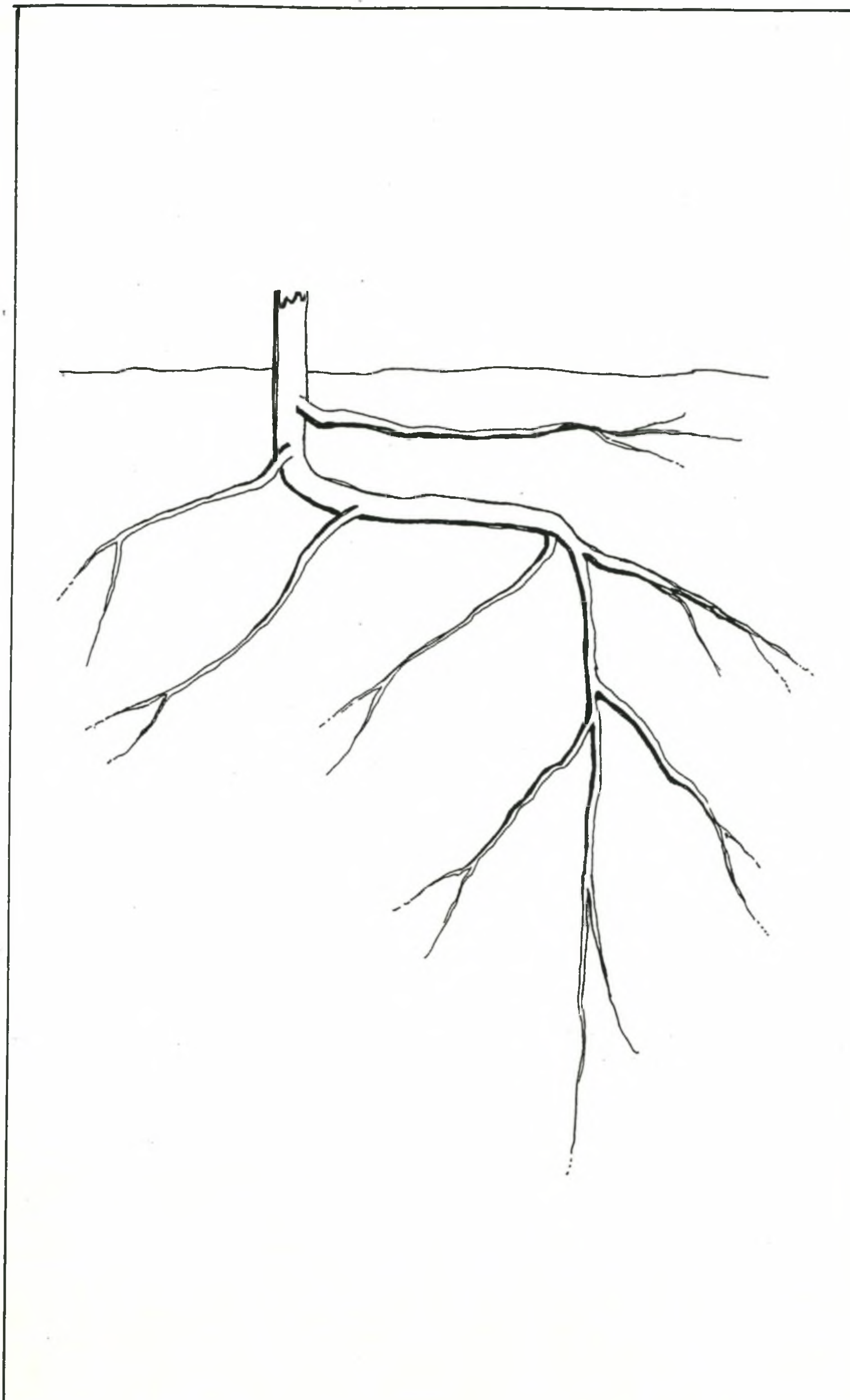

Figure 2.2 C: Menzies 4 taproot score (M1)
Taproot distinctly hooked

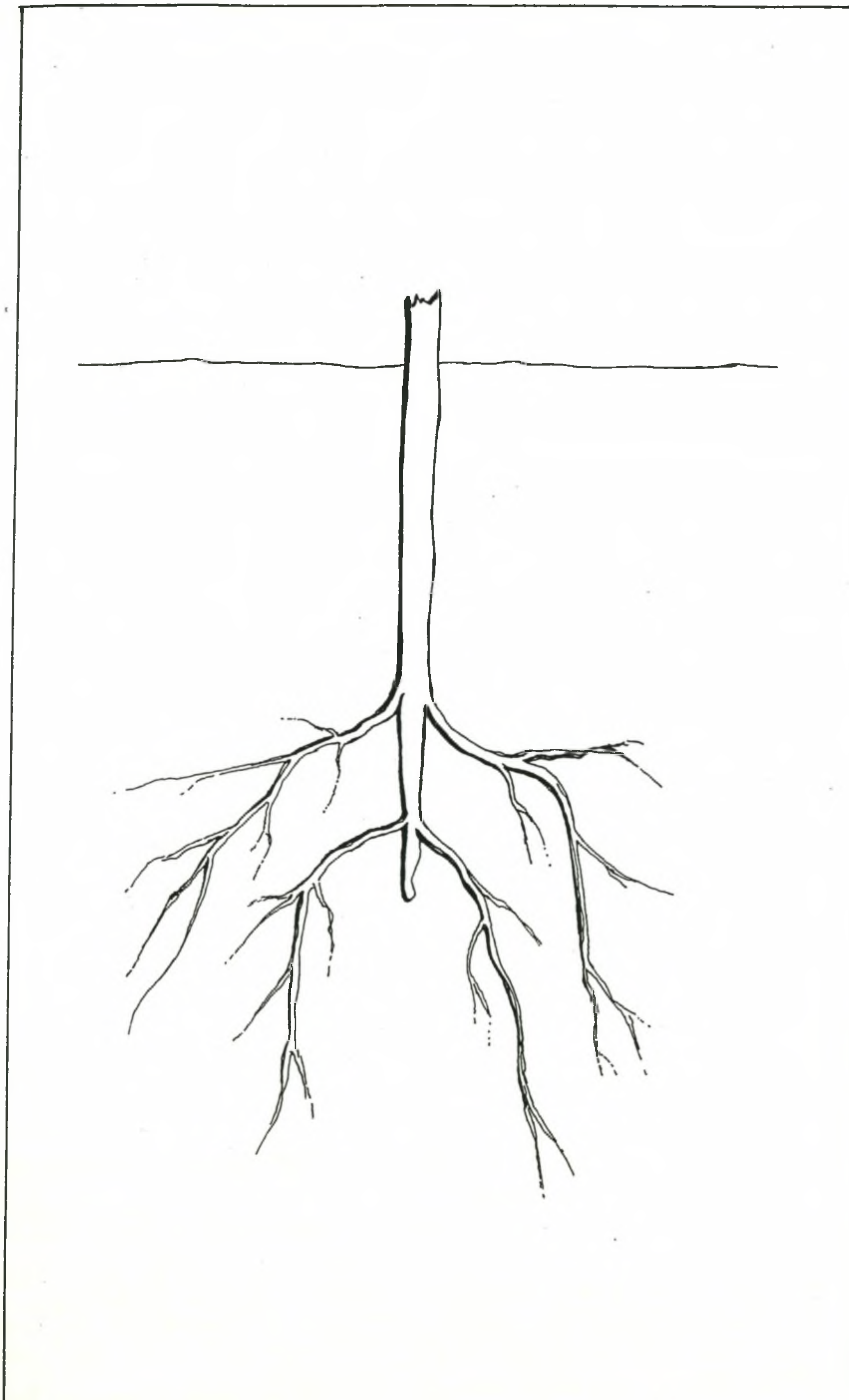

Figure 2.2 D: Menzies 5 taproot score (M1)
Taproot died off but lateral roots took over the function of taproot

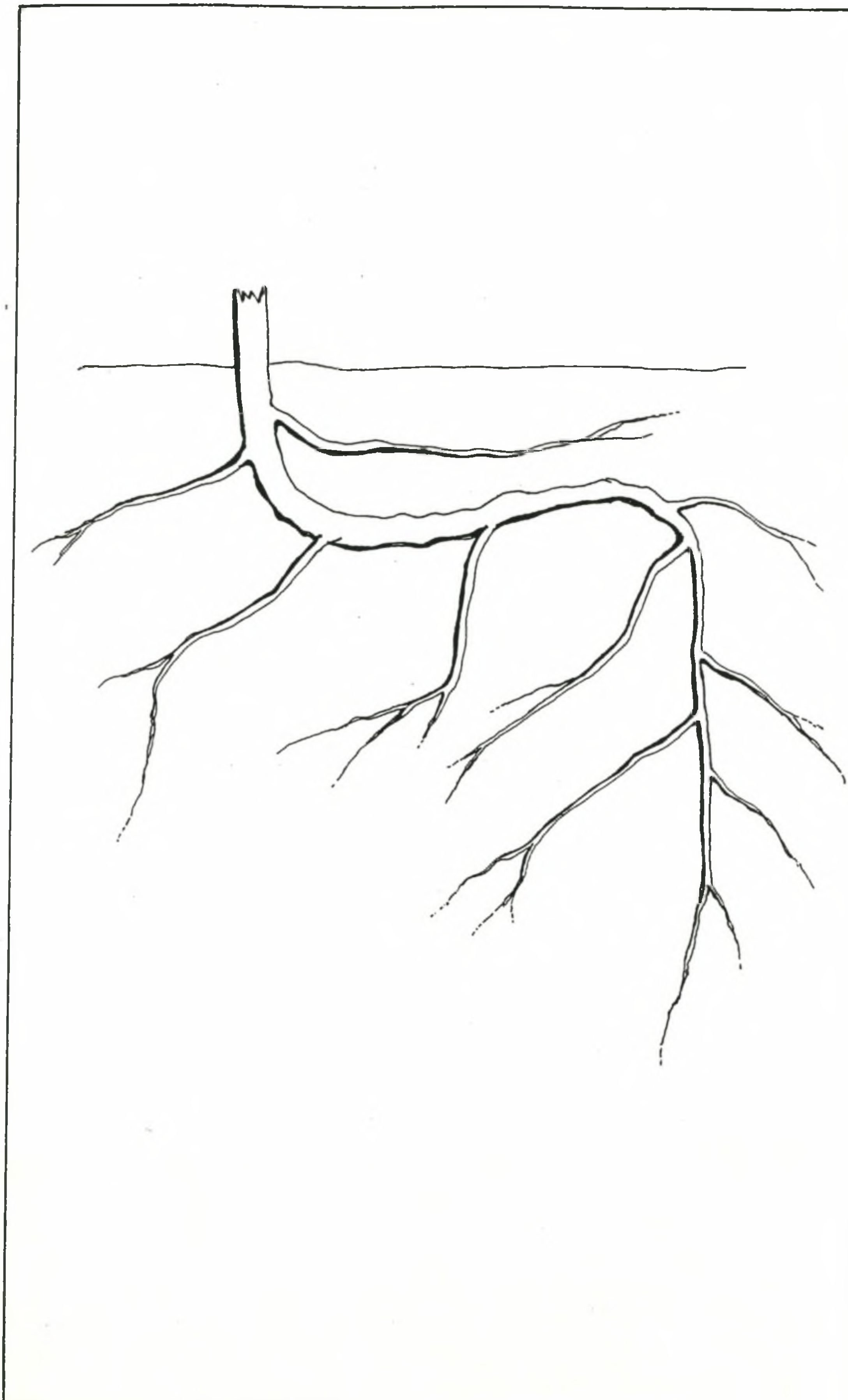

Figure 2.2 E: Menzies 6 taproot score (M1)
Taproot badly hooked but still downward development

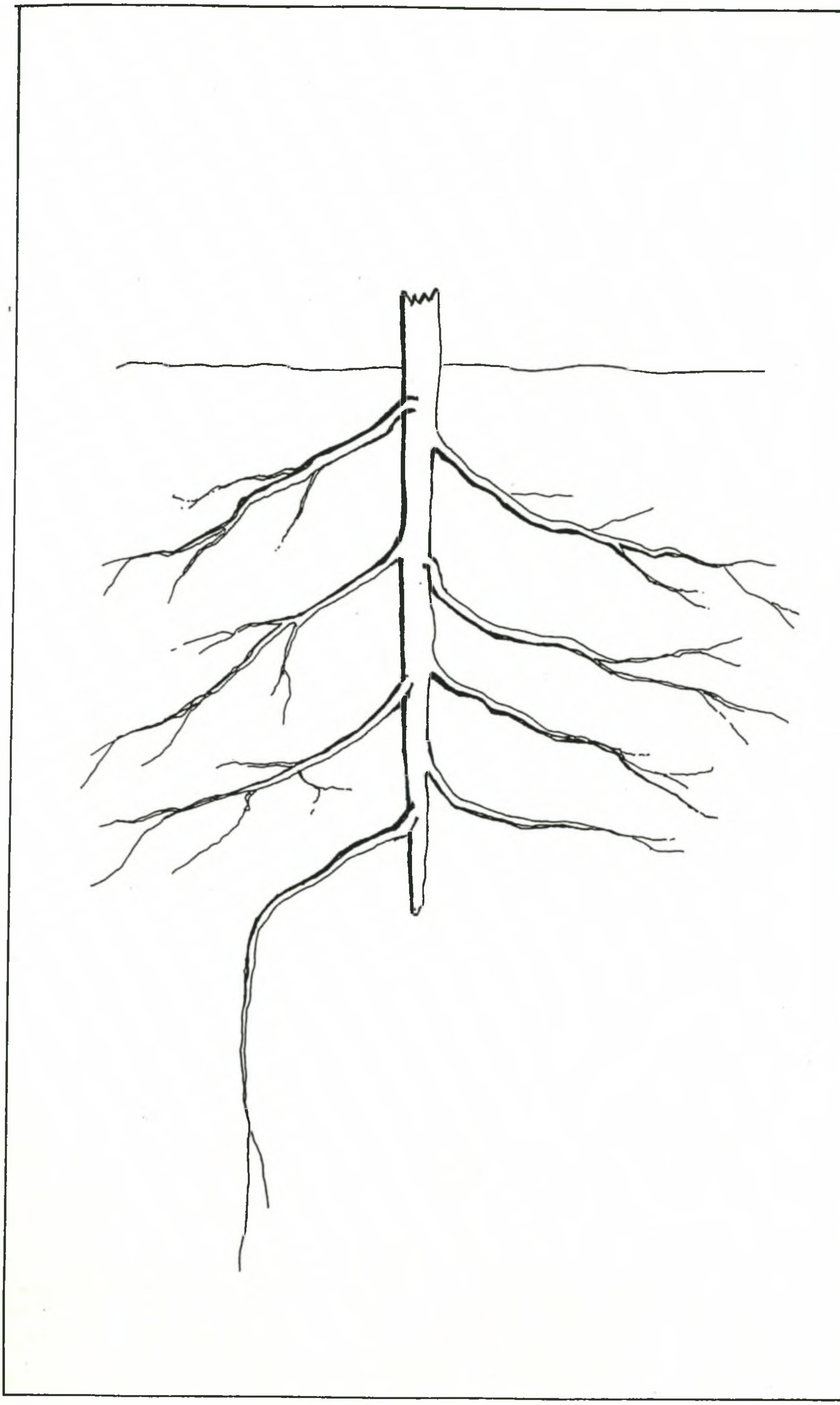

Figure 2.2 F: Menzies 7 taproot score (M1)
Taproot died off but laterals grow downwards and horizontally

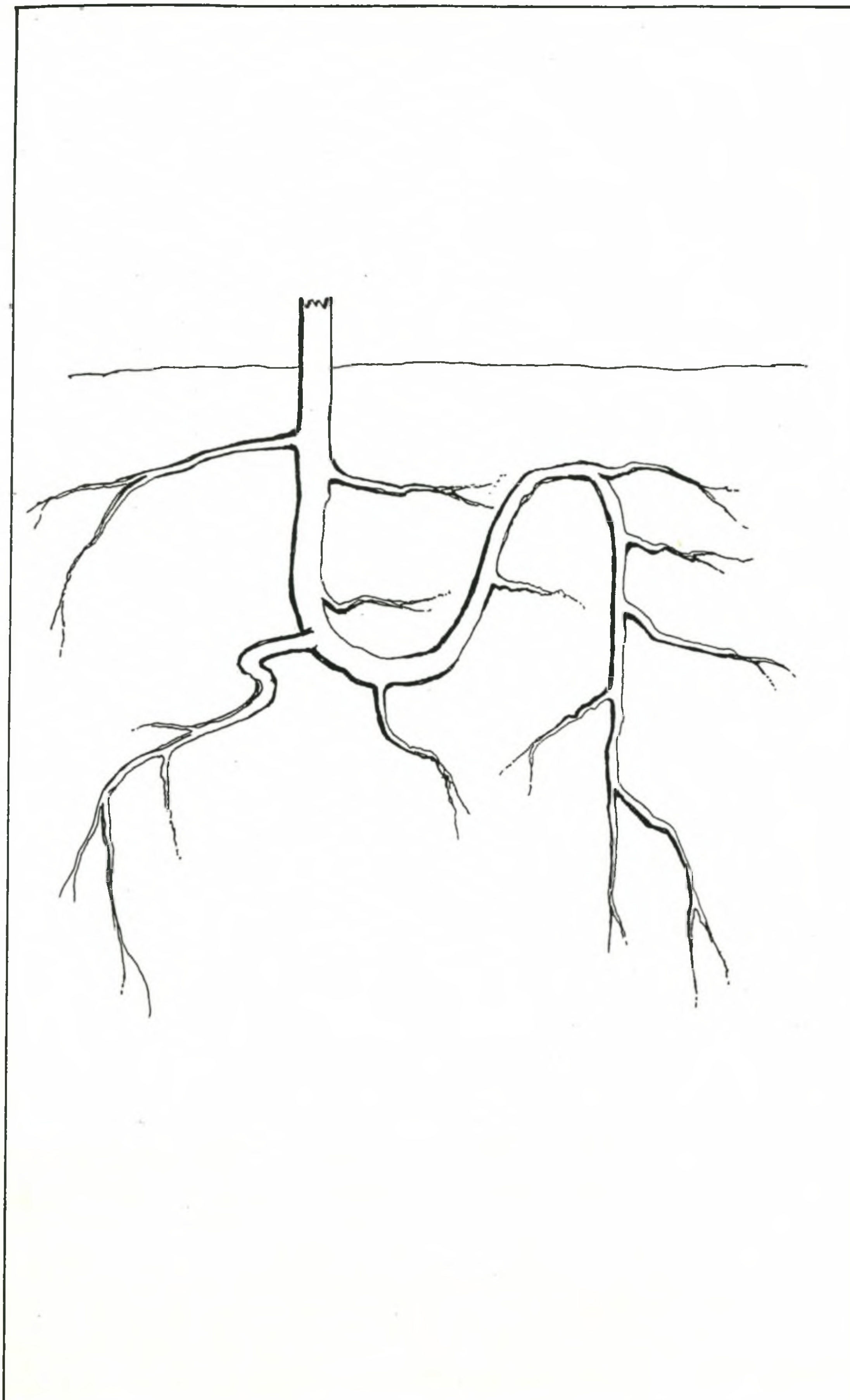

Figure 2.2 G: Menzies 8 taproot score (M1)
Taproot severely deformed into two or more fracture zones, growth still downwards

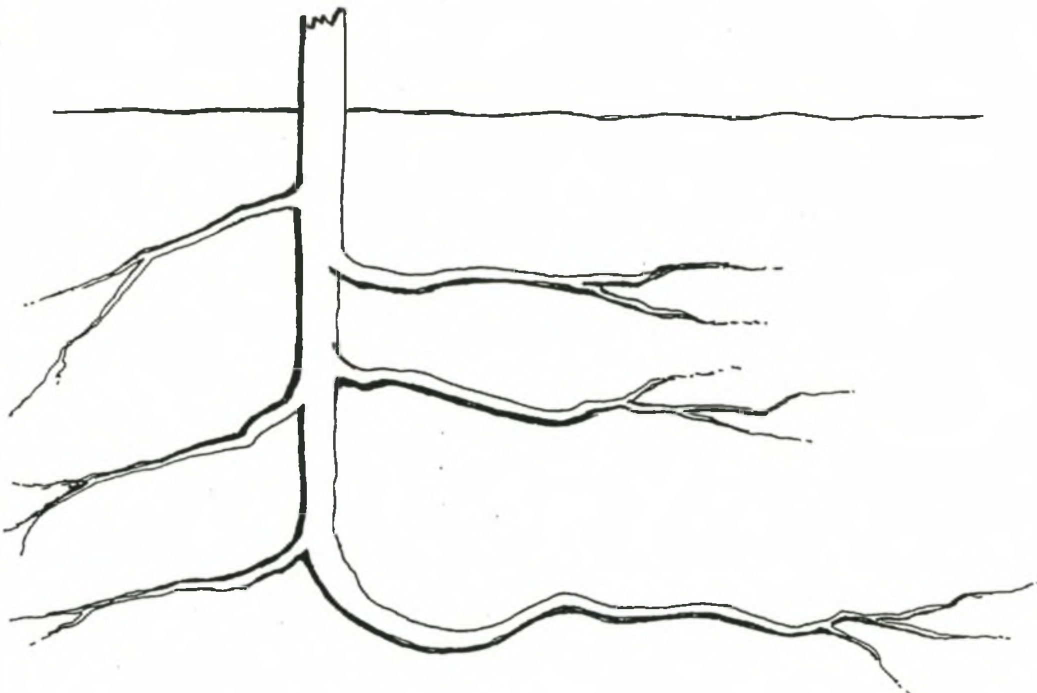

Figure 2.2 H: Menzies 10 taproot score (M1)
Taproot only grows horizontally

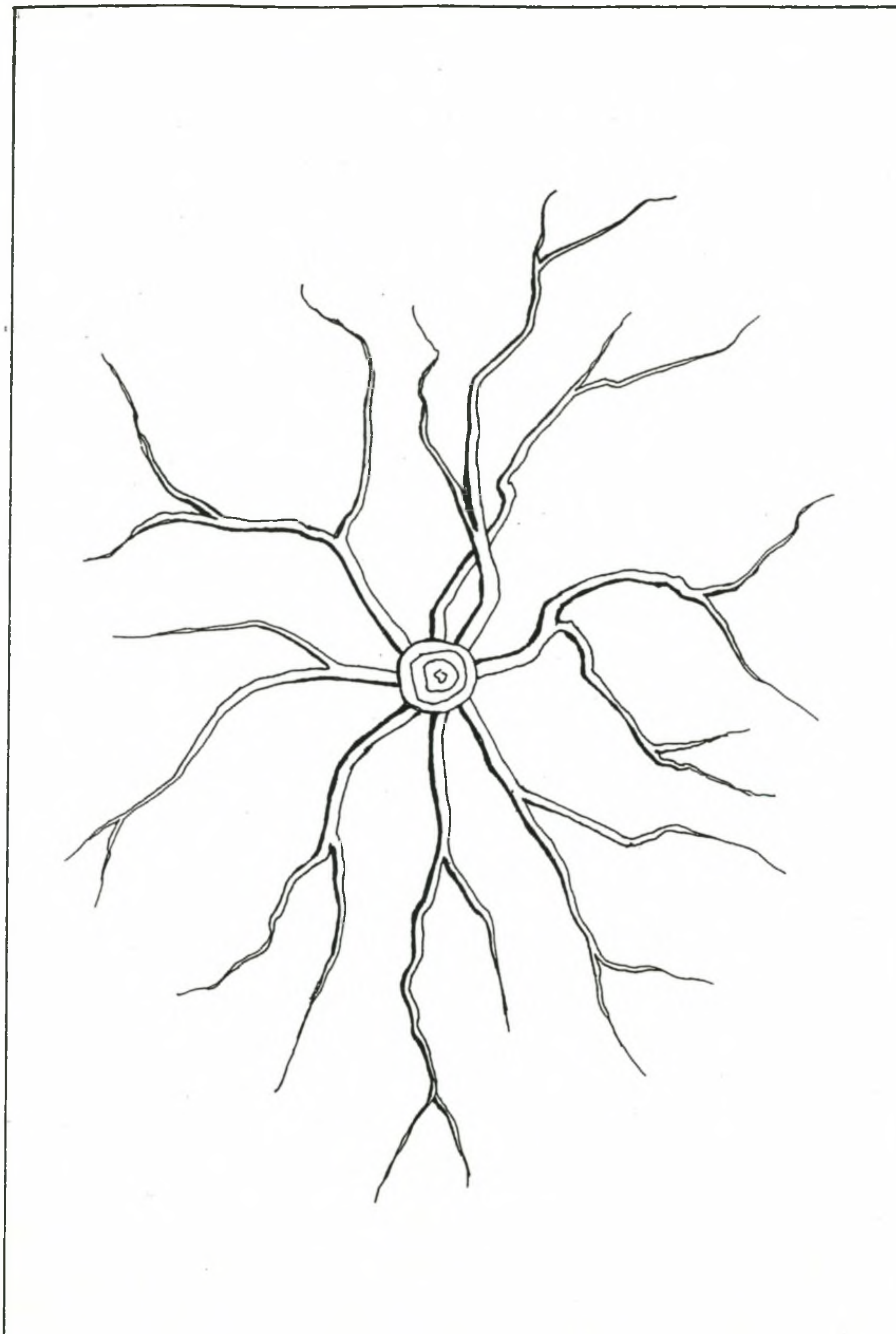

Figure 2.2 I: Menzies 0 lateral root score (M2)
Laterals on all four sides

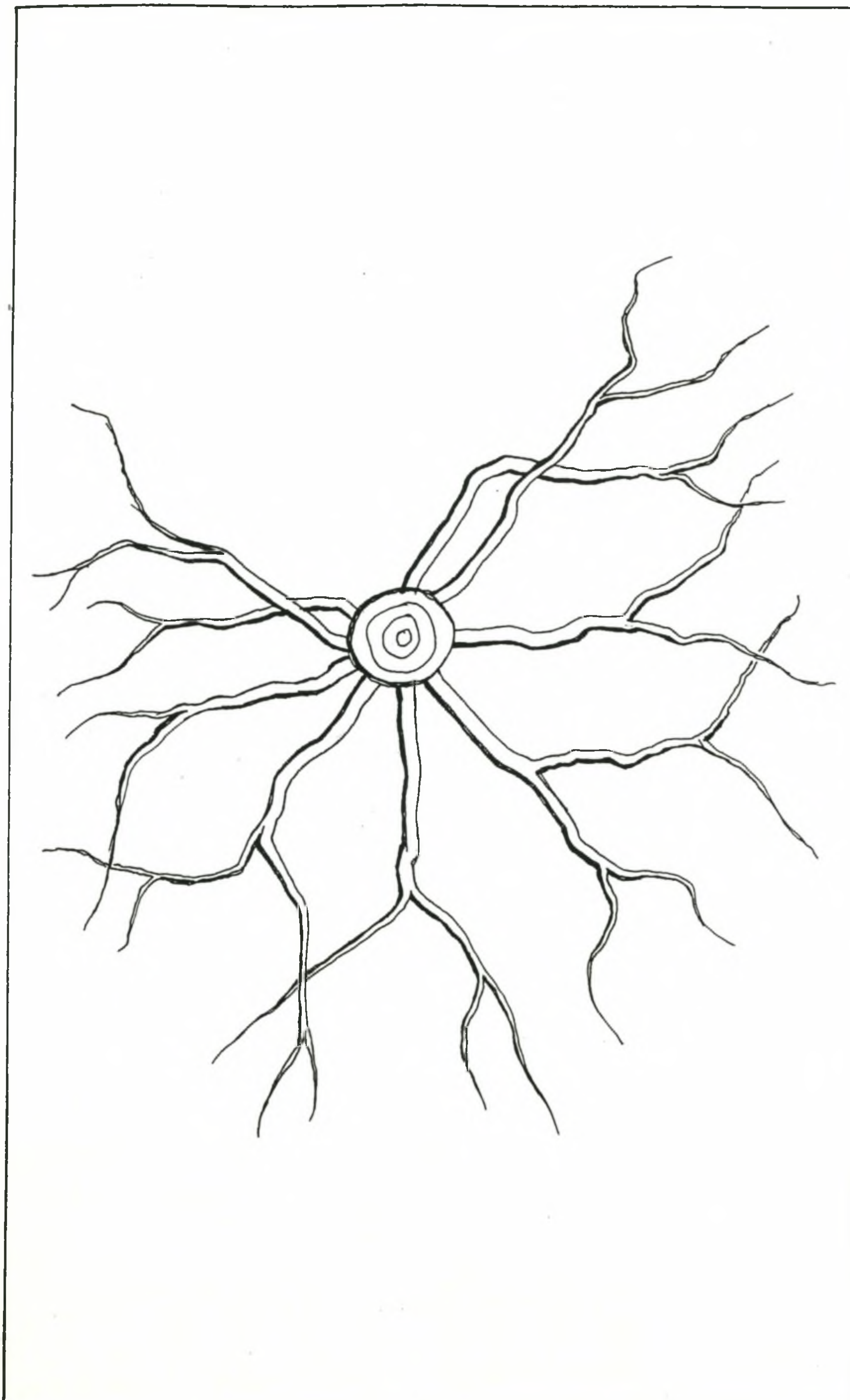

Figure 2.2 J: Menzies 2 lateral root score (M2)
Laterals in three quadrants

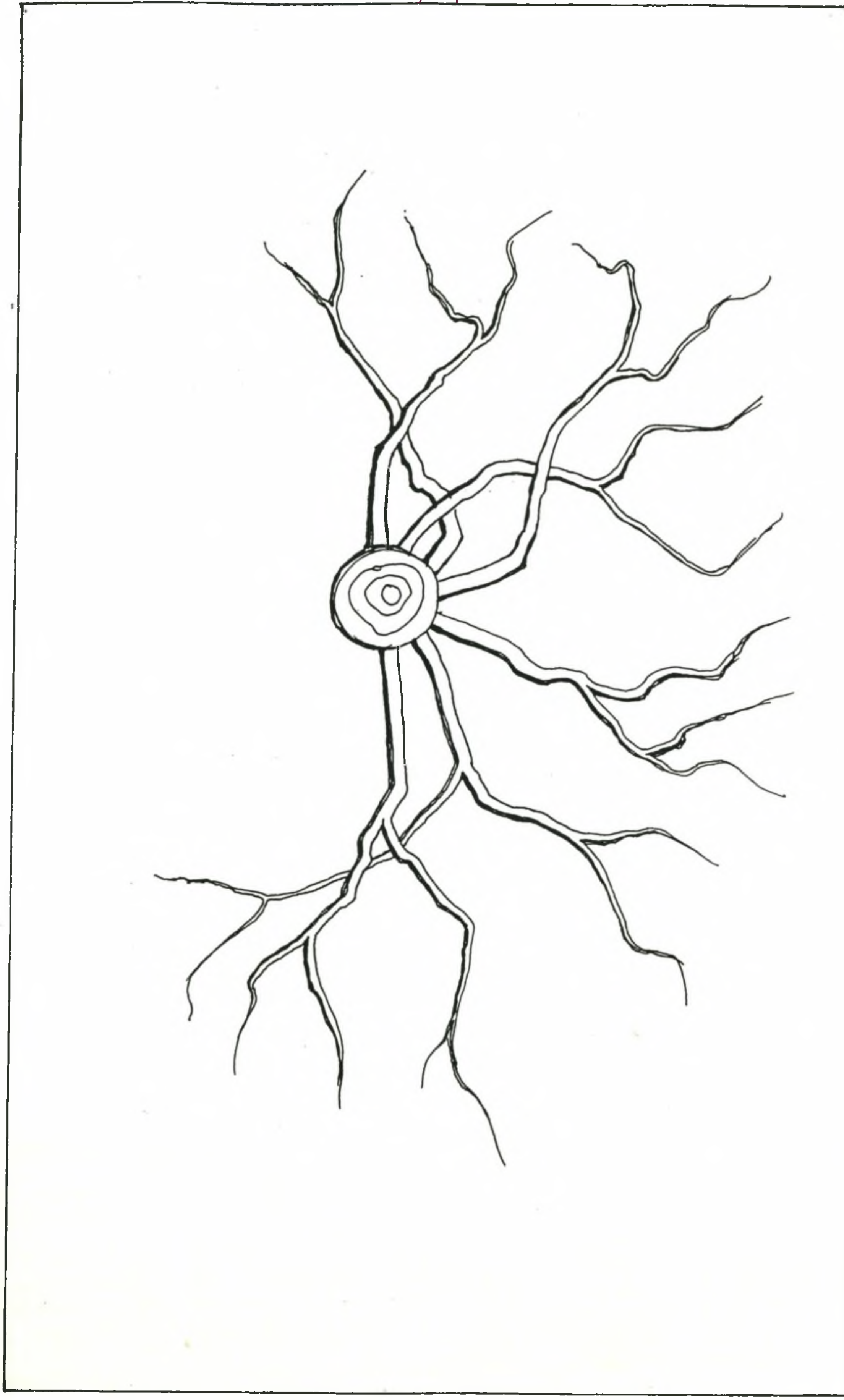

Figure 2.2 K: Menzies 4 lateral root score (M2)
Laterals in two adjacent quadrants

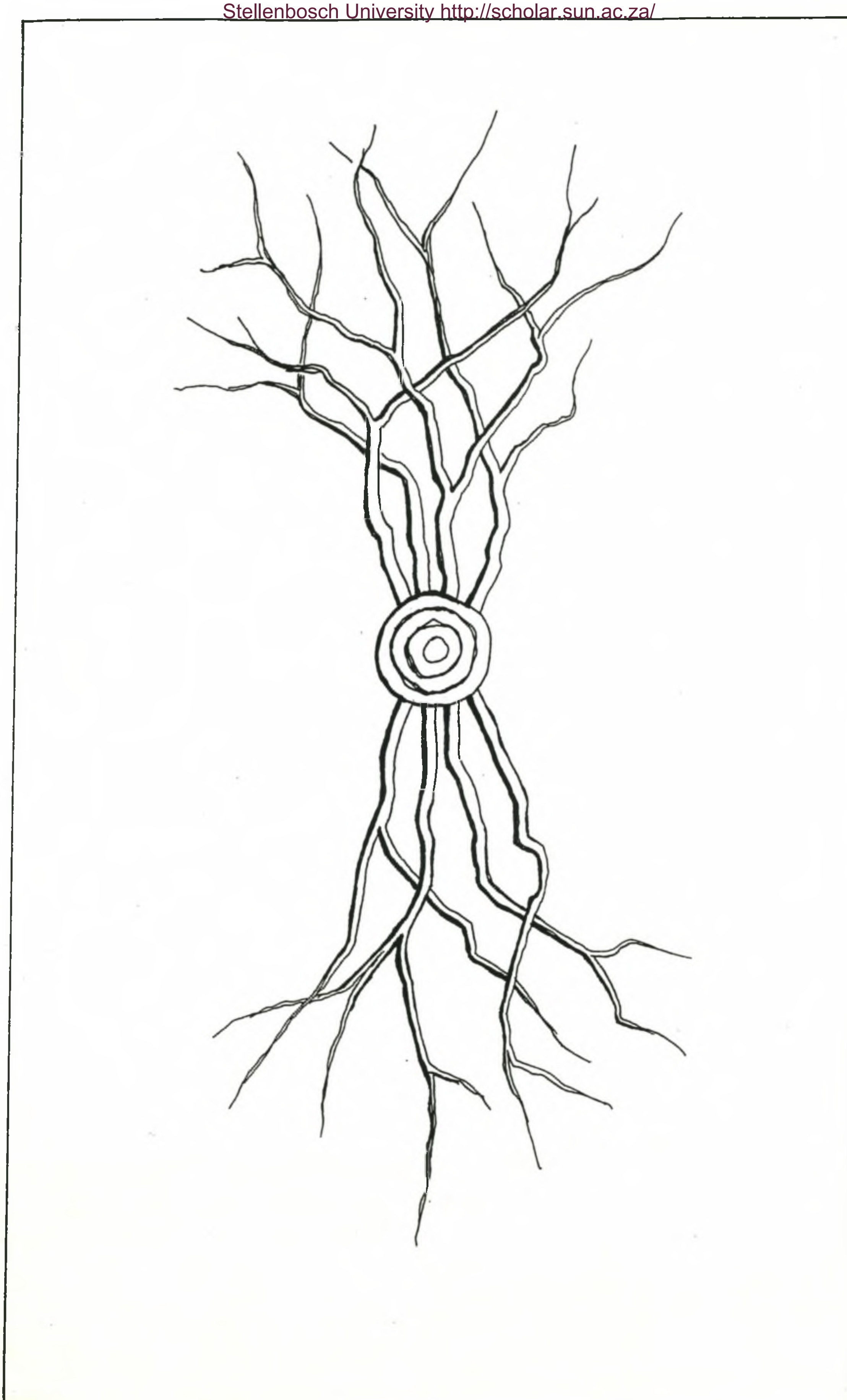

Figure 2.2 L: Menzies 6 lateral root score (M2)
Laterals in two opposite quadrants

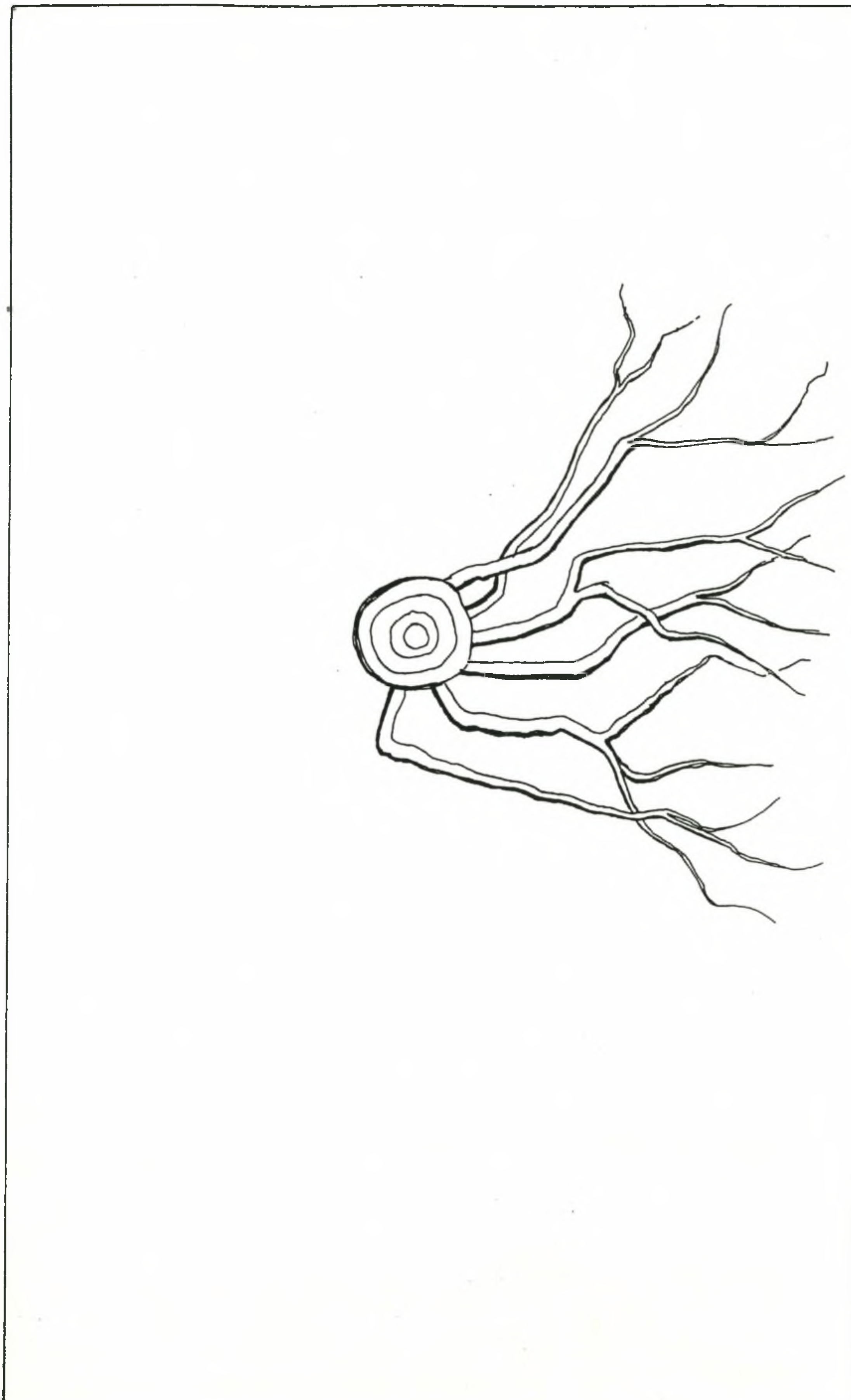

Figure 2.2 M: Menzies 8 lateral root score (M2.
Laterals in one quadrant

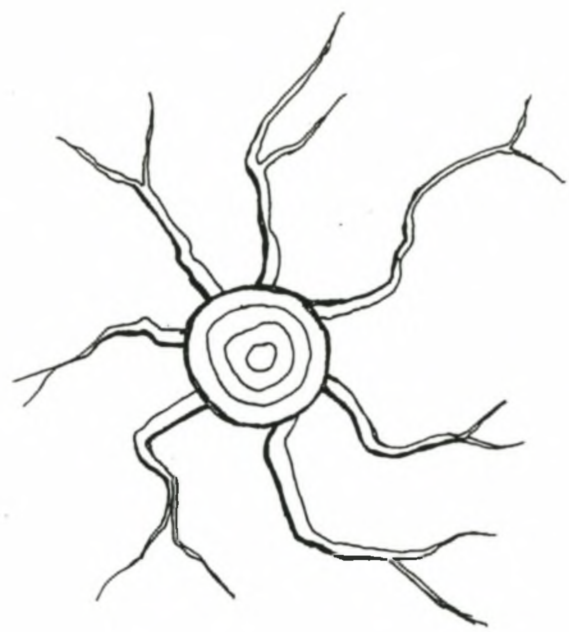

Figure 2.2 N: Menzies 10 lateral root score (M2)
No significant lateral development

Table 2.3.1: Menzies' scoring system and topple index of natural regenerated- and planted trees

Plant material	Taproot score (0:ideal; 10:poor)	Lateral root score (0:ideal;10:poor)	Topple index (1.8:ideal;1.2:poor)
Natural regeneration	0.33	1.44	1.84
Containerised planted	7.37	4.12	1.33
Standard errors	0.238	0.350	0.017

Table 2.3.2: ANOVA table for the response variables

Source	d.f.	MS	F	p	Error
Menzies 1	1	1344.7	873.5	<0.001	1.54
Menzies 2	1	194.8	58.3	<0.001	3.34
Taproot	1	20.4	359.7	<0.001	0.06
Topple index	1	7.06	891.4	<0.001	0.008

Table 2.3.3: Table for minimum, mean and maximum values

Source	Minimum	Mean	Maximum
Menzies 1	0.00	3.69	10.00
Menzies 2	0.00	2.72	9.00
Taproot	0.00	0.59	1.00
Topple index	1.14	1.59	1.86

2.4 Discussion

Taproot development was measured against the scoring system and scores allocated. Natural regenerated trees featured significantly ($p<0.001$) better than planted containerised trees (Table 2.3.1). Natural regenerated trees had no damaged taproot systems. Only minor kinks were observed. Containerised trees lacked taproot development in most cases. The reason for this is that initial taproot development in seedlings is so dominant that taproot air pruning takes place very early in the containers. When planted in the field, containerised seedlings have to reorganise their root configuration, with lateral roots taking over the function of the pruned taproot. This results in lateral roots growing in all directions resulting in bad spatial root distribution.

The lateral root scoring also significantly favoured natural regenerated trees ($p<0.001$) (Table 2.3.1). Lateral root development ranged from a mean score of 1.44 in natural regenerated trees to 4.12 in planted trees, with 0 being ideal (Table 2.3.1; Table 2.3.3). The difference in lateral root development between natural regenerated trees and planted trees was the angle between the taproot and laterals. Planted containerised trees had in most cases an angle of less than 90 degrees downwards, whereas natural regenerated trees had lateral root growth horizontally.

The above-mentioned results were used in the Menzies' topple index equation to predict the likelihood of trees being unstable. Natural regenerated trees were assumed to be the ideal. The topple index confirmed this assumption, with natural regenerated trees scoring 1.83 vs 1.32 of planted trees (Photos 2.4 (A-C)).

2.5 Conclusion

The reason for testing or calibrating the Menzies' scoring system was to develop a method to measure the impact of any silvicultural activity on tree stability. The assumption was made that natural regenerated trees represent the ideal root configuration and therefore stability. Natural regenerated trees fit the Topple index function which indicates that the likelihood of trees to be unstable can be predicted with the use of this scoring system.

Containerised trees investigated in this trial were removed from a compartment with prior instability problems. The low scores of these trees prove that containerisation influences the development of roots. Containerisation can therefore be detrimental to stand development and must be practised with caution.

The Menzies' scoring system was found to be an accurate and reliable method to evaluate the impact of activities on root configuration and tree stability. The method is easy to use but rather time consuming.

Photo 2.4 A: Natural regenerated trees had an average topple index of 1.84. Note the non-occurrence of stem weaknesses at the base of the stem

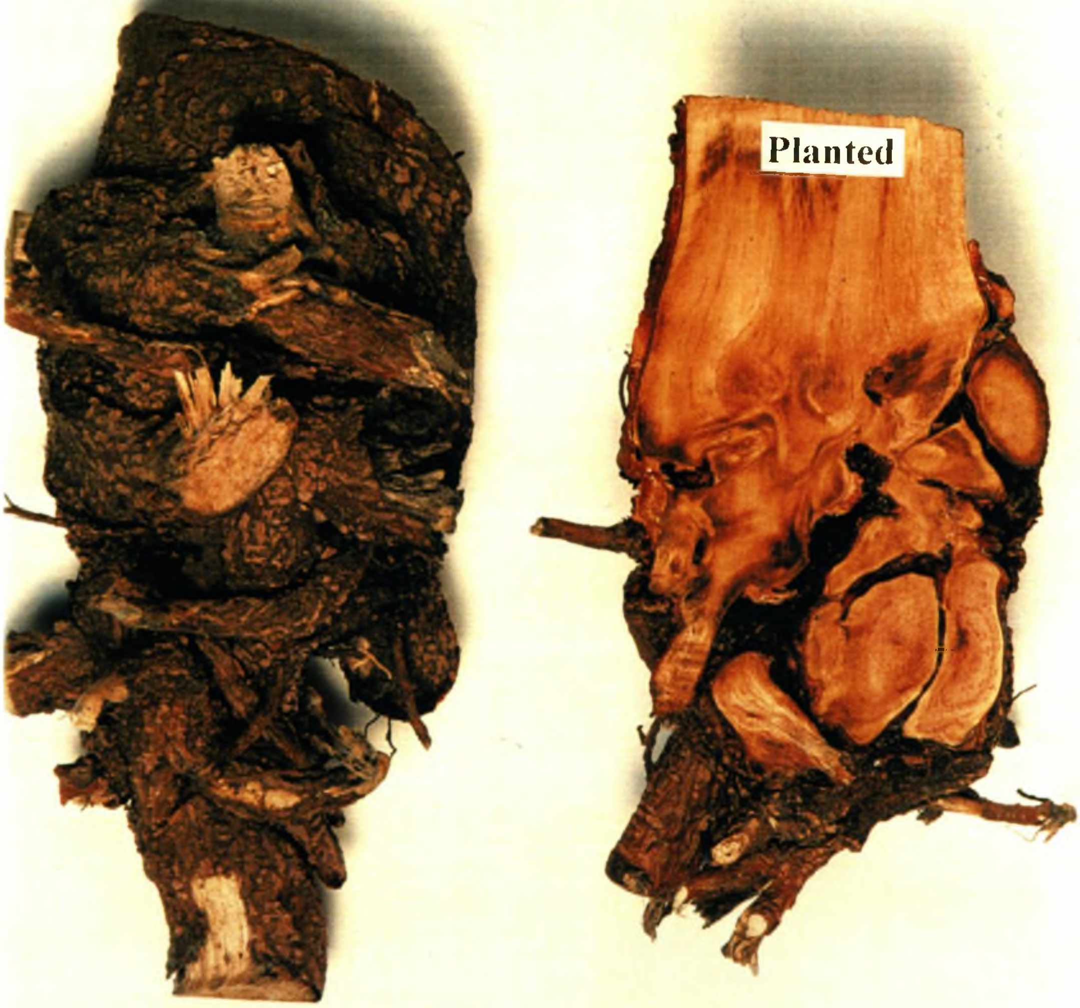

Photo 2.4 B: Planted containerised trees had an average topple index of 1.33. Note the occurrence of stem weaknesses at the base of the stem

Photo 2.4 C: Planted containerised trees had an average topple index of 1.33. Note the occurrence of stem weaknesses at the base of the stem

3. The effect of transplant grade and soil deterioration on survival and root development of *P. patula* transplants

Synopsis

Three different grades of containerised *P. patula* seedlings and one cutting grade were planted in pots and grown under a controlled environment for 60 days. Grades were allocated to transplants with different collar diameters and shoot lengths Survival, root development and shoot growth of transplants were monitored. The effects of soil type and transplant dimensions on survival and root growth were investigated. Transplant height, diameter increment, root development, survival and a quantitative scoring system were used to determine the ideal transplant grade as well as the effect of soil structure deterioration on transplant development. Soil structural deterioration is of the most common characteristics of old land soils. Soils collected from old lands had weak structural development. After 60 days, the small transplants (initial mean shoot length 67.3 mm and collar diameter 1.80 mm) had the best height increment ($p<0.001$) and second best diameter (non-significant) increment. Cuttings had the best diameter increment and second best increase in height. Cuttings scored highest in the quantitative scoring ($p< 0.1$) with medium transplants (shoot length 21.2 cm and collar diameter of 3.5 mm) scoring second best. Large transplants (shoot length 40.4 cm collar diameter 4.2 mm) scored lowest. The smallest transplants could not be properly evaluated quantitatively because the root plug broke up during washing. Mortality associated with old lands did not occur in this trial.

3.1 Introduction

Grading of transplants is not a routine procedure in South African forestry because very little literature is published on this topic (Bayley, 1995). Foresters, however, generally agree that relatively small seedlings, although not defined how small, should be planted for their better survival and growth.

Both stem diameter and shoot height are affected by nursery practices such as growing density, transplanting, top pruning, and root pruning. Stem diameter reflects the response (survival) of seedlings to the environment while shoot height is a good predictor of tree growth. Although these parameters indicate seedling performance potential, they do not reflect seedling vitality or vigour (Mexal and Landis, 1990). These parameters are also affected by time of sowing and other practices such as time of undercutting, fertilisation and nursery climate (Menzies *et al.*, 1986). Other morphological measurements such as transplant mass, number of first order lateral roots and presence of fascicle bundles can also be used to predict transplant performance and survival (Donald, 1992).

Small plants, because of their better root:shoot balance, will perform well under favourable site and climatic conditions. Difficult site combinations require relatively large, hardened plants, but the correct balance is difficult to achieve (Donald *et al.*, 1994). Reports by McGilvray and Barnett (1982) revealed that containerised transplants with a higher root:shoot ratio performed better than those with lower ratios. Growth of *P. taeda* transplants was negatively correlated with low root:shoot ratios at time of planting.

With fast growing species in South Africa, it is difficult to keep the height/diameter ratio below 60:1 and topping may be required to procure it. Pine seedlings can be topped without having a negative effect on subsequent growth, however, topping has to begin early and must be repeated frequently to avoid a depleted leaf area. Topping can improve survival under harsh conditions although many foresters prefer untopped transplants as they believe that these grow faster. Where transplants cannot be planted on time, topping may be essential but care must be taken not to reduce the leaf area too drastically (Donald *et al.*, 1994).

Hinze (1994) prescribes a nursery plant not older than one growing season as the roots may become distorted. If older than the prescribed age, root pruning is an option to minimise the problem. Pine transplants no longer than 300 mm in height and a diameter of 3-5 mm are prescribed. Wessels (1987) also prescribes transplants not taller than 300 mm. Hodgson (1979) visited several Transvaal open rooted nurseries during the growing season to determine the ideal *P. patula* seedling. Satisfactory seedlings ranged from ages 3 to 17 months, with stem lengths from 90 mm to 260 mm. The prescribed diameter should not exceed 3 mm and should not be less than 1mm. SAFCOL's current pine transplant specifications are a height of 80-150 mm and a collar diameter of >3 mm (SAFCOL, 19??).

Lopushinsky and Beebe (1976) have shown that visual root quality is a better performance predicting tool than quantitative measurements. In work with *P. ponderosa* transplants, Lopushinsky and Beebe (1976) found that survival of large rooted transplants increases by approximately 10% to 24%, compared to small rooted transplants. Kormanik (1987) found a strong correlation between number of permanent first order lateral roots with seedling size and performance. Hardwood seedlings with inferior lateral root development performed poorly.

Larger root systems will positively affect the rate of transpiration and gas exchange. Small rooted seedlings are under water stress, which cannot balance the transpiration losses from the needles. This might result in a reduction of photosynthate production, which will limit root growth. High root volume has been shown to improve growth after planting (Rose *et al.*, 1990). A large root area does not seem to compensate for root deformities (Håkansson and Lindström, 1995).

3.2 Materials and methods

Soil was collected from old agricultural lands and virgin grassveld in the plantations managed by Mondi Forests in the North Eastern Cape. Both soils were of the Oakleaf form, with the characteristic orthic A horison followed by a neocutanic B horison and an unspecified subsoil (Soil Classification Working Group, 1991). Collection took place in the top 15 cm of the profile because planting and initial root growth takes place only in the topsoil layer. Half of both soils were sterilised to monitor the effect of pathogens on transplant survival and growth.

Three different grades of *P. patula* seedlings and one *P. patula* rooted cutting were used. The grades were expressed as mean collar diameter and height. Table 3.2.1 lists the grades of planting material used. It was decided to use dimension as grade rather than age because dimension is a function of the variable nursery regime and the season during which the transplant is raised. Transplants of the same age can therefore have different dimensions. All transplants were raised in a composted pine bark medium in Unigro 128 containers. Cuttings were propagated in Unigro 98 containers filled with a pine bark/vermiculite mix as growing medium.

Table 3.2.1: Grades of *P. patula* seedlings and cutting material used

Growing material	Grade	Age	Mean Diameter (mm)	Mean Height (cm)
Seedling	Small	4 months	1.80	6.73
Seedling	Medium	7 months	3.49	21.20
Seedling	Large	12 months	4.20	40.40
Cutting	Cutting	12 months	4.37	25.81

Soils (old land/virgin), soil sterility (sterile/not sterile), and transplant grade (small, medium, large transplants and cuttings) were the three treatment factors investigated constrict the root's vascular system and therefore shortens the lifespan of a tree (Appleton, 1993).

Tinus (1976) lists the advantages of containerised seedling production compared to bare root production. Most obvious advantages are the opportunity to accelerate seedling growth in a greenhouse environment, optimising photoperiod, temperature, plant nutrition and pest control. Containerised seedlings have a higher survival and growth rate in the field than bare root seedlings (Owston and Stein, 1978; Hahn and Hutchison, 1978; Sloan *et al.*, 1987), and they can be held in the containers until planting conditions are suitable (Brisette, 1981). Containerised *P. ponderosa* seedlings outperform bare rooted seedlings, especially on harsh sites. On better sites the difference is less significant (Sloan *et al.*, 1987). Containerised seedlings suffer little transplant shock because little root disturbance occurs (Kinghorn, 1972 ex Romero *et al.*, 1986). Unlimited opportunities to control seedling growth, form, hardiness and physiological condition are obtained enabling the nursery manager to extend the planting season beyond bare root nursery seedling ability (Romero *et al.*, 1986). Hite (1978) mentions the cost advantage of containerisation in the northern Rockies which is 18% less than bare root seedlings. However, Chavasse and Balneaves (1971 ex Mason, 1979) and Lindgren and Orlander (1977) found that the occurrence of toppling was greater in tubed stock than in bare root stock.

Van Eerden (1981) observed that use of containers cause root deformations, which may lead to instability, basal sweep and toppling in some of the pines. Containerised rooting systems show the dominant influence that container design has on root morphology (Van Eerden, 1978). Hait and Tinus (1974 ex Tinus, 1981) experienced the problem of roots striking the container wall during development, resulting in malformed roots. Kopparfors (complete reference not available, ex Tinus, 1978) found that seedlings grown in trays with firm walls have less difficulty in growing into the neighbouring soil after planting than open rooted seedlings. According to him these roots develop better because they are in close contact with the soil. Containers with stiff, impermeable-walls, vertical ribs or grooves, lack of sharp horizontal corners, and a hole at the bottom for air pruning are used to produce seedlings with untangled roots (Stefánsson, 1978; Tinus, 1981). Unfortunately, most of the new roots grow from the bottom of the plug, leaving the seedling with an inadequate root system that may lead to swaying and toppling of older trees (Tinus, 1981). Harrington *et al.* (1986) reported that planted containerised *P. echinata* seedlings lack a tap root in 30% of the cases compared to a taproot absence of 15% in natural regenerated seedlings. Seedlings with vertical taproots exhibit greater height growth than trees with deformed root systems and are generally more stable.

the count the better the score. Thirdly, the number of sides from which roots protruded was counted, with four as full marks. Lastly, the root concentration was determined. A possibility of three scores could be given. If 50% or more of the root growth took place from the bottom of the plug, a score of one was given. This is also known as "onioning" (A.E. Bailey, pers. comm., 1995). If 50% of the root growth took place from the bottom of the plug, and 50% from the sides a score of two was given. If root growth took place evenly from all the sides, and less than 10% from the bottom of the plug, full marks (three) was given.

A three-way analysis of variance was carried out with final shoot diameter, shoot diameter increment, final shoot height, shoot height increment, root mass, shoot mass, number of weeds and the quantitative scores as response variables. The significance of the main effects of soil (source), sterilisation and transplant grade on the response variables was tested, as well as the interactions soil x sterilisation, soil x grade, sterilisation x grade, and soil x sterilisation x grade. It was decided, for each of the three quantitative criterions, to use the average of the four observers' scores (D. Saville, pers. comm., 1997). This was despite significant evidence of differences between the four observers, and weaker evidence of interaction between the observers and some of the treatment factors (i.e., observers sometimes ranked treatments differently).

3.3 Results

Table 3.3.1: Diameter and Height increment (means)

Soil source	**Soil treatment**	**Transplant grade**							
		Small		Medium		Large		Cutting	
		Diam	Ht	Diam	Ht	Diam	Ht	Diam	Ht
Virgin land	Sterile	0.8	10.8	0.9	6.9	0.9	5.9	0.9	9.4
	Non-sterile	0.7	8.3	0.4	7.4	0.5	7.6	0.9	6.7
Old land	Sterile	0.6	11.0	0.5	6.9	0.8	6.7	0.4	8.6
	Non-sterile	0.7	9.6	0.2	6.4	0.2	5.8	0.8	7.4

Diam: Diameter (mm) Ht: Height (cm)

Table 3.3.2: Quantitative scoring (means) of transplant grade

Soil source	Soil treatment	Transplant grade							
		Small		Medium		Large		Cutting	
		H	R	H	R	H	R	H	R
Virgin land	Sterile	2.1	13.0	2.0	19.1	2.1	18.8	2.7	33.9
	Non-sterile	1.9	14.8	2.4	27.1	2.3	20.2	2.7	49.5
Old land	Sterile	2.2	16.6	2.2	12.7	1.9	8.1	2.8	32.4
	Non-sterile	2.3	14.9	2.4	23.2	2.4	21.8	2.6	22.8

H: Roots protruding from horizontal levels R: # Roots growing from plug

Table 3.3.3: Quantitative scoring (means) of transplant grade

Soil source	Soil treatment	Transplant grade							
		Small		Medium		Large		Cutting	
		S	P	S	P	S	P	S	P
Virgin land	Sterile	2.6	1.8	2.8	1.8	3.0	1.6	3.9	2.3
	Non-sterile	2.9	1.8	3.5	2.3	3.4	1.9	3.7	2.5
Old land	Sterile	2.7	1.9	2.9	1.9	2.1	1.8	3.4	2.7
	Non-sterile	2.3	1.8	3.3	2.2	2.4	1.8	3.2	2.3

S: # Sides from which roots protruded P: Root concentration

Table 3.3.4: Weed count (means)

Soil source	Soil treatment	# Weeds
Virgin land	Sterile	1.10
	Non-sterile	0.15
Old land	Sterile	0.45
	Non-sterile	38.10

Table 3.3.5: Oven dry root and shoot mass (means)

	Dry root mass	Dry shoot mass
P. patula transplant (small)	0.01	1.44
P. patula transplant (medium)	0.25	3.36
P. patula transplant (large)	0.36	5.32
P. patula cutting	0.76	7.08

Measurements in grams

Table 3.3.6: Table for minimum, mean and maximum values of response variables

Source	Minimum	Mean	Maximum
Initial diameter (mm)	1.34	3.46	5.66
Initial length (mm)	3.00	23.53	46.00
Final diameter (mm)	1.56	40.10	6.59
Final length (mm)	14.00	31.37	51.00
Root mass (g)	0.00	0.35	1.31
Shoot mass (g)	0.75	4.30	10.30
Weeds (count)	0.00	9.95	61.00
Horisontal root growth (H)	1.25	2.29	4.00
Roots protruding plug (R)	4.00	21.78	65.50
Growth from sides (S)	1.50	2.98	4.00
Root concentration (P)	1.00	1.99	3.00

Table 3.3.7: ANOVA table for the response variables (Diameter increment)

Source	d.f.1	MS	F	p
Soil Source (STY)	1	1.98	8.51	0.005
Soil Treatment (ST)	1	0.003	0.01	0.917
Transplant grade and cutting (TGC)	3	27.61	118.59	<0.001
STY*ST	1	0.08	0.35	0.557
STY*TGC	3	0.18	0.76	0.523
ST*TGC	3	1.2	5.15	0.003
STY*ST*TGC	3	0.13	0.54	0.658
Error	64	0.233		

Table 3.3.8: ANOVA table for the response variables (Height increment)

Source	d.f.	MS	F	p
Soil Source (STY)	1	0.53	0.07	0.80
Soil Treatment (ST)	1	16.65	2.21	0.14
Transplant grade and cutting (TGC)	3	3163.86	419.49	<0.001
STY*ST	1	0.15	0.02	0.89
STY*TGC	3	19.48	2.58	0.06
ST*TGC	3	13.62	1.81	0.16
STY*ST*TGC	3	7.99	1.06	0.37
Error	64	7.54		

Table 3.3.9: ANOVA table for the response variables (H-criterion)

Source	d.f.	MS	F	p
Soil Source (STY)	1	0.11	0.67	0.42
Soil Treatment (ST)	1	0.25	1.50	0.23
Transplant grade and cutting (TGC)	3	1.42	8.38	<0.001
STY*ST	1	0.05	0.30	0.59
STY*TGC	3	0.09	0.55	0.65
ST*TGC	3	0.27	1.61	0.20
STY*ST*TGC	3	0.09	0.51	0.68
Error	64	0.17		

Table 3.3.10: ANOVA table for the response variables (R-criterion)

Source	d.f.	MS	F	p
Soil Source (STY)	1	599.51	13.97	<0.001
Soil Treatment (ST)	1	490.05	11.42	0.001
Transplant grade and cutting (TGC)	3	1575.53	36.72	<0.001
STY*ST	1	60.38	1.41	0.240
STY*TGC	3	214.75	5.01	0.004
ST*TGC	3	88.01	2.05	0.116
STY*ST*TGC	3	315.22	7.35	<0.001
Error	64	42.91		

Table 3.3.11: ANOVA table for the response variables (S-criterion)

Source	d.f	MS	F	p
Soil Source (STY)	1	4.39	38.27	<0.001
Soil Treatment (ST)	1	0.66	5.72	0.02
Transplant grade and cutting (TGC)	3	3.65	31.81	<0.001
STY*ST	1	0.34	3.00	0.09
STY*TGC	3	0.67	5.79	0.001
ST*TGC	3	0.61	5.29	0.003
STY*ST*TGC	3	0.13	1.15	0.34
Error	64	0.11		

Table 3.3.12: ANOVA table for the response variables (P-criterion)

Source	d.f.	MS	F	p
Soil Source (STY)	1	0.03	0.21	0.65
Soil Treatment (ST)	1	0.15	1.13	0.29
Transplant grade and cutting (TGC)	3	1.89	13.88	<0.001
STY*ST	1	0.53	3.89	0.05
STY*TGC	3	0.003	0.02	0.99
ST*TGC	3	0.29	2.11	0.11
STY*ST*TGC	3	0.06	0.45	0.72
Error	64	0.14		

Table 3.3.13: ANOVA table for the response variables (Weeds)

Source	d.f.	MS	F	p
Soil Source (STY)	1	6956.45	192.00	<0.001
Soil Treatment (ST)	1	6734.45	185.87	<0.001
Transplant grade and cutting (TGC)	3	64.57	1.78	0.159
STY*ST	1	7449.80	205.62	<0.001
STY*TGC	3	60.95	1.68	0.180
ST*TGC	3	67.75	1.87	0.144
STY*ST*TGC	3	74.83	2.07	0.144
Error	64	36.23		

Table 3.3.14: ANOVA table for the response variables (Oven dry root mass)

Source	d.f.	MS	F	p
Soil Source (STY)	1	0.25	9.25	0.003
Soil Treatment (ST)	1	0.08	3.08	0.08
Transplant grade and cutting (TGC)	3	1.97	73.59	<0.001
STY*ST	1	0.05	2.00	0.16
STY*TGC	3	0.16	5.96	0.001
ST*TGC	3	0.08	2.80	0.05
STY*ST*TGC	3	0.02	0.67	0.57
Error	64	0.026		

Table 3.3.15: ANOVA table for the response variables (Oven dry shoot mass)

Source	d.f.	MS	F	p
Soil Source (STY)	1	0.558	0.53	0.469
Soil Treatment (ST)	1	0.040	0.04	0.847
Transplant grade and cutting (TGC)	3	118.714	113.16	<0.001
STY*ST	1	0.116	0.11	0.741
STY*TGC	3	0.964	0.92	0.437
ST*TGC	3	0.220	0.21	0.889
STY*ST*TGC	3	0.088	0.08	0.968
Error	64	1.049		

3.4 Discussion

The idea for not putting transplants under any environmental stress was to test the effect that soil source has on root and shoot development as well as survival in different soils. The effects of soils on transplant development and growth were isolated and tested for significance. Other external factors were excluded from confounding these effects. The transplants were at no stage under environmental stress. Water and fertiliser were applied as needed by the transplants.

Weeds were pulled out and counted as they germinated. Old land soils had significantly ($p<0.001$) more weeds than soils from virgin lands. Weed counts on old land soils, which had not been sterilised, ranged from 20 to 61, weeds per pot (11309 square mm). In the virgin soil pots it ranged from 0 to 5 weeds per pot (Table 3.3.4).

However, sterilisation also had a significant effect ($p<0.001$), with non-sterilised soils being weedier (Table 3.3.13). The interaction between soil and sterilisation was highly significant ($p<0.001$). The non-sterilised, old land soil was weedy, and all other combinations not weedy. For sterilised soils, virgin land soil had insignificantly more weeds than the old land soil. The moisture and nutrient stress that the abundance of weeds inflicts on *P. patula* transplants can be responsible for high mortality in the field (Ellis, 1995).

No mortality occurred in any of the treatments. Mortality of transplants planted on old agricultural lands can therefore only be explained by other sources of stress. The causes of the old land syndrome are therefore complex. Poor soil structure due to repeated mechanical ploughing was probably responsible for the poor drainage in the pots filled with old land soils. When these pots were watered, the soil settled into the pot so that a fully filled pot ended up three-quarters full. After the initial wetting, it was difficult to water these pots due to the poor water infiltration. It was clear that the old land soils had a low structural stability, giving rise to a slow permeable material and a white fungus grew in the pots, which could be due to the low infiltration rate.

Transplant grade had a significant effect ($p<0.001$) on height increment (Table 3.3.8) after 60 days in the cabinets. The smallest transplants had the best height increment (Table 3.3.1). While planting, it was noted that the smallest transplants showed no sign of wilting while all the other transplants showed signs of stress. Problems were experienced when lifting and planting the smallest transplants because the roots did not fully bind the growing medium. The possibility of J-roots developing after transplanting is high in this situation. Mondi designed a planting pipe to minimise this problem. The Unigro plastic container makes it easy to lift these transplants as they can be dented on the sides to loosen the plug. Other containers can be more problematic. The cuttings had the second best height increment. Soil and sterilisation had no significant effect on height growth, and there was no significant evidence of interactions between treatment factors.

The effect of transplant grade on diameter growth was significant ($p<0.001$) (Table 3.3.7). Soil source ($p=0.005$) also had significant effects on diameter increment. Plants in virgin soils showed greater diameter increment than those in the old land soils, and sterilisation had a positive effect on diameter increment. The interaction of sterilisation and transplant grade was significant ($p<0.003$). For unsterilised soils, cuttings showed the highest diameter growth followed by small transplants. This was different for sterilised soils, with large transplants performing best, and cuttings worst.

Seedling grade had a significant effect ($p<0.001$) on root mass (Table 3.3.14). The cuttings outperformed all the transplants in terms of root and shoot dry mass with the large transplant second and the medium transplant third. Dry root mass decreased, as grade became smaller. Transplants raised in virgin soils had a significantly better ($p=0.003$) increase in dry root mass than those raised in old land soils. No significant differences in dry root mass could be determined between sterilised and unsterilised soils. Interaction between soil and transplant grade was significant ($p=0.001$). Root growth was better in virgin soils, except for the medium transplants where the reverse was true. The ranking of the transplant grades within the two soils was the same (i.e., cutting, large, medium).

The evaluation of root mass is under suspicion because it is difficult to completely separate roots and growing medium especially in the case of the small seedlings because the root plug deteriorated when washed. The difference in dry root mass between the smallest and largest reading was only 0.518 g. The number of roots developed is also of more value than the mass measurement (Lophushinsky and Beebe, 1976; Kormanik, 1987). Shoot dry mass is suspected to be of little value as no initial reading could be taken without damaging the transplant, and initial shoot mass was very variable. Transplants grown in soils collected from virgin grassveld showed a significant increase in dry root mass compared to old agricultural lands, as was expected due to soil structure deterioration in old lands.

Difficulty was experienced when evaluating transplants on a quantitative basis. The root plug, which was formed in the nursery by the container, was used as the base from which evaluation took place. Only growth from this plug was measured and evaluated. It was easy to identify the original plug in the case of the cuttings, and medium and large transplants. The small transplants had no plug left after the transplants had been washed out. The evaluation personnel agreed that it would do the small transplants an injustice if they were evaluated on this basis. Small transplants were quantitatively evaluated but the personnel agreed that results couldn't reflect the true picture. The results of small transplants were thus excluded from the analysis of the quantitative assessments.

Transplant grade had a significant effect ($p<0.001$) on the number of roots growing from the plug (Table 3.3.10). Cuttings had the highest number, with medium transplants in second place and the large transplants scoring lowest. Virgin soils enhanced root growth ($p<0.001$). The contradiction between dry root mass and the number of roots protruding from the plug must be noted. Root mass might be an unreliable variable since the measurements were very fine and it was difficult to accurately separate the roots from the growing medium. Sterilisation had a significant ($p=0.001$) detrimental effect on root growth from the plug. The interaction between transplant grade, sterilisation and soil type was significant ($p<0.001$). Sterilisation had a detrimental effect on the number of roots developing in transplants, but not in cuttings (Table 3.3.2).

Although cuttings had high growth vigour and the roots were evenly distributed and balanced, less than three roots (in most cases only one) grew from the base of the stem. A callus was formed at the point of initial root growth. When pulled, these roots broke off easily at that point. The callus is a point of potential weakness. Thus more work on root development in cuttings is essential, as trees may develop unstable root systems.

On the first quantitative scoring criterion, i.e. the horizontal scoring (Table 3.3.2), transplant grade had a significant effect ($p<0.001$) on root distribution (Table 3.3.9). Once again, cuttings outperformed all the others. Medium transplants ranked second followed by large transplants. The large transplants had very few roots protruding from the plug. These roots entered the soil at the bottom of the plug. This growth pattern looks like an onion and is called "onioning" by some researchers (Bailey, pers. comm., 1995). The large transplants were moribund and will probably recover very slowly, if ever. Roots, which have already grown around the stem (caging), will eventually strangle the transplant, causing stem weaknesses. This in turn may result in toppling which is usually confined to transplant planted plantations (Mason, 1985).

The development of roots on all sides of the plug was significantly (Table 3.3.11) affected by transplant grade ($p<0.001$) and by soil source ($p<0.001$). Cuttings scored best followed by medium and then large transplants. Virgin soils scored better than old land soils (Table 3.3.3). There was significant interaction between factors soil type x transplant grade ($p=0.001$) and soil type x transplant grade x soil treatment.

Transplant grade ($p<0.001$) had a significant effect on the vertical distribution of roots (Table 3.3.12). Large transplants tended to be more moribund with new root growth concentrated at the bottom of the plug. Stem damage due to root strangulation could also be noted. Medium transplants were also bad, cuttings were better and small seedlings showed no signs of strangulation or being moribund (Table 3.3.3).

Unfortunately the small transplants could not be properly evaluated quantitatively. The roots developed well and no moribundness was noted. The chance of planting these transplants with J-roots is high. J-rooting will result in unstable trees with malformed root systems at a later age. The Mondi pipe planting seems to be an effective method to overcome this. A short pipe is pushed into the planting pit after the soil has been loosened. The transplant is lowered into the pipe and the soil is compacted while the pipe is being pulled out. This enables the planter to compact the soil without deforming the roots.

The fact that mortality did not occur in this trial after 60 days suggests that old land soils and the occurrence of pathogens (non-sterilised soils), in the absence of other potential harmful factors, are not causes of transplant mortality. Other factors such as weeds and climate must also contribute to transplant mortality. The weed counts showed that weeds grow in abundance in old lands with unsterlised soils. Weed counts ranged from 20 to 61 weeds per 11309 square mm in these soils.

3.5 Conclusions

Transplant grade will influence the degree of shock a transplant experiences when planted in the field. Large transplants tend to be moribund and will have difficulty with root development and stability. Caging will also be a problem on these large transplants. The ideal transplant grade must not exceed a stem height of 212 mm and a collar diameter of 3.5 mm. It is unfortunate that difficulty was experienced with the quantitative evaluation of the small transplants (mean collar diameter of 1.79 mm and shoot length of 67.3 mm). These transplants outgrew all the other transplants and showed no signs of planting stress or root deformities. Transplants should be small rather than large.

This trial reiterates the importance of total silviculture. The so-called old lands syndrome is a high risk because it includes most of the common problems that can be found in plantations, such as weed competition, soil structure deterioration, pathogens, toxins, rodents, insects and soil nematodes. However, under ideal growing conditions, old land soils and pathogens in isolation appear not to be responsible for transplant mortality.

Shoot and root growth of cuttings was shown to be above average. If the potential problem of stem weakness at the stem base can be solved, cuttings can be planted with less risk of instability. It is therefore important to do more research on root development of cuttings, to prevent potential problems related to tree stability.

4. The ideal transplant dimensions for optimum *P. patula* seedling survival and growth

Synopsis

Three different grades of containerised *P. patula* seedlings, stratified seed, and one cutting were planted in the field and grown under reasonably favourable environmental conditions for 620 days. Transplants were graded small (1.75-mm diameter and 63.2-mm height), medium (2.78-mm diameter and 124-mm height), large (3.13-mm diameter and 197-mm height), cutting and seed. Transplant grades were tested for its increment in height and diameter as well as root development, stability and survival. The ideal transplant dimension for best performance were determined. After 620 days, the small transplants had the best height and diameter increment ($p<0.001$) and second best stability ($P<0.001$). The small seedlings significantly experienced the least restrictive influence that the container had on its root development. It was noted that large transplants were more moribund with definite root strangulation. The stratified seed did not germinate because rodents totally damaged this treatment.

4.1 Introduction

The ideal seedling concept attempts to define specific physiological and morphological seedling characteristics that can be linked to afforestation and reforestation success in terms of survival and growth (Rose *et al.*, 1990; Donald, 1992; Grossnickle and Folk, 1993). The intent of defining a quality seedling is to remove seedlings that do not meet the minimum standards, thereby ensuring better survival and growth (Donald, 1992; Grossnickle and Folk, 1993). The wide array of testing possibilities can lead to confusion in selecting the tests. Part of this confusion stems from the fact that these tests can have one of two different purposes, firstly the evaluation of nursery development and growth, or secondly forecasting field survival and growth. A clear understanding of the nature and purpose of these testing techniques will help managers to use appropriate tests (Grossnickle and Folk, 1993). The ideal seedling brings to mind morphological targets such as stem diameter, height and root:shoot ratio (Menzies *et al.*, 1985). The importance of parameters other than height and diameter to define seedling quality has only recently been realised (Rose *et al.*, 1990). Results from testing programmes can be integrated in the performance potential index (PPI) incorporating results of morphological, physiological and performance attribute tests. Errors in describing potential seedling performance can occur in this system. Seedlings have a dynamic pattern to their seasonal physiological response and morphological development (Ritchie and Tanaka, 1990), resulting in different physiological and morphological characteristics at different times in seedling development (Grossnickle and Folk, 1993). Seedling morphology can also be a misleading indicator of field survival in stressful planting situations (Sutton, 1979). The modern forest nursery manager is aware that although morphological targets are important, they fall short of guaranteeing high planting stock quality (Mexal and Landis, 1990). Morphological and physiological quality standards are important prerequisites for tailoring nursery stock to specific site characteristics and requirements (Van Eerden, 1981). Early rate of root growth and form are highly dependent on these parameters (Burdett *et al.*, 1983). Although seedling quality is subjective and hard to define, it does not mean that forecasting seedling field performance is impossible.

Survival and initial growth are quantifiable parameters. Site conditions and climate after planting will determine how each seedling will perform (Donald *et al.*, 1994). Chavasse (1978) recommends a seedling root system least likely to be badly distorted and which will develop into a system similar to a naturally regenerated tree. Basic survival requires that a seedling root system should be able to supply sufficient water for transpiration loss (Carlson and Miller, 1990). Washbourn (1984 ex Balneaves and De La Mare, 1989) stresses the importance of using quality seedlings capable of taproot regeneration after planting.

Many adverse events may take place between the nursery and the field, for example lifting and planting. The best quality seedlings, whatever the criteria, may be mishandled in leaving the nursery, and during storage and planting. Planting and site conditions may be so severe as to nullify good nursery practice. Increased co-operation between the nursery specialist and forestation specialists is essential to determine a combined seedling quality criteria based on seedling quality in the nursery as well as handling and planting quality (Leaf *et al.*, 1978; Grossnickle and Folk, 1993).

Using a single test or criterium to determine seedling quality is dangerous because seedlings have a wide array of physiological processes that continually respond to environmental conditions (Grossnickle and Folk, 1993). Bigg and Schalau (1990) recommend the use of both morphological and physiological parameters in the following ratio:

40% height
30% diameter
20% R.G.P. (root growth potential)
10% frost tolerance.

4.2 Materials and methods

The trial area is in the North Eastern Cape on Weatherly (Chillingly Estate) managed by Mondi Forests (Trial site marked "B" on map B). The trial site was selected on virgin land with an easterly as well as a westerly aspect. Soils were of the Hutton form. The soils had a clay loam texture with an effective rooting depth of approximately 80 cm the limiting factor being illuviation. Soils were ripped in three meter rows to a depth of 100 cm. Rip lines were disked into a seedbed. Planting holes were made manually with dimensions of 30 cm x 30 cm x 30 cm.

The trial was laid out as a randomised complete block design with five treatments and four replicates.

After the soil had been prepared and settled, three *P. patula* seedlings of different dimensions, as well as one cutting and one direct sowing treatment were planted. Transplants were graded small (1.75-mm diameter and 63.2-mm height), medium (2.78-mm diameter and 124-mm height), large (3.13-mm diameter and 197-mm height), cutting and seed. Water and fertiliser were not applied in order to possibly affect survival and development negatively. Seedlings were left in the field for 620 days.

Tree height and collar diameter were measured at the end of the trial period. Height and diameter increments were calculated and processed. Trees were then dug out and washed in order to determine the root development quantitatively as well as qualitatively.

Taproot presence was measured as incorporation into the Menzies' scoring system. The likelihood for trees to topple in later stages was calculated with an amended topple index equation. The effects of containerization cannot be efficiently measured with this system when seedlings are still young, so it was decided to expand the Menzies' index. The Menzies' system measures and judges taproot development as primary variable. The expanded system quantifies any root development from the plug that serves as a sinker or lateral roots. The expanded system visualizes the plug as the cage from which roots have to break free. If root development continued the pattern initialized in the nursery plug, it was regarded as unacceptable and a score of 5 was given. A score of 1 was allocated to a seedling with a root pattern totally normal and natural. This scoring system was named the Conter scoring system. This system effectively incorporates all root deformities inflicted by unnatural conditions in the nursery. The Topple index equation is now changed and the M1 variable is replaced by the Conter score called L1 (Equation 4.2.1).

Equation 4.2.1 Topple index = 1.844 – 0.07032 (L1) + 0.01827 (number of sinkers)

Caging and ball and socket were also measured. Caging was defined as a root system that has been caged by it's own lateral roots. These roots grow so dense that root development from this cage becomes very difficult or even impossible. A score of one was allocated if caging occurred and nil if no caging could be observed. Ball and socket is a more measurable parameter to quantify the extent of root strangulation. The horizontal and vertical root growth around the root base was measured. Ball and socket had a score range from one to eight. One was allocated if no root strangulation took place. Lateral root development halfway (180 degrees) around root base scored four with total root strangulation scoring eight.

A one way analysis of variance was carried out with final shoot collar diameter and length, taproot presence and length, lateral root presence and number, caging, ball and socket, Menzies' scores, topple index, and Conter scores as response variables.

Map A: Trial site marked "A"

4.3 Results

Results are summarized in Table 4.3.1.

Table 4.3.1: Mean values of shoot and root growth response of different dimensions of *P. patula* transplants

Seedling dimension	Height Increment	Diameter increment	Topple index *	M2	L1	Caging	Ball and socket
Small	100.4	19.76	1.53	2.75	1.90	0.13	4.18
Medium	96.4	17.48	1.60	3.27	1.85	0.40	3.89
Large	88.5	17.05	1.43	4.67	2.80	0.81	7.78
Cutting	77.7	13.51	1.42	5.20	3.15	0.53	4.23

* Topple index using the L1 variable

Height and diameter increment (mm)

Table 4.3.2: Table for minimum, mean and maximum values of response variables

Source	Minimum	Mean	Maximum
Height increment	0.00	90.75	156.00
Diameter increment	0.00	16.95	35.00
Topple index	1.20	1.50	1.90
M 2	0.00	3.98	10.00
Conter (L 1)	1.00	2.43	5.00
Caging	0.00	0.45	1.00
Ball and socket	0.00	4.97	9.00

Table 4.3.3: ANOVA table for the response variables

Source	d.f	MS	F	p	Error
Height	3	4005	2.14	0.098	1873
Diameter	3	267.09	3.93	0.010	68.04
Topple index	3	0.276	6.57	<0.001	0.042
M2	3	53.08	4.68	0.004	11.34
LI	3	16.967	9.38	<0.001	1.81
Caging	3	3.209	16.76	<0.001	0.19
Ball and socket	3	136.325	17.37	<0.001	7.85

4.4 Discussion

Direct sowing had a germination percentage of less than ten percent. It was decided to exclude this treatment from analyses because direct sowing could be analysed with injustice. The biggest attributing factor to the bad germination of the seed was that the seeds were removed from the soil. Seed shells were found all around the planting holes where rodents had eaten them, notwithstanding the fact that seeds were treated with a repellent. Rodent populations were also reduced before planting. It is therefore important to consider rodent populations when planting.

According to Bigg and Schalau (1990) one should judge seedling quality allocating 70% of the importance to height and diameter increment. In this trial both diameter ($p = 0.010$) and height ($p = 0.098$) resulted in non-significant differences. It can however be expected that the differences will become more significant if root constraints start to inhibit normal development at a later stage. The small trees had the best height and diameter increment with cuttings scoring worst.

When measuring topple index (using the L1 variable), the medium seedlings significantly ($p<0.001$) outscored (L1 = 1.85) (unacceptable = 5; ideal = 1) the small seedlings with the large seedlings coming third and the cuttings scoring lowest. Difficulty was experienced when judging the cuttings because their root development and configuration differed totally from that of seedlings. The reason for this is that the cuttings had an attachment point (joint) on the basis of the stem that is absent in seedlings. This joint forms callus tissue and only one or two roots grow from this callus. If the root system is isolated from the growing medium the root system looks like a "knobkierie" with two roots protruding from the knob. The joint can also be a stability risk. More detailed work has to be done on pine cuttings to ensure stable healthy rooted cuttings. The difference between the topple index of the small and medium seedlings is minute and seedlings with dimensions ranging from 1.75-mm diameter and 63.2-mm height and 2.78-mm diameter and 124-mm height can be considered ideal to optimise tree stability.

The Menzies' (M2) score is a quantitative measurement of amount of lateral root development. Disturbed root systems had the highest M2 (unacceptable) score with the small seedlings scoring lowest ($p=0.004$) therefore the nearest to the ideal. The work on natural regenerated trees showed a similar trend. The more disturbed the taproot, the more vigorous the lateral root development. It is expected that lateral root development will slow with time as the taproot becomes more dominant.

Small seedlings experienced significantly ($p<0.001$) less detrimental (caging) effect than large seedlings, because small seedlings were kept in the nursery tray for a shorter period than the large seedlings. The medium seedlings had the second least caging, with cuttings and large seedlings being third and fourth. For the ball and socket scoring almost the same trend occurred. The medium seedlings were best and the small seedlings second ($p<0.001$). The longer the seedlings are kept in the nursery, the more their root pattern is changed (Photo 4.4 : A-D). It will therefore be ideal to design a tray with plug dimensions and volume enabling the planting of seedlings with unpruned roots that bind the plug growing medium. The effect of caging is that mature trees have weaknesses at the base of the stem which later result in breakages.

Survival data are essentially binomial, with response either dead or alive. A standard analysis of variance cannot be used and therefore a logistic regression was used instead. The odds ratio of survival for a seedling with initial diameter 0.5 mm bigger than another seedling, is 0.52. The 95% confidence interval for this odds ratio is (0.292 mm, 0.932 mm), i.e. seedlings with small initial diameters have a better chance of survival than those with large initial diameters. An increase in diameter of 0.5 mm has a significant effect, approximately halving the odds of survival.

4.5 Conclusions

Direct sowing is a definite option for minimising root disturbance but this trial highlighted some of the potential problems encountered with such an operation. Seed stratification is not simple and external factors can influence germination markedly. *P.*

patula seed is too expensive to over-sow in order to achieve high germination and survival rates.

Results obtained with small and medium seedlings indicate that smaller nursery stock should be planted in the field (Photos 4.4: A-D). Small transplants had better height and diameter increment than big plants, as well as good field stability and survival. Root malformation was also limited in the smaller transplants.

Vigorous growing trees with well developed root systems enable them to be stable and utilize the site to its full potential. Relatively small transplants are one of the required inputs for establishing such stands. The ideal transplant dimensions for achieving this target should be a transplant not smaller than 1.75-mm diameter and 63.2-mm in height and not bigger than 2.78-mm in diameter and 124-mm in height.

Photo 4.4 A: Planted containerised medium seedlings. Note the non-occurrence of stem weaknesses and root strangulation at the base of the stem.

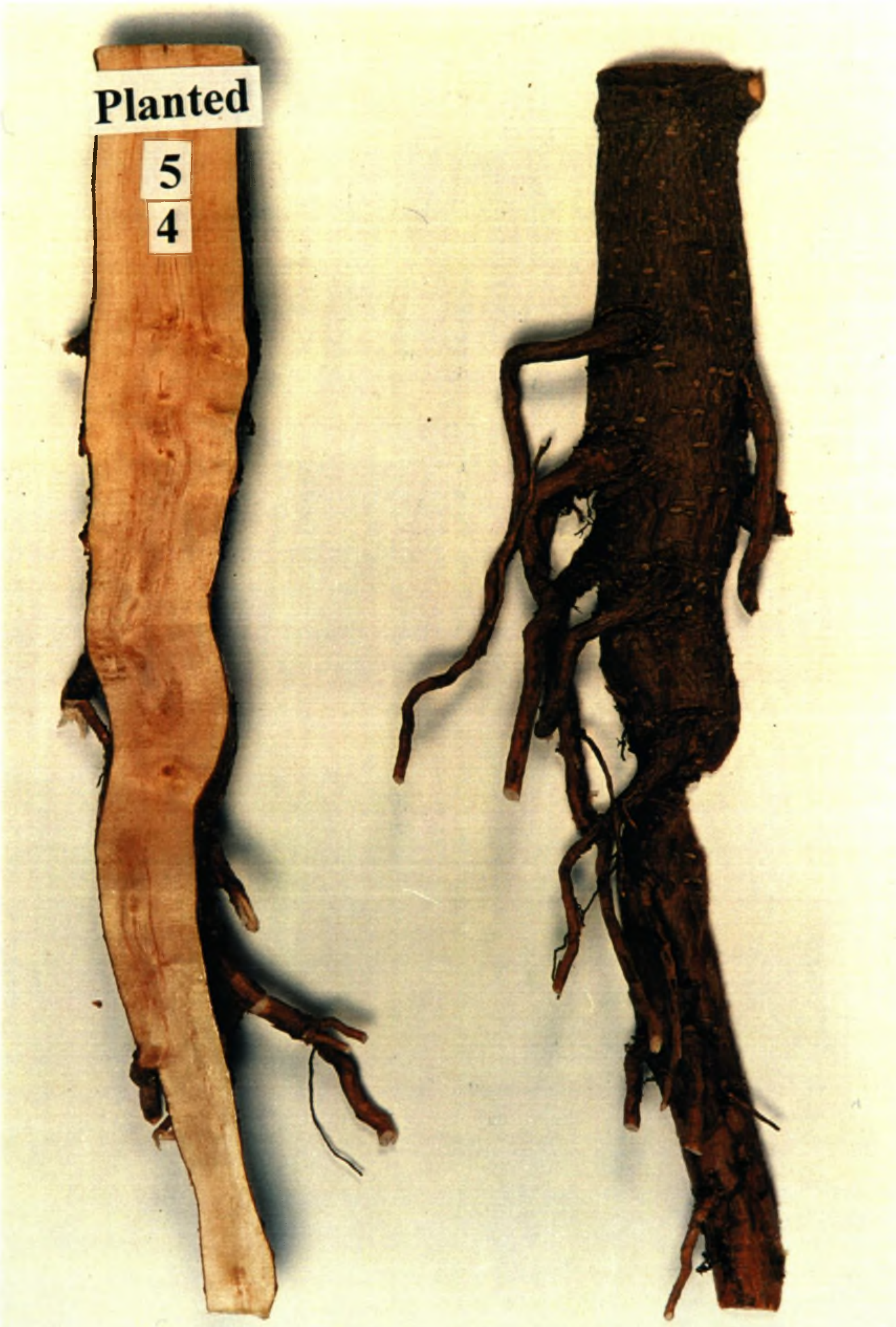

Photo 4.4 B: Planted containerised medium seedlings. Note the non-occurrence of stem weaknesses and root strangulation at the base of the stem.

Photo 4.4 C: Planted containerised large seedlings. Note the occurrence of stem weaknesses and high degree of root strangulation at the base of the stem.

Photo 4.4 D: Planted containerised large seedlings. Note the occurrence of stem weaknesses and high degree of root strangulation at the base of the stem.

5. *P. patula* seedling survival on old agricultural soils

Synopsis

Soil structure deterioration and the method of soil preparation were identified as problem areas to be investigated on old agricultural lands. Soils on old lands in the North Eastern Cape were prepared in four different ways. Scalping, ridging, between ridging and pitting were considered the soil preparation methods currently in use that could alleviate the problem. Lime, gypsum, Stockosorb®, organic matter, organic manure and a no treatment control were thought to be sufficient to address the soil structure deterioration problem. *P. patula* seedlings were planted on an old agricultural land which was still in use the previous year. No mortality was observed. Chemical soil treatments had no significant effect on seedling survival and growth. Soil preparation method however had a significant effect on root development and seedling development with between ridging scoring best, and ridging second, except in the Conter scoring system.

5.1 Introduction

The so-called old land syndrome (OLS) is one of the biggest challenges in South African forestry and cause expenses of millions of rands (E.A. Droomer, pers. comm., 1994). Blanking and replanting in most cases are the end result of this problem. Recently, survival problems occurred in the *P. patula* plantings in the North Eastern Cape. This mortality mainly occurred in the compartments which previously were old agricultural lands.

Symptoms of the OLS are suppressed growth, needle necrosis, needle wilting, needle dieback and finally mortality. Other symptoms include poor root development, stunting, lack of apical dominance, necrotic spots on the needles and growing tip (J.B. Zwolinski, pers comm., 1995). This problem is mainly confined to *P. patula.*

The OLS can be ascribed to a combination of different soil and environmental restrictive factors, which reduce tree survival and development (Ellis, 1995). When the old land soil complex was simulated with *P. patula* in greenhouse trials, foliar nitrogen deficiencies and a strong response to nitrogen fertilisers and soil fumigation were observed (Noble and Shumann, 1993). Roth *et al.* (1948) showed that *P.*

echinata with littleleaf disease had nitrogen and calcium deficiencies in the foliage. Littleleaf disease had the same symptoms as the OLS. De Ronde (1992) found that those nutrient imbalances (especially the N/P ratio) as well as possible aluminum toxicity could be responsible for the OLS. He also reported on significant differences between nutrient status of old land topsoil compared to virgin soil. The difference faded lower in the soil profile. Buchler and Ellis (1997) observed in potting trials that *P. patula* seedlings grown in North Eastern Cape soil showed signs of chlorosis, the suspected reason being a molybdenum deficiency. A positive improvement was observed after a sodium molobdate (39.5% Mo) treatment. In contrast, Hunter (pers. comm., 1995) believes that nutrients might be applied in excess rather than being deficient.

Louw *et al.* (1994) surveyed areas in the Ugie District and compared physical soil properties between old land soils and virgin land soils. Higher soil strength as well as clods occurred in the old lands. Van Huyssteen (pers. comm., 1995) observed a virgin soil aggregate stableness eightfold better than old land soil. Schumann and Noble (1993) concluded from their research on scalping, that the degradation of old land soil and nitrogen deficiency are the two primary factors causing the OLS.

Toxic levels of soils must be scrutinized if repetitive plantings show no improvement (Schumann and Noble, 1993). Atrazine is the most common herbicide used in maize and *P. patula* seedlings are tolerant to rates of 3 kg active ingredient per hectare. This seemed not to be the problem (72 ppm). Several investigations during the last decade have shown that allelopathy may be more severe under low fertility conditions and that an increase in nutrients can ameliorate some of the allelochemical effects (Schumann and Noble, 1993).

Van Laar (1995) reported that the occurrence of *Pythium irregulare* was significantly negative correlated with growth performance. Pathogenic fungi can therefore be associated with unacceptable seedling survival and growth. Linde *et al.* (1994) isolated *P. irregulare* from diseased roots as well as from soil previously cultivated. *P. irregulare* was highly virulent when inoculated onto four-year-old *Pinus patula* seedlings. It also seemed as if the ridges concentrated the pathogenic fungi in the planting zone. Wingfield *et al.* (1994) report some inconsistencies in findings, with some healthy lands with high *Pythium* populations.

"The trees died of drought because of the severe competition with weeds immediately after planting" (Ellis, 1995). The main motivation for vegetation management is to prevent a decrease in survival and growth through competition for limited resources. Weeds recover quickly from disturbance caused by harvesting and site preparation (Goodall *et al.*, 1989), causing financial and physical problems. Weeds mainly compete for water, nutrients and growing space (Busby, 1988) resulting in lower crop yields. Louw (1995) blames weed competition as primary cause for the OLS. Severe weed competition was observed on old lands by Louw *et al.* (1994).

5.2 Materials and methods

The trial site was selected on an old agricultural land that was historically under maize production. This site is situated on Weatherly (Chillingly Estate) in North Eastern Cape Forests managed by Mondi Forests (Trial site marked "B" on map B). Soils were of the Oakleaf form and collection for soil sampling took place in the top 15 cm of the profile because planting and initial root development takes place only in the topsoil layer. Soil samples included soil chemical and physical analyses as well as a pathogen count. The soils had a sandy loam texture with an effective rooting depth of approximately 70 cm with the increase in clay content the limiting factor. A ploughpan was observed at 25 cm.

For the pathogen count soils were sampled per soil preparation method with ten samples per preparation method. These soils were analysed by the Department of Microbiology and Biochemistry of the University of the Free State. Soils were tested in discs and data results were expressed as percentage of discs infected with *Pythium*.

The trial was laid out as a randomised block with four replicates and twelve treatments. This was used to test the influence of treatment (five soil structure treatments; four soil preparation methods; no treatment control) on *Pinus patula* seedling survival and growth.

Four different soil preparation methods were used with lines three metres apart. These were scalping, ridging, between ridging and pitting. Scalping is a process where the topsoil is removed and pushed to the sides of the planting line with a V-blade. The exposed subsoil was ripped. Ridging also constitutes of a ripline with the topsoil worked onto the ripline. Between ridging is the opposite of ridging, a ridge is made, ripping and planting still takes place in the topsoil in-between these ridges. The idea of these ridges was to conserve moisture. Pitting is the making of square planting pits on totally uncultivated topsoil with the pit dimension of 30 cm x 30 cm x 30 cm.

Map B: Trial site marked "B"

Soil was treated in order to improve the soil physical structure. Gypsum (10 g/tree), lime (20 g/tree), organic matter (2 litres/tree), Stockosorb® (4 g/tree), and organic manure (500 g/tree) were tested against a no treatment control. Treatments were applied as a once off surface application in the case of the gypsum, lime and organic manure with the other two treatments mixed into the soil at planting. Problems were experienced to keep the organic manure in place. The reason for this was that the manure was applied in a paper bagged form. The bags were washed away in some instances. Due to the inability to stabilise these bags, this treatment was not measured although trees with bags in place grew markedly well. The growth response could be attributed to the high fertility of these bags (7:3:1). Organic matter was applied in the form of composted pine bark. A two-litre container was used to apply the matter as mulch. Stockosorb® was pre-hydrated and applied to the planting hole. The gel was mixed into the pit before the seedling was planted.

Seedlings with average collar diameter of 1.94-mm and average shoot length of 72.2-mm were planted in early spring. Seedling dimension planted proved to be ideal from previous work. All blocks were planted within one day and it the average rainfall was above average. The trial was discontinued after 410 days in the field. Tree height and collar diameters were measured. Trees were then dug out, roots washed and judged.

Taproot presence and length were measured as well as lateral root presence and number of laterals. Root systems were then judged against the Menzies' scoring system and a topple index allocated. It was felt necessary to expand on the Menzies' scoring system because young containerised trees could not be efficiently measured with this system. While the Menzies' system predicts the likelihood for a tree to topple, this new system quantifies the root development from the plug. This system (Figure 5.2.1) identifies the plug as the mould roots have to break free from. If root development continues the pattern initialised in the nursery plug, it is seen as unacceptable and a score of 5 is given. A score of 1 is allocated to a seedling with a root pattern totally normal and natural. This scoring system was named the Conter scoring system.

Old lands are renowned for high weed populations. Weed counts were made on 1 m x 1 m squares. Sample area was adjacent to the treatment plots. All weeds were removed from mentioned blocks, sorted per species and counted.

A two-way analysis of variance was carried out with final shoot collar diameter and length, taproot presence and length, lateral root presence and number, Menzies' scores, Topple index, and Conter scores as response variables. The significance of the effect of soil preparation and chemical treatment on the response variables was tested as well as the interaction soil preparation x chemical treatment.

Pathogen infestation data was determined as a percentage. As these data were binomial, transformation of data had to take place by means of an angular (arcsin) transformation, in order to meet the assumptions required for an analysis of variance. The transformed data were expressed as degrees but reported as percentages. The transformation serves to stabilize the variances (Chiswell, pers. com., 1998).

5.3 Results

Significant response variable results are summarized in Table 5.3.1.

Table 5.3.1: The response of Topple index, Conter scoring system, diameter increment and height increment to soil preparation method

Soil preparation method	Topple index	Conter	Diameter increment (mm)	Height increment (mm)
Scalping	1.53	3.22	6.05	41.3
Ridging	1.65	2.89	5.72	46.1
Between ridging	1.65	2.68	7.32	57.4
Pitting	1.55	3.43	4.71	37.1

Results of soil chemical analysis and soil physical analyses are summarised in Tables 5.3.2 and 5.3.3.

Table 5.3.2: Soil chemical analyses results of topsoil before treatments

pH (KCL)	R Ohm	H Cmol(+)/kg	P	K
			Mg/kg	
4.4	3480	1.42	16	53

Exchangeable cations (cmol(+)/kg)					Micro-elements (mg/kg)			
Na	K	Ca	Mg	CEC	Cu	Zn	Mn	B
0.00	0.14	1.37	0.65	3.58	0.80	0.8	5.3	0.50

Table 5.3.3: Water retention potentials of soils

Moisture (%V/V)		Clay	Silt	Stone	Available moisture	
10 kPa	100 kPa	%	%	%	Per sample	Per root depth
27.1	10.5	8.0	10.1	9.8	166.1 mm/m	99.7 mm/60 cm

Each soil preparation method was sampled to test the effect of soil preparation on *Pythium* populations. Table 5.5.4 summarizes these counts.

Table 5.4.4: Pythium counts per soil preparation method

Soil preparation method	*Pythium* count as a percentage (means)
Scalping	19.0
Pitting	15.0
Ridging	61.0
Between ridging	33.0

Table 5.4.5: Table for minimum, mean and maximum values of response variables

Source	Minimum	Mean	Maximum
Topple index	0.90	1.60	1.90
Conter 1	0.00	3.05	5.00
Ball and socket	0.00	3.15	10.00
Diameter increment	0.00	5.95	14.85
Height increment	0.00	45.49	116.00

Table 5.4.6: ANOVA table for the response variables (Topin)

Source	d.f.	MS	F	p
Soil preparation	3	0.515	7.27	<0.001
Chemical	4	0.033	0.46	0.764
Soil*chem	12	0.079	1.12	0.341
Error	480	0.071		

Table 5.4.7: ANOVA table for the response variables (Conter (L1))

Source	d.f.	MS	F	p
Soil preparation	3	14.023	7.06	<0.001
Chem	4	0.898	0.45	0.771
Soil*chem	12	1.690	0.85	0.598
Error	480	1.99		

Table 5.4.8: ANOVA table for the response variables (Ball and Socket)

Source	d.f.	MS	F	p
Soil preparation	3	109.58	6.63	<0.001
Chem	4	20.59	1.25	0.290
Soil*chem	12	14.57	0.88	0.566
Error	480	16.52		

Table 5.4.9: ANOVA table for the response variables (Diameter increment)

Source	d.f.	MS	F	p
Soil preparation	3	145.46	9.76	<0.001
Chem	4	11.89	0.80	0.527
Soil*chem	12	27.19	1.82	0.042
Error	480	14.90		

Table 5.4.10: ANOVA table for the response variables (Height increment)

Source	d.f.	MS	F	p
Soil preparation	3	9584.7	10.82	<0.001
Chem	4	606.6	0.69	0.603
Soil*chem	12	1317.4	1.49	0.125
Error	480	885.5		

5.4 Discussion

Planting between ridges significantly ($p<0.001$) outscored scalping, pitting and ridging in terms of the Topple index, Conter scoring, ball and socket, diameter increment and height increment (Tables 5.4.5, 5.4.6, 5.4.7, 5.4.8, 5.4.9, 5.4.10). These results must be seen in context because the year in which this trial was planted and grew was a very wet year. Results from this trial can therefore be misleading for areas prone to drought damage. Scalping had the problem in the sense that the scalp line served as a channel to catch water, transport and store it. The actual planting stations were lower than the soil surface and nearer (some spots within) to the water table. These scalp lines were wet and mostly saturated during the rainy season. The ridge plantings were second best according to the Topple index, Conter scoring and height increment. The reason for this is the opposite than in the case of the scalping, i.e. the roots could develop above the seasonal wetness. *Pythium irregulare* could inhibit root development and growth more than in the other soil preparation methods because ridging is known to concentrate topsoil, and therefore pathogens, in the ridge (Linde *et al.*, 1994). Pitting had poor results as no subsoil preparation was done and thus the ploughpan remained a problem. Planting between the ridges had an advantage in this season because the trees were planted in a ripline. The topsoil had been disturbed and removed but to a much lesser extent than in the case of the scalped plantings. The trees had therefore neatly ripped subsoil with thinner but healthier topsoil.

Pathogens were concentrated significantly ($p<0.008$) more on the ridges than in the scalpline. The ridges had the highest pathogen infection, between ridges second and pitting the lowest pathogen infection. The high infestation on- and in-between the ridges and the low infestation in the scalpline could be predicted but pitting had the lowest pathogen count, which cannot be explained. However, seedlings planted in soils with high pathogen counts outgrew seedlings with lower counts. This emphasizes the complexity of the old land syndrome.

Weed counts significantly ($p<0.001$) isolated *Cyperus esculentus* or commonly known as the Yellow nut-grass as the most common weed in the trial area. This weed had a mean count of 170 weeds per square meter and had a highest score of 406 plants per square metre. *C. esculentus* also releases an allelophathic toxin in the soil (Bromilow, 1995). Some of the other weeds identified in much smaller quantities were: *Panicum schinzii, Paspalum dilatatum, Bidens bipinnata, Conyza bonariensis, Sonchus olereceus, Tagetes minuta, Oxalis pes-caprae, Hypochoeris radicata* and *Taraxacum officinale*.

Chemical alterations in isolation had no significant effect on root development and tree growth. The reason for this might be ascribed to the favourable conditions and season in which the trial was planted. If an abundance of water ensures plant survival and growth, soil structure deterioration as a single tested factor may be excluded from the list of lethal enemies. These factors can contribute towards mortality, but will not necessarily be lethal in isolation. It should be noted that the conditions for plant survival and growth was extremely favourable and the contrary could be proven in harsher growing conditions.

5.5 Conclusions

It is important to plan and plant trials attempting to include all-important variables. This trial seems to be of little value due to the perfect growing conditions. There is however much to learn. Soil structure deterioration seems not to be the single contributor to seedling mortality. Soil preparation method however had a marked influence on seedling survival and growth. Problems such as the high weed competition, soil moisture variances, pathogen concentrations and nursery practise were identified in this trial as future research possibilities and soil preparation methods that did not consider those constraints, failed.

6. A comparative study of four superabsorbents and organic matter on *P. patula* seedling survival and growth

Synopsis

Pinus patula seedlings were planted on old agricultural lands with four different superabsorbents, organic matter and a no treatment control. Root development using the Menzies' scoring system was measured. Shoot height, collar diameter and mortality were also measured. No significant differences were noted. The non-significance in itself indicates that superabsorbents will not have a negative effect on root development in periodically saturated soils. Organic matter will not serve as a multipurpose water absorbent, fertiliser and soil structure rectifier.

6.1 Introduction

"The trees died of drought because of the severe competition with weeds immediately after planting" (Ellis, 1995). The survival and health of seedlings measure the success of tree planting operations after establishment. Seedling survival can only be assured if soil moisture and nutrients are present at adequate levels (Viljoen, 1997). Water stress can lead to inferior root growth, which in turn leads to a lack of photosynthesis. Root and shoot growth depend on photosynthesis and therefore tree development depends on successful root establishment (Theron, 1994). Bad planting often results in poor root-soil contact (Theron, 1997).

Low and unreliable rainfall is one of the major contributing factors to bad seedling survival and growth (Theron, 1994). To accomplish good survival and growth, superabsorbent polymers have been introduced in the South African forestry arena improving the water storage capability of soils (Johnson and Veltkamp, 1985). Superabsorbent polymers enhance initial tree growth due to more efficient water utilisation (AECI, 1993; Viljoen, 1997; Huls, 19??). Soil water management with the use of superabsorbent polymers results in better survival, improved initial root and shoot growth, healthier trees, reduced blanking and optimised water logistics (AECI, 1993). Planting seasons can be stretched by using superabsorbents with a reduction in water usage and nutrient loss through leaching (Theron, 1997).

Establishment with pre-hydrated polymers result in the replacement of water plantings with a remarkable reduction in cost and water usage. Polymer amended soils provides a buffer against temporary drought stress and reduces the risk of intensive blanking operations (Viljoen, 1997).

Theron (1994) reports on a highly significant improvement in root growth when soils were treated with 4 grams Stockosorb® per plant. Required watering decreased in that trial and shoot growth increased non-significantly by 30 percent. Stockosorb® non-significantly increased root and shoot growth in a potting trial on *P. radiata* seedlings (Theron, 1994).

Futura and Auto (1988) tested three types of starch- and synthetic based polymers and reported mixed results. Plants performed well but some plant soils responded negatively to polymer treatments. Growth reductions, when they occurred, have been attributed to bad soil aeration and toxicity or both. Unfortunately no definite distinction were made between starch and synthetic polymers. Uncertainties on this topic should be more intensively tested in field trials (Theron, 1994; Theron, 1995).

When judging different superabsorbents, care must be taken in not misunderstanding the issue. Superabsorbents differ in their chemical makeup and therefore in functionality, especially when the material is used under harsh soil and other conditions (Waterworks, 1992). The number, makeup and chemical composition of the polymer hydrocarbon side chains, how they are cross linked, and with which initiators, appear to be critical in the performance of a polymer in the soil.

6.2 Materials and methods

The trial site was selected on an old agricultural land that had been planted to pastures the year before. The site is situated on the Weatherly Estate in North Eastern Cape Forests managed by Mondi Forests. Soils were of the Clovelly form. The soils had a loamy texture with an effective rooting depth of approximately 60 cm. Soils were ripped to a depth of 80 cm. Rip lines were disked to form a seedbed. Planting holes were made manually.

The trial was laid out as a randomised complete block design with five replicates and six treatments. This was used to test the influence of treatments (4 superabsorbents; 1 organic matter; no treatment control) on seedling survival and growth.

Superabsorbents tested were Stockosorb® (3 gram per tree), Synpol® (3 gram per tree), Terrasorb® (3 gram per tree), Waterworks® (3 gram per tree) and organic matter (1 kg per tree). Superabsorbents were pre-hydrated in 300 ml water. Gel was applied in the planting pit and mixed into the soil. Seedlings with average height of 69.2 mm and collar diameter of 1.89 mm were planted. The trial was discontinued after 480 days in the field. Tree height and collar diameters were measured. Trees were then dug out, roots washed, measured and judged.

Taproot presence and length were measured as well as lateral root presence and number of laterals. Root systems were then judged against the Menzies' scoring system and a Topple index allocated. It was felt necessary to expand on the Menzies' scoring system because young containerised seedlings could not be efficiently measured with this system. While the Menzies' system predicts the likelihood for a tree to topple, this new system quantifies the root development from the plug. This system identifies the plug as the mould from which roots have to break free. If root development continues the pattern initialized in the nursery plug, it is regarded as unacceptable and a score of 5 is given. A score of 1 is allocated to a seedling with a root pattern totally normal and natural. This scoring system was named the Conter scoring system.

A one way analysis of variance was carried out with final shoot collar diameter and length, taproot presence and length, lateral root presence and number, Menzies' scores, Topple index, and Conter scores as response variables. The significance of the effect of superabsorbents on the response variables was tested.

6.3 Results

Results are summarized in Table 6.3.1

Table 6.3.1 Response of response variables to superabsorbent treatments

	Diameter increment (mm)	Height increment (mm)	Topple index
Stockosorb®	19.80	90.1	1.53
Terrasorb®	18.01	87.1	1.50
Synpol®	18.55	88.3	1.57
Waterworks®	17.95	91.5	1.56
Organic matter	18.14	89.2	1.58
Control	19.65	89.2	1.59

Table 6.3.2: Table for minimum, mean and maximum values of response variables

Source	Minimum	Mean	Maximum
Height increment (mm)	0.00	89.22	141.00
Diameter increment (mm)	0.00	18.68	33.00
Topple index	1.20	1.57	1.86

Table 6.3.3: ANOVA table for the response variables

Source	d.f.	MS	F	p	Error
Length	5	112	0.10	0.99	1104
Diameter	5	34.69	0.93	046	37.43
Topple index	5	0.059	1.20	0.31	0.049

6.4 Discussion

No significant differences between treatments and control were observed.

No mortality occurred during the trial period. No visually stressed trees were observed during the mentioned period. The reason for this was that the area under investigation had more than normal rainfall. There was even a possibility of seedlings drowning. Superabsorbents seem thus not to inhibit seedling survival and growth during very high rainfall periods.

The organic matter treatment also showed no significant improvement in seedling survival and growth. Better results were expected because organic matter can serve as a superabsorbent as well as a substance to improve soil structure and soil nutrient status.

Root development was at no stage influenced by the superabsorbents and developed as well as the control seedlings. Superabsorbents therefore had a neutral effect on root development in saturated conditions.

Stockosorb® caused the biggest seedling diameter increment whereas Waterworks® had the best influence on height. The trees in the control plots had the best resistance against toppling.

6.5 Conclusions

Superabsorbents do not improve root and shoot development in an oversupply of soil moisture. Although all comparisons were non-significant there is much to learn from it. Root and shoot growth will most likely develop normally in saturated soils. Using superabsorbants without fearing drowning when soils are saturated for periods can be done when planting in an area known for the occurrence of short dry spells (i.e. summer rainfall areas with dry spells in rainy season).

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