Factors Affecting the Early Growth and Survival of Indigenous Seedlings Planted for the Purpose of Ecological Restoration.

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Abstract

This report consists of two parts: 1) a review of factors affecting the early growth and survival of indigenous seedlings planted for the purpose of ecological restoration; 2) field trials of different treatments at establishment of planted *Coprosma robusta* and *Phormium tenax* on an overburden dump and coastal dunes at Cape Foulwind, Westport, New Zealand.

The literature review includes information from New Zealand and international sources. Where little is information is available on indigenous species information from forestry research has been discussed. Little is known about the nutrient requirements of indigenous seedlings in the field. Mycorrhiza may have some importance in restoration, particularly on disturbed ground. Weeds and vertebrates have a major influence on growth and survival, while the effects of invertebrates requires further evaluation.

The fertiliser trial showed that cement kiln dust significantly reduced growth compared to the control in some instances. No significant response was observed from blood and bone. It was concluded that insufficient blood and bone was applied. The addition of compost in the planting hole did not have a significant effect on growth or survival. In several analyses there was significantly greater growth and survival in plots receiving weed mat than in plots receiving hand weeding or no weeding. Hand weeding resulted in similar growth, but higher survival, as not weeding. Little difference in growth and survival was detected in the planting density trial. Physical and chemical analysis of the overburden dump soil showed this site to be a poorer medium for growth than the coastal dunes. This was supported in all analyses by significantly less growth on the overburden dump than on the coastal flat.

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Introduction

The purpose of this report is to add to the understanding and knowledge of the restoration of indigenous forest. The aim of ecological restoration is to "return a degraded system to some form of cover which is protective, productive, aesthetically pleasing, or valuable in a conservation sense" and "develop a system which is sustainable in the long term" (Hobbs and Norton, 1996). Restoration of indigenous ecosystems provides many important functions, for example:

- Habitat for threatened indigenous plants and animals.
- Protection of soil and watersheds.
- Community involvement in conservation.
- Wildlife corridors.
- Opportunities to increase ecological knowledge.
- Buffers around existing natural areas.
- Protection of local genetic diversity.
- Material for cultural use by Maori.
- Improving representativeness of natural communities.
- Aesthetic benefits.

Recognition of these functions has resulted in many restoration projects, for example: Mana Island, Tiritiri Island, Hinewai Reserve, Mangere Island, Cuvier Island, Pyramid Valley, Otukaikino (Wilson's Swamp), Matawai Park and numerous smaller community and privately initiated projects. The effort required to restore a site can range from minor intervention, for example occasional pest control, to a major undertaking, for example replacing top soil over a large area followed by planting indigenous species.

This report focuses on the establishment phase of planted indigenous seedlings, as this is one of the most critical stages in any attempt at restoration. A literature review was carried out on the factors affecting the establishment of indigenous seedlings and trials were performed on pasture and an overburden dump examining some operational functions of this process.

Mine sites create considerable disturbance to ecosystems during the construction of pits, overburden dumps and tailings. Without active restoration these sites can remain bare of natural vegetation for decades, or longer. Once the area is no longer being used there exists an opportunity to examine how those ecosystems may be restored. Milburn Cement Co. (Westport) have built a nursery, contracted a horticulturist and assigned land for the purpose of a restoration project that will eventually cover approximately 150 hectares. Although there is a legal obligation to restore some mine sites to the previous state, Milburn Cement Co. has no legal obligation to restore their site; the motivation for the project comes from within the company. They have provided financial support and the opportunity to combine the trials detailed in this report with their restoration project.

Part I: Literature Review

Introduction

This review considers the factors that influence the early growth and survival of seedlings indigenous to New Zealand that have been planted for the purpose of ecological restoration. As there has not been much research completed on this topic in New Zealand much of the information presented comes from overseas and forestry examples. A relatively large section on mycorrhiza has been included as their importance in restoration often seems to be overlooked.

1. SOIL

1.1 Soil Chemical Factors

1.1.1 Essential Nutrients and Fertilisers

Plant growth and survival is adversely affected by a deficit of essential nutrients; this can be alleviated and improved by the application of fertilisers (for example: During, 1980; Kozlowski *et al.*, 1991; McLaren and Cameron, 1993). The effects of different levels of essential nutrients in soils on economically important species growth and survival has been well researched. Species vary considerably in their capacity to absorb essential nutrients and in their tolerance of limited supplies of essential nutrients (Kozlowski *et al.*, 1991). Therefore, the known fertiliser requirements of crop species may not be applicable to indigenous species. Little research has been undertaken to determine the essential nutrient requirements of the indigenous species that are used in ecological restoration in New Zealand. Porteous (1993) describes the fertiliser requirements for maximum health and growth rates of native plants as "generally unknown". Davis and Langer (1994) knew of no studies (other than their own) to determine possible fertiliser requirements of indigenous forest species on materials resulting from mining in New Zealand. Some trials have been conducted on indigenous species to determine fertiliser effects, for example:

- Davis and Langer (1994) found *C. robusta* responded significantly to treatments containing urea (45-0-0, 24g per plant) mixed with blood and bone (6-7-0, 150g per plant), but not superphosphate (0-9-0, 110g per plant) , on an overburden dump.
- Dakin (1976a, 1976b, 1977) experimented with five species and four fertiliser types, plus a control (no fertiliser) on disturbed clay soil. There was a highly significant growth response to all fertiliser treatments compared to the control. Mag-amp (7-17-6, with 12% magnesium, 85g per plant) and Osmocote (18-2.6-10, 113g per

plant) resulted in the best growth rates. Regardless of treatment survival was considered good.

- Guest (1985) applied varying amounts of blood and bone (6-7-0, 30g and 50g per plant) and magamp (7-17-6, 25g, 50g and 100g per plant) and no fertiliser to totara, kahikatea, matai and rimu at establishment. No significant difference in growth or survival between treatments was detected. These plants were sited in a selectively logged forest.
- Hawkins and Sweet (1989) experimented in a greenhouse with totara, kahikatea and rimu seedlings grown in vermiculite, without mycorrhiza. Effect of varying concentrations of a balanced nutrient supply on growth were examined. All species were found to increase growth with an increase in nutrient supply. However, the growth response of totara and kahikatea was significantly greater than that of rimu.

Both Porteous (1993) and Metcalf (1987) make general recommendations of chemical and organic fertiliser rates for indigenous seedlings, no references are cited for these rates. Sowden (1986) found significant correlations of species density with some soil and environmental variables; particularly soil acid extractable phosphorous and drainage. It was observed that *Coprosma rhamnoides*, *C. rotundifolia* and *Pennantia corymbosa* are effective indicators of young fertile and weakly developed soils. While mature *Quintinia acutifolia*, *Pseudopanax crassifolius* and *Coprosma foetidissima* are indicators of strongly differentiated, gleyed and podzolised soils. However Mew (1975) considered that soil drainage appeared to have more influence in determining the forest pattern than soil fertility. Wardle (1991) notes nine broad soil fertility classes to which some species can be associated.

Will (1978), in a review of forestry nutrient deficiencies, noted that in agriculture almost all New Zealand soils are P responsive and that it can be expected that a P deficiency will be found in forests. It was also noted that skid sites and landings in forestry situations, where the top soil had been removed and the soil compacted, are very N deficient. Such sites are likely to be comparable to overburden dumps, i.e. no, or little top soil and compacted. Stroo and Jencks (1982) found that compaction of soil during reclamation slowed N accumulation.

Fertilisers in excess can be detrimental to plants (Porteous, 1993; Kozlowski *et al.*, 1991). Barker (1978), in a review of silvicultural effects of fertilisers on *Pinus radiata*, noted that nitrogen fertilisers can decrease resistance to frost, root infections and sap sucking insects. Barker also noted that weed growth may be increased by fertilisers to the point that tree growth and survival are reduced. Guest (1985) noted that indigenous species that had been heavily fertilised tended to have depressed growth.

1.1.2 Toxic Elements

Mining and industry can produce large quantities of waste containing chemicals in concentrations that are toxic to plants. These sites can remain bare of vegetation for decades if remedial action is not taken. In areas where heavy metals have caused a toxicity problem in acidic wastes, lime can be used to reduce their solubility, and so their availability to plants. Applying organic matter to the surface of the waste has also been used to reduce heavy metal toxicity effects. This method relies on the ability of organic matter to absorb heavy metals (Bradshaw and Chadwick, 1980). For waste with high concentrations of heavy metals covering with a nontoxic material may be the only solution (Parker and Parker, 1986). Cement kiln dust has been shown to be fatal to *Dactylis glomerata, Festuca rubra, Lotus pedunculatus* and *Trifolium repens*. However when cement kiln dust was mixed with other materials (soil, sewage or saw dust) and cement kiln dust constituted 43% or less of the growing medium then these species were able to grow (Norton *et al.*, 1995)

Pahlsson *et al.* (1989), has reviewed the effects of the heavy metals zinc, lead, copper and cadmium on forest trees and concluded that with our present knowledge it is difficult to propose a limit for toxic concentrations of these metals. Antonovics *et al.* (1971), reviewed heavy metal tolerances in plants; however, this review did not include any indigenous New Zealand species. Both reviews supported the theory that high concentrations of heavy metals are toxic to plants. Heavy metal tolerance varies between and within plant species (Antonovics *et al.*, 1971; Bradshaw and Chadwick, 1980).

Most micronutrients are toxic when present in high concentrations. Excessive fertilisation (Kozlowski *et al.*, 1991) or low pH (McLaren and Cameron, 1993) can result in micronutrients becoming available in toxic concentrations.

1.1.3 pH

Water culture experiments have shown that plants can tolerate a wide range of pH. However in soil there are secondary effects that can inhibit growth and survival, i.e. nutrients become unavailable or toxic chemicals are released into the soil solution (Bradshaw and Chadwick, 1980; Russel, 1988). Optimum pH levels for plants vary between and within species (Bradshaw and Chadwick, 1980; McLaren and Cameron, 1993). No references of optimum pH ranges for New Zealand indigenous species were found. However, typical optimum ranges for some New Zealand economic plant species lie between pH 4.8 and 7.5 (McLaren and Cameron, 1993). In many natural soils pH is outside this range and plants will grow successfully on these sites. In restoration it is therefore necessary to consider the pH of the site and the pH naturally occurring in the habitat of the desired species.

Below pH 4 to 5 aluminium and manganese become soluble and can have toxic effects (McLaren and Cameron, 1993). However manganese toxicity as a result of low pH is rare in New Zealand (During, 1984). At low pH micronutrients also become very soluble and may be toxic if sufficient quantities are present (McLaren and Cameron, 1993). Above approximately pH 8 iron, manganese and boron become difficult for plants to absorb and phosphorus becomes unavailable (Bradshaw and Chadwick, 1980). Soil acidity can be reduced by the application of lime (During, 1980); while excess alkalinity can be overcome by the application of nutrients (Bradshaw and Chadwick, 1980).

Mine wastes that contain pyrite (iron sulphide) may become acidic due to weathering. As the pyrite weathers it releases sulphuric acid, and the pH may drop as low as 2. The sulphuric acid can be leached out by rain, but it may take decades for the pH to return to normal as the pyrite weathers slowly (Bradshaw and Chadwick, 1980).

1.2 Soil Physical Factors

1.2.1 Disturbed Soil

The following section focuses on the physical conditions of disturbed soils, particularly mine sites. This is because of the assumption that soil physical conditions on sites with undisturbed soil and exotic vegetation are sufficiently similar to the 'natural' state, and so are unlikely to inhibit the growth and establishment of vegetation that had previously occurred there naturally.

The soil physical characteristics that affect plant growth and survival are those that limit aeration, drainage, moisture and root penetration (Glinski and Lipiec, 1990). These characteristics can be quantified by the measurement of bulk density, mechanical impedance, aeration and hydraulic conductivity of the soil. Roots will rarely enter a soil when bulk density exceeds 1.5 to 1.6 g/cm^3 in a light soil or 1.7 to 1.8 g/cm^3 in a heavy soil (Russel, 1988; and Bowen in Glinski and Lipiec, 1990). *P. radiata* root growth has been shown to be restricted where mechanical impedance exceeds approximately 3MPa (Mason and Cullen, 1986; Sands, *et al.*, 1979, Greacen and Sands, 1980). However, this figure varies widely between species and soil types; for example Greacen, *et al.* (1969) quotes various authors as giving a range from 0.8 to 5MPa (mean 2.5MPa). Glinski and Lipiec (1990) note that as soil moisture content and a plants stage of development will affect the plants ability to penetrate a soil, these figures are incomparable. Glinski and Lipiec (1990) concluded that plants grown in mechanically impeding soil had reduced root size, nutrient uptake, water uptake, and vesicular arbuscular mycorrhiza colonisation; while root rot incidence, amounts of assimilates and oxygen per unit of roots, lateral branching and root thickness was increased. No figures for maximum limits of bulk density and mechanical impedance were found for indigenous New Zealand species. Poor aeration can limit plant growth when air filled porosity is less than 10% (Glinski and Stepeniewski in Glinski and Lipiec, 1990; Vomicil and Flocker in Resinger *et al.*, 1988). The rate of hydraulic conductivity at which plant growth is reduced is dependant on a wide range of plant and site factors and interactions. McLaren and Cameron (1993) list soil hydraulic conductivity classes.

Soils manipulated in surface mining are often compacted, resulting in poor reclamation success (Clevland and Kjelgren, 1994). Compaction increases bulk density and mechanical resistance and decreases aeration and hydraulic conductivity. Compaction of minesoils is caused by the passage of earth moving equipment; for example a large scoop can exert a pressure of 500kPa (Bradshaw and Chadwick, 1980). Eriksson (in Rolf, 1994) noted that a single application of a pressure of 800kPa was sufficient to completely compress all macropores. Compaction has also been found to cause slow organic matter and N accumulation and consequently lowers microbial activity (Stroo and Jencks, 1982) and significantly reduce ectomycorrhizal mycelium growth (Skinner and Bown, 1974). Hunter and Currie (1956) presented evidence showing that surface mining causes a deterioration in soil physical properties, particularly of bulk density and total porosity. Anderson *et al.* (1989) concluded that on reclaimed mine sites storage and grading methods that result in poor soil physical properties may adversely influence seedling establishment.

Models exist for predicting changes in bulk density resulting from compaction by machinery (Froehlich, *et al.*, 1980) and for predicting root growth relative to mechanical impedance (Dexter in Glinski and Lipiec, 1990). Information and models on the effect of compaction on growth and survival from forestry examples should be applied cautiously to minesoils. Compaction in forestry mainly affects the surface and decreases rapidly with depth (Froehlich, *et al.*, 1980); while minesoils are often compacted more evenly throughout the profile. In addition, minesoils are often low in organic matter (Schafer, *et al.*, 1980), and such soils are more easily compacted than those high in organic matter (Sands, *et al.*, 1979). Although no models were found relating compaction to survival and stem growth there are several papers that observed the effects of compaction on survival and growth; particularly in forestry situations, for example:

- Lockaby and Vidrine (1984) found that compaction by logging vehicles reduced height and survival of young loblolly pine by 39-59% and 88-91% respectively, compared to nontrafficked areas.
- Wert and Thomas (1981) found trees growing on compacted forest sites took four years longer to reach breast height than those growing on uncompacted sites.

Given the above observations it would therefore seem logical to expect a similar relationship on mine sites where vehicle traffic has compacted the soil.

Grazing stock have been noted to cause compaction of (Norton and Hobbs, 1996). This has resulted in an increase in penetration resistance and soil temperatures and reduced soil moisture levels compared to an ungrazed site. Which in turn may reduce seed germination and seedling establishment. As a result of these changes to soil conditions, and other influences of grazing, the authors concluded that without management grazing will continue to degrade woodland fragments.

1.2.1.1 Solutions to Compaction

Compaction of minesoils can be reduced by using soil placement techniques that do not involve the passage of heavy traffic over the soil, for example, initial placement of the soil by a dump truck followed by levelling with an excavator or bulldozer (Bradshaw and Chadwick, 1980; Rolf, 1994). Also by not permitting traffic on the soil when the soil is at or near saturation will reduce the degree of compaction (Greacen and Sands 1980; Moehring and Rauls, 1970).

Compaction can be reduced by ripping (for example Berg, 1975; Philo *et al.*, 1982). There have been numerous papers on the effect of ripping on plant growth and survival, for example:

- On an overburden dump, black walnut seeded into ripped sites had 85% survival c.f. 65% survival and significantly less root growth on the unripped site (Philo *et al.*, 1982).
- In an area of poor drainage ripping significantly increased radiata pine seedling survival by 30% to 39% (Guild, 1971).
- On a gravely sand radiata pine growth and survival was significantly increased by 10% (Mason and Cullen,1986)

Ripping should be done when the soil moisture content is below the plastic limit, as this will allow the soil to fracture without smearing (McLaren and Cameron, 1993). Ripping a soil with a high proportion of silt is not recommended as the effect is relatively short lived (Rolf, 1994).

Rolf (1994) stated dynamiting as a method that had been used for reducing compaction. This method may be useful in areas where boulders make ripping unpractical. Barantsev (1989) found that dynamited soil had 91% (in the surface layer) to 8% (at 50cm depth) less mechanical resistance than unblasted soils, while seedlings grew 69% and 36% higher than on the control. This effect lasted at least 10 years.

The time required for a soil to recover naturally from compaction varies with the degree of compaction, drainage, depth at which soil is measured, vegetation and texture (Greacen and Sands, 1980). The surface layer of forest soils compacted by logging have been found to return to normal (in terms of bulk density) in 5 to 40 years, but deeper layers may take much longer (Thorud and Frissell, 1976; Wert and Thomas, 1981; Froehlich, *et al.*, 1985; various authors in Greacen and Sands, 1980). However, as stated previously information on compaction in forest soils should be applied cautiously to mine sites. No data was found on the time required for minesoils to recover from compaction, or whether they do naturally recover from compaction over a long period of time (for example 80 years). This information may not exist for modern methods of overburden placement by scoop. This is because previously it was common practice to deposit overburden from dump trucks, which results in less compaction than that created by scoops (Schafer *et al.*, 1980).

1.2.2 Soil Water

Seedling growth and survival can be affected by either an excess or deficit of water (Kozlowski *et al.*, 1991). Davis and Langer (1994) noted that poor growth and high mortality of indigenous plants placed in depressions on an overburden dump, indicating that drainage is likely to be important on such sites where rainfall is medium to high. Seedlings are more sensitive to water stress than mature plants, and will grow much slower if soil moisture is below field capacity (Zahner in Kozlowski *et al.*, 1991). Plants generally become permanently wilted when soil water potential is below about -1500kPa (McLaren and Cameron, 1993). To overcome the possibility of moisture stress it is best to plant in autumn or winter (Porteous, 1993).

Waterlogging can reduce growth and kill species not adapted to wet conditions; mainly as a result of oxygen deficit in the root zone (Kozlowski *et al.*, 1991). Waterlogging can also lead to the death of roots as a result of increased *Phytophthora* fungi activity (Kozlowski *et al.*, 1991). Some indigenous species are adapted to periods of waterlogging or permanently waterlogged soils (Wardle, 1991).

Pollock (1986) has given general waterlogging and drought tolerances of some native species. *Coprosma robusta* is noted as having a moderate tolerance of waterlogging; i.e. it will withstand frequent waterlogging but not continual waterlogging for periods of more than several weeks. *C. robusta* is also noted as having moderate drought tolerance; i.e. can withstand drought so long as soil moisture is not below the wilting point for more than several weeks. *Phormium tenax* is noted as having a moderate drought tolerance and a high tolerance of waterlogging; i.e. it can withstand roots continually in wet or waterlogged soil, growth may be slower but it is otherwise unaffected. It is important to observe the natural habitat of a species to determine the type of conditions it will grow best in. (D. Norton, personal communication, March, 1996).

2. MYCORRHIZA

2.1 Introduction

Several authors have noted the benefits of mycorrhiza in the restoration of disturbed land (for example: Allen and Allen, 1980; Cuenca and Lovra, 1992; Daft *et al.*, 1975; Schramm, 1966 in Marx, 1976); although other publications on restoration have paid mycorrhiza little attention (for example Bradshaw and Chadwick, 1980; Sendlin *et al.*, 1983).

In 1885 A.B. Franks first used the term mycorrhiza and was also the first to describe ectomycorrhiza and endomycorrhiza; he also published the first reports on the increased growth of mycorrhizal seedlings compared to uninfected seedlings (Soderstrom, 1991). Some doubt remained as to whether or not mycorrhiza were beneficial to plants however until Bjorkman published results proving the benefits of mycorrhiza in 1937, 1940 and 1942 (Wills, 1978). The main benefits to a plant from a mycorrhizal association, as reviewed by Mosse (1973) are increased P, N and water uptake and protection from root pathogens. Phillips and Hayman (1970) have described a method for clearing roots and staining vesicular arbuscular mycorrhiza (VAM), and Giovannetti and Mosse (1980) have evaluated techniques for measuring mycorrhizal infection in roots. By 1973 over 3,000 papers had been published on mycorrhiza and plants, and most of these relate to forest trees (Hacskaylo and Tompkins in Marx, 1976).

There are four types of mycorrhiza:

1. Ectomycorrhiza form a sheath around the root and penetrates the root cortex, but not the cells. The fungal component of this mycorrhiza is mostly formed by basidiomycetes and a few by ascomycetes (Raven *et al.*, 1992). Ectomycorrhiza have also been referred to as ectotrophic mycorrhiza (for example Harley, 1965).

2. Endomycorrhiza penetrate the cells of the root but do not form a sheath around the root. Zygomycetes are the fungal component of this mycorrhiza (Raven *et al.*, 1992). Endomycorrhiza are also referred to as endotrophic mycorrhiza (for example Harley, 1965).
3. Ericoide mycorrhiza are formed by ascomyceteous fungus and members of the Ericaceae. The hyphae penetrate the epidermal cells of the distal regions of the fine root (Raven *et al.*, 1992).
4. The fourth type of mycorrhiza is formed with members of the Orchidiceae (Raven *et al.*, 1992).

In the northern hemisphere mycorrhizal research has concentrated on ectomycorrhiza, as this is the type of association usually formed with the important forest tree species there, for example: *Pinus*, *Fagus, Quercus* (Marx, 1976). Grossnickle (1985, abstract only) has reviewed the use of ectomycorrhiza in the reclamation of mined land. However, endomycorrhiza are more common than ectomycorrhiza, occurring on about 80% of all vascular plants (Raven *et al.*, 1992). Endomycorrhiza can be divided into two types: those produced by septate fungi and those produced by nonseptate fungi. The latter are called vesicular arbuscular mycorrhiza (VAM) (Gerdemann, 1968) and belong to the Endogonaceae family (Soderstrom, 1991). Mosse (1973) and Gerdemann (1968) have reviewed VAM; both authors supported the suggestion that VAM belong to the Endogonaceae family and are beneficial to plant growth. Cooper (1982) has reviewed mycorrhiza and their role in the establishment of horticultural plants and concluded that mycorrhiza are of benefit during establishment. In the international literature there has been much produced on mycorrhiza and the natural colonisation of disturbed land (for example Janos, 1980; Cuenca and Lovra, 1992) and the effect of mycorrhiza on trees and shrubs planted on disturbed land (for example Allen and Allen, 1980; Allen, 1987; Daft *et al.*, 1975; Schramm, 1966 in Marx 1976; Wills, 1978; Wilson *et al.*, 1991). Grossnickle (1985, abstract only) reviewed the literature on ectomycorrhiza and mined land reclamation and cited 94 references. However no publications were found on the role of mycorrhiza in the colonisation or restoration of disturbed land in New Zealand by indigenous species.

2.2 Mycorrhiza in New Zealand

Mycorrhiza are probably universal in natural vegetation in New Zealand; the majority of these associations formed are endomycorrhizal of the VAM type (Johnson, 1977; Wardle 1991), and predominately of the Endogonaceae[1] family (Cooper, 1976; Crush, 1973; Johnson, 1977). The distribution of mycorrhiza in New Zealand ecosystems has been studied by several authors (for example: Baylis *et al.*, 1963; Baylis, 1959; Chu-Chou and Grace, 1983; Cooper, 1976; Crush, 1973; Johnson, 1977; Mejstrik, 1975; Mosse and Bowen, 1968; Powell, 1977; Neil, 1944). In a survey of hill country pasture soils Powell (1977) found that of the three species of mycorrhiza that occurred in the forest soils (i.e.: *Acaulospora laevis, Glomus fasciculatus* and *G. macrocarpus* var. *macrocarpus*) at least one of these was also found in all but one of the 26 pasture soils examined. The importance of this for ecological restoration is that where plantings are to be done into pasture there may already be mycorrhiza present that are suited to native forest species.

Among native plants only *Nothofagus* spp. are purely ectomycorrhizal. Manuka *(Leptospermum scoparium)* and kanuka (*Kunzea ericoides*) can be either endomycorrhizal or ectomycorrhizal (Wardle, 1991; Cu-Chou and Grace, 1983). Members of the Ericaceae are normally infected with the ericoide mycorrhizal fungus (Read and Stribly, 1975). There are only two genera in New Zealand of this family, *Gaultheria* and *Pernettya* (Wilson and Galloway, 1993). Out of the range of New Zealand trees, shrubs and ferns investigated for their ability to form a mycorrhizal association only *Asplenium bulbiferum* has failed to do so (Johnson, 1977).

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[1] Taxonomy described by Gerdemann and Trappe (1975).

The effects of mycorrhizal associations on growth and survival of indigenous New Zealand species have been well researched (for example: Baylis *et al.*, 1963; Baylis, 1959, 1967, 1972, 1980; Cooper, 1976; Hall, 1975; Johnson, 1977, 1976; Mejstrik, 1975). In glasshouse and laboratory conditions *Podocarpus totara* (Baylis *et al.*, 1963), *Griselinia littoralis*, *Coprosma robusta* (Baylis, 1967), *Nothofagus spp.* and *Weinmannia racemosa* (Baylis, 1980) seedlings were found to stop growing if a mycorrhizal relationship was not formed and available phosphorous was low. Baylis (1967) concluded that mycorrhiza are essential to promote sufficient phosphorous uptake for normal growth in New Zealand soils. The level of available P at which a plant becomes mycotrophic (i.e. stimulated by mycorrhiza, *sensu* Baylis (1975)) varies between species (Wardle, 1991). The presence of a mycorrhiza is not always beneficial to a plant; Johnson (1976) found that mycorrhiza increased the growth of *Fuchsia excorticata* at a soil P concentration of 11 µg/ml (Truog method), but decreased it's growth at a soil P concentration of 25 µg/ml (Truog method).

2.3 Benefits of Mycorrhiza in Restoration

Mycorrhiza infected plants planted on disturbed land have been shown to have increased survival and growth in many cases when compared to nonmycorrhizal plants (for example: Marx, 1976; Marx and Bryan in Mooreman and Reeves, 1979; Wilson *et al.*, 1991). Schramm (in Marx, 1976) concluded that ectomycorrhiza were essential for the seedling establishment of *Pinus rigid, P. virginiana, Quercus rubra, Q. velutina, Betula lenta*, and *B. populifolia* on anthracite wastes. Increases in growth of mycorrhizal plants compared with nonmycorrhizal plants vary from 6% to 962%, and for survival from 0% to 850% (various authors in Marx, 1991). Figures for increases in growth and survival due to mycorrhizal infection in the field vary considerably between experiments due to environmental conditions, plant and fungi genotype and rate of natural colonisation of plants by mycorrhizal fungi.

Menge *et al.* (in Cooper, 1982) found that mycorrhizal seedlings recovered quicker from transplanting into the field and were usually less susceptible to wilting and the slowing of growth as a result of transplanting. Mycorrhizal associations deter infection of roots by soil borne nematodes and fungal pathogens (Cooper, 1982; Baltruschat and Schonbeck in Mosse 1973). Mycorrhiza can also influence the establishment of naturally arriving plant propagules and vegetation change (see below).

2.4 Effect of Soil Disturbance on Mycorrhiza

Soil disturbance has been noted to reduce mycorrhiza spore numbers and mycorrhizal infections in many cases, for example:

- Moorman and Reeves (1979) found that six years after a disused road had been abandoned and ripped, mycorrhizal infection of plants on the old road surface had approximately only one fortieth of the level of infection in plants on nearby undisturbed soil.
- After about three years mycorrhizal infection and spore counts on a reclaimed strip-mine had increased to up to only 50% of that recorded on nearby undisturbed land (Allen and Allen, 1980).
- Cuenca and Lovra (1992) found a reduction in the number of VAM propagules following disturbance by a bulldozer during road construction.

Stockpiling of soil is also detrimental to mycorrhizal populations, for example:

- Reddell and Milnes (1992) found that in comparison to native woodland soils, ectomycorrhiza and VAM were absent or poorly represented in stockpiles of natural soils (irrespective of age, the oldest stock pile being eight years old), young mine soils and mine soils without plant cover.

- In bare topsoil stored during surface mining mycorrhizal infection was noted to decrease from 82% to 50% from the third year to the fourth year (Gould and Liberta, 1981).

One exception to this trend is Mosse and Bowen (1968) who found, in New Zealand soils, live *Endogone spp.* spores were more abundant under cultivated soils and pasture than under natural vegetation. Baylis (1969) suggested two reasons for this, firstly, in cultivated soils, conditions might exist that stimulate sporulation or select for species of VAM that sporulate. Secondly, under forest conditions where actively growing roots are almost continuously present VAM that do not expel energy on sporulation may have been favoured. Contrary to Mosse and Bowen, Johnson (1977) found densities of Endogonaceae spores in New Zealand forest soils to be two to four times higher than that recorded under agricultural soils anywhere. Also, Moorman and Reeves (1979) have noted an inconsistency between spore numbers and mycorrhiza development in plants. So, although Mosse and Bowen found fewer spores under natural vegetation than cultivated soils, there may have been higher mycorrhizal infection of plants under native vegetation than in plants under cultivation.

2.5 Factors Affecting the Recovery of Mycorrhiza on Disturbed Land

The recovery of mycorrhiza in terms of infection and spore population on disturbed land appears to be dependant on a number of interacting factors, among them: initial spore counts, wind and animal vectors, soil chemical and physical properties, moisture, host plant species, plant cover, and time since reclamation (Allen and Allen, 1980). Initial spore count following disturbance is discussed above. Little research was found on the recovery of mycorrhiza on disturbed land in New Zealand.

2.5.1 Wind

Dispersal of mycorrhiza fungi spores onto disturbed land by wind varies depending on the fungal type. Ectomycorrhiza are usually basidiomycetes (class homobasidiomycetes), which produce spores from basidiocarps (i.e. mushrooms); which are readily dispersed great distances by the wind (Marx, 1991). Endogonacea produce spores from sporocarps both above and below ground. Endogonacea spore borne above ground are immediately available for wind dispersal, and those borne below ground can be brought to the surface by insects, rodents and worms and also become available for wind dispersal (Daniels Hetrick, 1984). Tommerup and Carter (in Daniels Hetrick, 1984) showed that wind speeds of 0.36 to 2 km/hr were sufficient to transport VAM spores. Warner *et al.* (1987) found wind to be a potentially important disperser of VAM spore in a highly wind eroded, mesic environment. Spore traps used at this site showed no correlation in distance from undisturbed land and the number of VAM spores trapped (the maximum distance measured was 55m). Following a volcanic eruption Allen (1987) found ectomycorrhiza spores to be primarily dispersed to the disturbed site by wind and VAM by migrating animals.

2.5.2 Insects and Animals

Insects and animals have been shown to be capable of dispersing viable VAM fungal spore through their faeces or adhered to their bodies (Allen, 1987; McGee and Baczocha, 1994; Trappe and Maser, 1976). Earthworms of differing ecological strategies have been clearly demonstrated to be vectors of VAM spores, but not of ectomycorrhizal spores (Reddell and Spain, 1991). Reddell and Spain (1991) suggested that earthworms might transport VAM spore at rates of a few meters per year. However, in waterlogged soils and under temperate forest with adequate moisture where root growth is almost continuous few VAM spores may be produced (Redhead in Mosse, 1973 and Baylis, 1969 respectively).

2.5.3 Soil

The soil characteristics that affect plant growth (see Chapter 1) also have similar effects on mycorrhizal recovery on disturbed land, for example: pH, texture, moisture and nutrient availability. Effect of moisture is discussed below (section 2.5.4). Skinner and Bown (1974) found that mycelial strand growth of ectomycorrhiza was approximately 70% less in soil with a bulk density of 1.6 g/cm^3 compared to soil with a bulk density of 1.2 g/cm^3. Therefore, where machinery has caused heavy compaction of soil mycorrhiza recovery may be reduced. Ectomycorrhiza are generally considered to be acidophillic and pH tolerances reported vary between and within species (Slankis, 1974). Mikola (in Nicholas and Hutnik, 1971) found the pH tolerance of one species of ectomycorrhiza to be between 2.4 and 7.0, with an optimum of 4.0. Some ectomycorrhiza have been reported to thrive in soils with a pH higher than 7 (Slankis, 1974). VAM have a wide tolerance of pH range, for example *Glomus fasciculatus* (Endogonaceae) will infect a variety of plants from pH 5.5 to 9.5 (Menge, 1984). *Endogone mosseae* (Endogonaceae) was found to be able to infect *C. robusta* at pH 5.6 and 7.0 but not at pH 3.3 or 4.6 (Hayman and Mosse, 1971). *Rhizophagus tenuis* (Endogonaceae) was found infecting grasses in a Te Anau soil of pH 4.9 (Crush, 1973).

2.5.4 Moisture

Extremes of moisture can severely reduce VAM and ectomycorrhizal infection (Menge, 1984 and Slankis, 1974, respectively). A water potential of -0.2 bar has been shown to result in maximum infection (Reid and Bowen in Menge, 1984). Reduced O_2 concentrations can severely inhibit VAM spore germination and root colonisation (Saif, 1981). This may occur in soils with small spore space (Griffen in Allen and Allen, 1980) or waterlogged soils (Redhead in Mosse, 1973). Thus it may be unlikely that plants on disturbed soil with a high clay content and/or in areas of high rainfall and/or where the soil has been compacted by large earth moving equipment will readily develop a mycorrhizal association.

2.5.5 Host Plant

As VAM and ectomycorrhizal fungi appear to be obligate or near obligate organisms (Gerdemann and Nicholson, 1963; Hacskaylo in Marx, 1991; respectively) inoculum viability could be depressed by the absence of a host (Cuenca and Lovra, 1992; Powell, 1979) on a restoration site. As VAM are non-host specific (Daniels Hetrick, 1984) the species of host plant present on the restoration site is not as critical as for ectomycorrhiza, which often exhibit a high degree of specificity (Raven *et al.*, 1992) and some vascular species require specific mycorrhiza to grow. However, some ectomycorrhiza fungi are capable of infecting many different genera, for example *Pisolithus tinctorius* (Marx, 1991).

Janos (1980) suggests in the lowland wet tropics, where spore production is limited, mycelial growth associated with extension of root systems may be the most rapid cause of mycorrhizal fungi invasion into disturbed land. This may also hold true for wet lowland rainforests of New Zealand. Powell (1979) found that the hyphae of mycorrhizal fungi in sterilised soil spread at rates of 0.6 to 1.5 m/yr in nonmycorrhizal plants and at rates of 0.9 to 3.2 m/yr into mycorrhizal plants. Powell noted that interpretation of these results into the field is difficult.

2.5.6 Plant Cover and Time

It was noted above (section 2.4) that Gould and Liberta (1981) found mycorrhizal infectivity of unvegetated top soil to decrease over time. However, if cover of host plants is maintained on a site (other factors not limiting) the proportion of roots infected will increase over time (Visser *et al.*, 1991).

2.6 Mycorrhiza and Vegetation Change on Disturbed Land

Non-mycorrhizal plants are effective colonisers of disturbed land and the lack of mycorrhizal fungi on such sites exerts a profound influence on species composition (Reeves *et al.*, 1979). Janos (1980) notes that disturbance that favours non-mycorrhizal plants might lead to a stable community different from the climax vegetation. He also states that non-mycorrhizal plants are likely to dominate on poor soils in which mycorrhiza do not form; but on poor soils where mycorrhiza do form obligate mycotrophs (*sensu* Janos, 1980) are likely to dominate. On fertile soils, regardless of mycorrhizal fungus content, faculative mycotrophs are likely to dominate. Janos further suggested that if mycorrhiza were present in sufficient numbers immediately following disturbance the time required for obligate mycotrophs to become dominant would be significantly less than if mycorrhiza were absent or few. Cuenca and Lovra (1992) concluded that their reclamation efforts on a disturbed site allowed the recovery of VAM inoculum and as a consequence there was an increase in the number of native plants colonising the site at a higher rate than what would have resulted from natural colonisation. Wilson (1994) and Baylis (1980) have suggested that common ectomycorrhiza may be a factor influencing the abundant regeneration of *Nothofagus spp.* observed under mature kanuka and manuka.

2.7 Conclusions and Practical Implications

1) Mycorrhiza can improve the growth and survival of plants on restoration sites and influence vegetation change. However, at some restoration sites there may be sufficient propagules available in the soil on the site, or naturally occurring infection in the roots of seedlings to be planted, so that artificial inoculation of mycorrhiza would have no significant effect on plant growth or survival (for example Anderson *et al.*, 1989).

2) As most nursery media used for raising plants are devoid of mycorrhiza (Johnson, 1982) and recently disturbed sites are often low in mycorrhizal fungi; it is likely that inoculation of plants with mycorrhizal fungi will be beneficial to plant growth and the restoration project on such sites. This is assuming that the likely dominant species are mycotrophic. Menge (1984) has detailed methods of VAM inoculum production and Marx(1991) has done so for ectomycorrhiza.

3) In moist areas where sporulation of VAM fungi may be inhibited the rate of natural colonisation by these mycorrhiza will be at a much slower rate than in areas where VAM can sporulate readily. Thus the importance of inoculating planted seedlings is greater in such situations.

4) Given the importance of mycorrhiza for plant growth and survival and that mycorrhiza may be an important source of food for invertebrates; the percent of plant roots infected with mycorrhiza may be one useful, readily quantifiable, measure of the success of a restoration project. This would require considerable investigation to determine the variability of mycorrhizal infection in natural systems and to what extent mycorrhiza are (or are not) important in invertebrate diet.

5) Reddell and Milnes (1992) have suggested the use of 'ecological islands' in the restoration of disturbed land. This involves planting small groups of mycorrhiza inoculated plants in project areas. After one or two years invertebrates, worms and other soil organisms, demonstrated to be essential to establish nutrient cycles and act as vectors to spread seed and symbiotic micro-organisms, could be introduced. The much larger remaining areas might then be revegetated using cheaper methods such as aerial seeding or hydromulching.

6) McGee and Baczocha (1994) noted that if populations of animals that rely on sporocarps of mycorrhiza fungi are to be maintained then the fungi they would normally eat must also be present. Thus plants placed in these habitats must be inoculated with sporocarpic mycorrhizal fungi rather than the nonsporocarpic "weed fungi" of disturbed habitats. Hyphae of a VAM, *Glomus fasciculatum*, have been found in the gut of springtails (Warnock *et al.* in Daniels Hetrick, 1984); indicating that hyphae as well as sporocarps are part of the food chain.

7) Some indigenous vascular species rely on other forms of microbial associations to facilitate growth. For example, *Coriaria arborea* forms a symbiotic association with the nitrogen fixing actinomycete *Frankia.* This association has been noted to be capable of fixing 192kg/ha of nitrogen annually (Silvester in Burrows, 1990). On sites where there is little nitrogen in the soil (such as recently exposed mineral soil) this level of nitrogen input may increase growth and survival of other plant species on the site.

3. WEEDS

3.1 Effects on Seedlings

Richardson 1993), in a review of weed management in plantation forests, stated that weeds reduce growth and survival of crop plants through competition for site resources (light, water and nutrients). Weeds can also affect growth and/or survival through: parasitism, allelopathy, physical damage and by counteracting favourable treatments (for example fertilising). Control of weeds can also improve site conditions, for example, by exposing soil, minimum frost temperatures can be raised sufficiently to significantly increase survival on frost prone sites (Menzies and Chavasse, 1982).

Much has been published on the effects of weed control on the growth and survival of crop trees; Richardson (1993) cites eighteen such references from Australasia. The increase in growth as a result of weed control can vary considerably, for example, 18% (Cellier and Stephens, 1980) and 196% (Berg, 1975). The effect of weed control on survival is also very variable, for example, no significant difference (Balneaves and Henely, 1992) and a 62% increase (Anderson *et al.*, 1989). This variation is mainly due to site, weed, crop and management differences. Sheppard (1995) observed that the growth of seedlings was significantly inhibited when fertiliser or irrigation was applied and there was vegetation surrounding the seedlings. However if there was no surrounding vegetation fertiliser and irrigation significantly enhanced the growth of seedlings.

Few trials have been carried out in New Zealand to specifically observe the effects of weed control on the growth and survival of indigenous species. Timmins *et al.* (1987) describe a weed control trial established on Mana Island for restoration purposes, but the results of this trial have not been located. Guest (1985) observed reductions in growth and survival of podocarp seedlings planted in indigenous forests that, unintentionally, had not been weeded. In a survey of New Zealand native tree and shrub plantings Pardy *et al.* (1992) stated that the main cause for failure of native plantings was a lack of weed control; particularly in the period following planting. Tall grasses (for example tall fescue, yorkshire fog, cocksfoot and paspalum) smothered small seedlings on open sites. Seedlings were also overtopped by bracken, blackberry and creepers (for example: Japanese honeysuckle, wandering Jew, bush lawyer and cathedral bells). Seedlings that had been overtopped were often malformed and had restricted growth.

3.2 Methods of Control

Methods of weed control on restoration sites vary with the type of weeds and desired plants present, stage of restoration (i.e. preplanting, height of seedlings), economics, environmental conditions, sensitivity of surrounding vegetation, site access and management preferences. Weeds can be controlled by herbicides, mechanical methods (for example discing), manual methods, fire, grazing, oversowing, biological control and mycoherbicides (Richardson, 1993). Mulching (for example with paper or sawdust) is also used; generally one year of control is obtained from this method (Pardy *et al.*, 1992). Increasing the density of planting has also been used to control weeds in wheat crops (Medd *et al.,* 1985). Schroeder (1988) quotes five authors as saying that weed control is necessary until canopy closure, and two authors as saying that canopy closure usually takes three to eight years depending on species, spacing and site.

Herbicides are commonly used in many situations for weed control, both before and after planting (Davenhill, 1995). Contact herbicides have been used to release native seedlings (one to two meters high) without damage (Pardy *et al.*, 1992). However, many herbicides are detrimental to indigenous species (for example Beveridge, 1966; Davenhill, 1995; Preest, 1966) and should be used cautiously. Porteous (1993) describes the use of herbicides in New Zealand restoration and types of herbicides suitable for common forest weeds.

Balneaves and Henely (1992) experimented with spot releasing *Pinus radiata*, varying radii for up to one meter, and found the larger the radius the greater the height growth. However, the greatest response in height was equally obtained from spraying a strip two meters wide and total weed control. Davenhill (1995) lists herbicides in current use in New Zealand forestry and the weeds they will control.

4. PESTS AND DISEASES

4.1 Vertebrates

Vertebrates can reduce growth and survival of seedlings through browsing and trampling (Porteous, 1993). It has been recognised at some restoration sites that establishment would be impossible without control of vertebrates (for example Boswell and Cossens, 1990). In a four year establishment trial, Dakin (1977) observed that where *C. robusta* became prostrate (through trampling, animal damage or natural development) continuous browsing by hares or rabbits ensured that this species did not recover. In plots that did not receive fertiliser, browsing of *C. robusta* and *Carpodetus serratus* by vertebrates resulted in no height increase. Brockie (1992) notes that some indigenous plant species (for example rimu) are less palatable than others to vertebrates.

The main vertebrates that can cause damage to seedlings in New Zealand are: cattle, sheep, deer, horses, goats, thar, chamois, wallabies, possums, rabbits and hares (Porteous, 1993). Rats have also been noted to severely damage or destroy planted indigenous seedlings. At one site Norway rats damaged 20% of planted totara and kahikatea seedlings by nipping through stems; often at a 45° angle similar to that observed for hares (Beveridge and Daniel, 1965). Domestic species, and some wild species, can be controlled with adequate fencing. Wild species may be controlled by shooting, poisoning or trapping. Techniques of shooting, poisoning and trapping must be varied to suit the target species. Repellents can also be used to deter browsing of seedlings by vertebrates (Porteous, 1993). Also, plastic tubes have been used to deter browsing by small mammals, for example hares and rabbits, but are comparatively expensive (Maclaren, 1987). No studies were found comparing the effectiveness of killing methods, or comparing the effectiveness of killing methods against repellent methods.

Crozier (1987) compared the effectiveness of several commonly used repellents in the field (with hares) and in pens (with rabbits and possums) using *P. radiata* seedlings. A mixture of egg powder and paint was found to be the most effective repellent. This reduced browsing of seedlings from 70% to 5%. It was noted that growth of indigenous plants did not show any appreciable reduction. Morgan and Woodhouse (1993) tested 11 compounds as repellents to prevent possum browsing. Compounds were compared against "Treepel" and those that contained mustelid predator odours or Bittrex and synthetic fermented egg were found to be more effective.

4.2 Invertebrates

The effects of invertebrates on the growth and survival of indigenous plant species have not been extensively studied (Gadgil *et al.*, 1995). While it has been observed that invertebrates have reduced the growth of some indigenous seedlings (Alma, 1979; Hocking, 1944; Metcalf, 1987; various authors in Wardle, 1984) no references were found stating that invertebrate damage is a major concern in New Zealand restoration projects. Some invertebrate damage has been observed on restoration plantings, but further research is required to determine effects on growth (Richard Gordon, personal communication, March, 1996). Hosking (1993) concluded that insects and the damage they cause are usually symptoms of decline in indigenous plants, rather than the cause of it. Alma (1979) stated that a natural balance has developed between native insects and hosts and that exotic insects have not been known to cause severe damage to native trees. Metcalf (1987) details invertebrates that may damage indigenous plants and chemical control methods.

4.3 Diseases

Gadgil *et al.* (1979) stated that the indigenous trees of New Zealand have reached a natural balance with their parasites and, although there are some common leaf parasites, rusts and gall forming fungi, these cause little damage. However there are some diseases that will cause the death of seedlings. For example, Phormium yellow-leaf virus can cause stunted growth, premature flowering, root death and rhizome rotting which leads to death in *Phormium* species (Metcalf, 1987). Cabbage Tree Sudden Decline results in wilting of leaves followed by trunk, rhizome and root decay and eventually death of the plant. The cause of this disease requires further research, but is likely to be caused by the same virus that causes Phormium yellow-leaf; and the current epidemic may have been triggered by environmental factors (Simpson, 1993). Metcalf (1987) details other diseases that may damage indigenous plants and how to control those diseases.

5. SEEDLING FACTORS

In this chapter seedling factors up to the time of planting are considered; these factors include: seedling quality, selection culling, seedling type (i.e. bare-rooted or containerised), handling and transport of seedlings. The importance of seedling factors has received little attention, possibly as a result of the considerable amount of research already conducted on this topic in forestry situations. Thus, much of the following information is based on forestry situations.

5.1 Seedling Quality

For the purpose of this section seedling quality is defined as the morphological and physiological state of the seedling immediately prior to planting on the site. Seedling quality is one of the main factors affecting field performance (Chavasse, 1980). Seedling quality is affected by: nursery site, genetic make up of the stock, seed, methods of production, the space occupied by the seedling in the nursery bed, time of sowing, age of seedling, time of year seedlings are lifted, nursery weed control methods and effectiveness, seedling nutrition, methods of seedling conditioning, insect attack, diseases and care in lifting, handling and transporting, (Chavasse, 1980; Menzies *et al.*, 1995; Smith, 1986). Nursery practice is beyond the scope of this report.

5.1.1 Measures of Seedling Quality

Seedling quality in forestry has traditionally been measured by morphological features, for example: height, diameter at root collar, sturdiness (i.e. height/diameter ratio), root weight to shoot weight and presence of mycorrhiza (Forest Research Institute (F.R.I.), 1988; Menzies *et al.*, 1995). However, it has become clear that both morphological and physiological criteria need to be considered in determining seedling quality (F.R.I., 1988; Smith, 1986).

At the time of planting the Forests Amendment Act (1993) requires indigenous seedlings to be a minimum of 60cm high (Anon. 1993), and F.R.I. recommends indigenous seedlings to be a minimum of 50cm high (F.R.I., 1980). Hardwoods, such as *Coprosma* and *Pittosporum*, need to be at least 80cm tall at planting to endure browsing by deer, rabbits and possums (F.R.I., 1980). Pollock (1986) notes that the desirable plant size will largely depend on the seedlings growth rate and conditions at the planting site. He recommends that:

- Slow growing species should be at least 50cm tall at planting.
- Fast growing species (i.e. those capable of 20 to 40cm top growth in one season in the nursery) are ready for planting out in the first winter.
- Podocarps should be as much as 80cm at planting.

For most plants there is a certain minimum size that needs to be attained, before there are sufficient stored nutrients or conductive tissue, to resume growth after the damage incurred during planting (Smith, 1986).

Baylis (1967) found data that suggested that at least a third of *C. robusta* roots on seedlings must be mycorrhizal before growth begins. Whether this was necessary at planting or if the seedling could develop this degree of infection once planted in the field was not discussed. The presence of mycorrhiza on a seedling becomes more important for growth and survival as the planting site becomes more difficult for establishment success (Barnett, 1984). No figures for the other morphological seedling quality indicators mentioned above for indigenous seedlings were found.

Figures for commonly used morphological seedling quality indicators of *P. radiata* include (F.R.I., 1988):

- Height (from root collar to top) 20 to 40 cm.
- Diameter at the root collar at least 5 mm.
- Sturdiness ratio 40 to 60.
- Presence of mycorrhiza.

Smith (1986) recommends that conifer seedlings should be at least 10 to 30cm high, have a shoot to root ratio not greater than four to one and have a root collar diameter of at least 3mm. Ballard (1974) found that height at planting of *P. radiata* seedlings was not of importance in determining subsequent growth, other than the tallest seedlings at planting will be the tallest at the end of the growing season.

No figures for physiological seedling quality indicators for indigenous species were found. Figures for physiological seedling quality indicators of *P. radiata* include: water potential greater than -0.5 MPa; root growth potential score of four to five; an adequate and balanced supply of mineral nutrients and carbohydrates (F.R.I., 1988). Refer to F.R.I. (1988) for desirable levels of minerals in seedling top dry matter.

Assuming that most of the requirements for seedling growth in forestry situations are likely to be similar, if not identical, to that of ecological restoration, it therefore, seems reasonable to apply the principles of determining forestry seedling quality to seedlings used in ecological restoration. However, it would seem that further research is required.

5.2 Selection Culling of Seedlings

In forestry situations it is recommended that seedlings malformed by birds or insects and seedlings less than two-thirds of the mean height are not planted, as these are likely to perform badly (Menzies *et al.*, 1995). Smith (1986) recommends that seedlings to be used in forestry should be culled if they have distinctly poor roots, are badly damaged or have virulent fungi or insect pests. Porteous (1993) recommends that badly root bound indigenous seedlings should not be planted in ecological restoration projects, as these will not develop normally.

Selection culling in forestry situations of non-uniform seedlings is desirable to produce a uniform crop, which simplifies harvesting and marketing. However, selection culling of seedlings, other than those that are unlikely to survive, may have the effect of reducing genetic diversity (Smith, 1986). Protecting genetic diversity is one of the objectives of ecological restoration stated in the introduction of this report, and, thus selection culling may produce undesirable results in ecological restoration.

5.3 Bare-root versus Containerised Seedlings

Containerised seedlings allow more flexibility in timing of planting than do bare-root seedlings or cuttings. Although bare-rooted stock is usually cheaper to produce, containerised stock has the advantage that the roots remain in contact with soil and so can be planted at a time when the roots are not actively growing. Success of bare-root seedlings depends on planting when two to three weeks of root elongation can be expected. It is important to note that rapid shoot or leaf formation demands most of the supply of constructive materials and this can restrict root elongation. Therefore, planting of bare-root stock should not be performed when there is rapid shoot or leaf formation (Smith, 1986). Davis *et al.* (1995) experimented with indigenous seedlings and found little difference in performance between container grown and bare-root stock planted on an overburden dump of finely weathered material granite gravels. In another trial, where soil had been replaced on the overburden, containerised stock generally grew better than bare-root stock. However it was observed that growth and survival of bare root stock of several species (koromiko, karamu, kahikatea and totara, as well as red and silver beech planted on gravels) was sufficient that their use be further investigated. Murray Davis (personal communication, March, 1996) noted that four year old bare-rooted kahikatea performed better than container grown kahikatea seedlings of the same age. This was considered to probably be a result of nutrient depletion of the container grown stock. Indigenous plants grown in containers can grow to plantable size quicker than those grown in the open ground (Pollock, 1986).

Container size has been shown to positively influence growth of seedlings planted in the field, but not survival (Bruzon and Serna, 1980; Kinnunen and Lemmetyinen, 1980). For fast growing indigenous seedlings, i.e. those attaining 20 to 40cm height in one season, Pollock (1986) recommends root trainers of 200 to 400ml capacity or polythene bags of 800 to 900ml capacity. Pot size has also been noted to affect mycorrhiza population in nurseries; Ferguson (in Menge 1984) found that 1500cm^3 pots produced 90 times more spores than 750cm^3 pots.

5.4 Handling and Transport

Chavasse (1980) found that high survival of *P. radiata* seedlings depended on care in handling from lifting to planting. During transport and handling seedlings must be kept moist, cool and aerated to maintain quality (F.R.I., 1988; Smith, 1986). Bare-root seedlings should be transported lying on their sides to avoid damage to tap roots, which will assist in reducing the potential for toppling, i.e. trees growing on a lean rather than upright (F.R.I., 1987). Care should also be taken in handling container grown seedlings as roots may also be damaged in containers. Kanuka is very sensitive to handling, and poor growth after handling is often attributed to disturbance during handling and transport (D. Norton personal communication, March, 1996).

6. PLANTING FACTORS

For the purpose of this section planting factors includes: quality of planting, timing of planting, site preparation, fertiliser at planting and planting density. Chavasse (1980) considers such planting factors to be among the main influence of seedling field performance. As is the case for seedling factors most studies on planting factors have been undertaken in forestry situations, not in ecological restoration. Site preparation includes soil amelioration and weed control; these topics have been discussed in chapters 1 and 3, respectively.

6.1 Quality of Planting

Growth and survival of seedlings is affected by planting quality (for example: Chavasse, 1980; Porteous, 1993; Smith, 1986). Shiver *et al.* (1990) compared the survival of paired plots of commercially planted seedlings to carefully planted seedlings (i.e. tightly packed soil to root collar depth with no swept roots or up pointing roots). It was found that survival of seedlings was increased by a mean of 10% when carefully planted. Smith (1986) recommends that seedlings should be planted so that moist soil is packed around the roots and no large air spaces left in the planting hole. Also, seedlings should be planted firmly enough to resist a gentle tug by hand. Roots should be placed in the ground with as little distortion as possible (Trewin, 1995). Planting seedlings with roots swept or pointing upwards has been noted to increase toppling of *P. radiata* (F.R.I., 1987).

Metcalf (1987) notes that although a number of indigenous plants can be planted relatively deep it is desirable not to plant deeper than the soil line on the stem of the plant. Porteous (1993) states that bare-root indigenous seedlings must be planted at the depth that they were growing in the nursery. No studies on the influence of planting depth on the growth and survival of indigenous seedlings were found. Planting conifers with the root collar above the ground line has been found to reduce survival; but, there was no significant difference in survival between planting the root collar at ground level and the root collar below ground level (Shiver *et al.*, 1990).

6.2 Timing of Planting

Metcalf (1987) recommends planting indigenous species from March to May or from July to the end of August. However, in all except frost prone sites planting can be carried out from March to August if the soil is in suitable condition. Porteous (1993) recommends that indigenous seedlings be planted in late autumn or winter to avoid dry spells. In addition, containerised seedlings can be planted any time of year provided sufficient water is available. It was discussed above (section 5.3) that the timing of planting of bare-rooted stock is less flexible than that of containerised stock. Morrison and Llyon (1972) found that the early growth and survival of kauri was influenced by the month of planting at Waipoua Forest (Northland). Growth and survival of seedlings planted in April were increased by 10.2cm and 15%, respectively, compared to seedlings planted in July. Also, April plantings had a 24% higher survival rate than August plantings.

6.3 Fertiliser at Planting

Fertiliser can be applied at planting to overcome early growth stagnation and to ensure planting success where insufficient nutrients are available (Ballard, 1978; Mead, 1995). Many indigenous plants grow well on fertile soils without fertiliser; the response from fertiliser is likely to be greatest on poor soils (Porteous, 1993). Both Porteous (1993) and Metcalf (1993) make broad recommendations of chemical and organic fertiliser rates for indigenous seedlings, however, no references are cited for these rates. Experiments with indigenous species and fertiliser have already been discussed (section 1.1.1).

Fertiliser applied at planting has been shown to result in a greater increase in growth when applied in a spade slit 15cm from the seedling than when broadcast over the site or placed in the planting hole (Ballard, 1969a in Ballard, 1978). Fertiliser placed too close to seedling stem or roots can reduce survival of seedlings, for this reason fertiliser is usually placed 15cm from the seedling (Ballard, 1978). Moberly *et al.* (1978) detail experiments with blood and bone. They found that, with *Eucalyptus delegatensis*, 28g of blood and bone per seedling at establishment increased the height increment from 35cm to 85cm. An application rate of 56g did not result in any further increase in growth response, but 112g did. Application of blood and bone near the stem reduced survival and increasing the rate of application, near the stem, also reduced survival.

6.4 Planting Density

There has been little research on the effect of planting density on growth and survival in ecological restoration. However, there has been considerable research of this topic in forestry. Thus the following information relates to trees; as shrubs are smaller than forest trees the following information may not be directly applicable. Lanner (1985) stated that it is almost axiomatic that height growth of canopy trees is insensitive to initial spacing. Lynch (in Smith, 1962) notes that stand density has little effect on height growth except where the stand is extremely dense or so open that the trees are distinctly isolated. In contrast Sjolte-Jorgensen (1967), in a review of the influence of spacing on conifers, found that growth was positively influenced by increasing spacing. Evert (1972), in another review of spacing studies, stated that Sjolte-Jorgensen's conclusion may have been influenced by the high proportion of experiments with small spacing in the data reviewed. Evert (1972) noted that experiments with initial spacings less than 1 to 2.5m show height growth to increase with increasing spacing. However, experiments with wider spacing show the effects of spacing on height growth to be very little.

Mackenzie (in Sjolte-Jorgensen, 1967) in 145 spacing experiments found that the early loss of plants after establishment was independent of the spacing. However, on the most exposed sites closer spaced trees survived better, except for one species for which disease attacks were more serious in closely planted stands than more open stands. Evert (1972) found that mutual competition was definitely one of the factors causing tree deaths for stand ages ranging from 12 to 40 years with spacing less than 1.83 m. The proportion of trees surviving increased as spacing increased up to a maximum of 1.83m. However, at spacings greater than 1.83m death in stands appeared to be attributed either to random causes, heavy grass competition, diseases, fire or rodents.

It is worthwhile noting that in a restoration trial on a landfill it was found that the number of self sown plants per plot was positively correlated with increasing planting density (Robinson and Handel, 1993). Porteous (1993) does not specify any planting density, but does recommend group planting as the best planting strategy.

7. SUMMARY

There is little known about the nutrient requirements of indigenous seedlings in the field. However, Hawkins and Sweet (1989) have observed the influence of different nutrient regimes on the growth of three podocarps in a sterile growth medium in a glasshouse. Also, there have been several experiments that have observed the effects of various fertiliser types and rates. It appears that fertilisers are of little benefit to indigenous seedlings on fertile sites but can increase growth on sites where there is no top soil. Where the top soil has been removed height growth of indigenous seedlings has been increased following applications of mag-amp, osmocote and urea. Further research to determine what levels of soil concentrations of essential nutrients are necessary to optimise growth and survival of indigenous seedlings would be useful. Soil physical conditions affect soil aeration, drainage, moisture and root penetration; these factors have a strong influence on the growth and survival of terrestrial plants. Soil physical conditions on disturbed land are often less than ideal for optimum growth and survival. Although a small proportion of the New Zealand landscape, disturbed land presents many challenges in providing seedlings with optimum opportunities for establishment.

Mycorrhiza have been shown to be essential to plant growth and survival of nearly all the indigenous plant species that have been tested, when soil P is low. Sterilised nursery soil may not contain mycorrhiza and heavily manipulated soils of overburden dumps without vegetation may also be lacking mycorrhiza propagules. However, New Zealand pastures might contain mycorrhiza suitable for indigenous species. Inoculation in the nursery of seedlings with mycorrhiza can be of benefit to growth and survival on sites such as overburden dumps where there are likely to be few mycorrhiza propagules.

Weeds can reduce growth and survival of seedlings through competition for resources (for example light, water, nutrients). There are a variety of proven physical and chemical weed control methods that can be used in ecological restoration. Weeds can respond to fertilisation of the target species and increase competition for resources and thus reduce growth and survival of the planted species. Thus weed control is recommended when applying fertiliser.

Vertebrates are the main pest of indigenous seedlings likely to influence growth and survival. These require control to ensure success of a restoration project. Invertebrates and diseases have not been noted to be a major influence on growth and survival of indigenous seedlings in New Zealand, however their influence requires further evaluation.

Seedling quality measures have not been determined for indigenous species. However, some of the general observations of seedling quality used in forestry are likely to be applicable to indigenous seedlings used in restoration plantings. Planting timing and quality can influence growth and survival. Planting, and timing of planting, needs to be performed in a manner that ensures a constant supply of moisture and nutrients to the roots. Fertiliser at establishment has been shown to enhance early growth, and both increase and decrease early survival. Tree growth has been found to increase with increasing planting spacing up to 1 to 2.5m, thereafter the effects of spacing on height growth are very little. Survival of trees increases with increasing spacing up to a distance of 1.83 m, thereafter deaths appear to be a result of other factors.

The factors discussed in this review are the major influences on growth and survival of indigenous seedlings planted for the purpose of ecological restoration. Nearly all of these factors can be manipulated by project managers. More research would be useful to increase the understanding of the specific requirements of planted indigenous seedlings, especially in the areas of mycorrhiza and of soil chemical requirements.

Part II: Field Trials

8. INTRODUCTION

There is a legal requirement for some mining companies to restore indigenous plant species to mine sites as part of the conditions of their resource consent. Also a large number of ecological restoration projects have been undertaken by charitable trusts, private individuals, city councils, iwi, Department of Conservation, etc.. However, despite this few trials have been undertaken to determine optimum fertiliser, weed control and planting density regimes in such situations. Details of the research undertaken on indigenous species with these regimes has been described in Part One. While many restoration programs are being performed effectively, it is hoped that the following trials will contribute to the knowledge of restoration and allow such projects to be performed more efficiently.

The objectives of the trials are:

1) To determine if at planting (a) the application of blood and bone (B+B) fertiliser or cement kiln dust (CKD), and, (b) the addition of compost, will influence the early growth and/or survival of *Phormium tenax* (P.t.) or *Coprosma robusta* (C.r.) seedlings.
2) To determine if hand weeding or the use of hessian sacking (to reduce weed growth) will influence the early growth and/or survival of *P. tenax* or *C. robusta* seedlings.
3) To determine if planting density will influence the early growth and/or survival of *P. tenax* or *C. robusta* seedlings.

Fertiliser and weed control regimes can utilise a considerable proportion of a restoration budget. Therefore optimising these items is of financial interest to those undertaking restoration programs. Planting density will also make a large difference to a restoration project's budget. For example: if seedlings are placed at 1m x 1m spacing then 10,000 seedlings/hectare will be required, while at 1.5m x 1.5m spacing 4,444 seedlings/hectare will be required. At a cost of $1 per planted seedling this would make a difference of $5,556/hectare. There would also be reductions in fertiliser and weed control costs at the lower planting density, if these operations were costed on a per tree basis.

9. METHODS AND MATERIALS

9.1 Locality Description

The trials are located at Cape Foulwind in Tauranga Bay, 15km south of Westport, South Island, New Zealand (latitude 41°46′S, longitude 171°28′E), approximately 100m inland from the high tide mark, with a variation in altitude from approximately 5 to 30 m above sea level.

At Westport, average annual rainfall is 2157 mm, spread evenly throughout the year. There is an average of 1937 sunshine hours per annum (46% of the possible). On average there is little soil water balance deficit, as runoff occurs in every month. There are an average of 0.6 dry spells (i.e. not more than 1 mm/day of rain for at least 15 days) per year. Mean annual temperature is 12.1° C and mean annual daily range 7.3°C. There are an average of 27.2 days of ground frost and 1 day of screen frost (1.2 m above ground level) each year, which are mainly confined to the winter months. The predominant wind flow is a sea breeze from the south west, winds from the west and north east are also common. Over 50% of the wind is force 2 to 4 (Hessell, 1982).

Trials were placed on two sites approximately 100m apart. The first site is on an overburden dump (O.D.). This was formed approximately 15 years prior to the study by the excavation of the adjacent Milburn Cement Cape Foulwind Limestone Quarry. The second site is on a coastal flat (C.F.). Both sites were vegetated in pasture species (*Holcus lanatus, Trifolium repense* and *Dactylis glomerata*) and some weeds (mainly: *Rumex obtusifolius, Rununculus repense, Plantago major* and *Ulex europaeus*). Prior to planting both sites had provided grazing for cattle. The overburden dump soil consists of compacted sand and clay. The coastal flat soil is Okari recent soil series (Mew and Ross, 1991). Adjacent to the overburden dump there is a small gully (William's Gully) vegetated in indigenous species, with a canopy height ranging from near ground level to 13 m. A species list, and the importance values of species in this gully, is given in appendix 5.

9.2 Experiment Design

Three trials were undertaken to determine the effects of various fertilisers, weed control methods and planting densities on the growth and survival of seedlings, from planting to eight months. Two species were used for each trial: *Phormium tenax* and *Coprosma robusta*. On the coastal flat all three trials were undertaken. On the overburden dump only the fertiliser trial was performed.

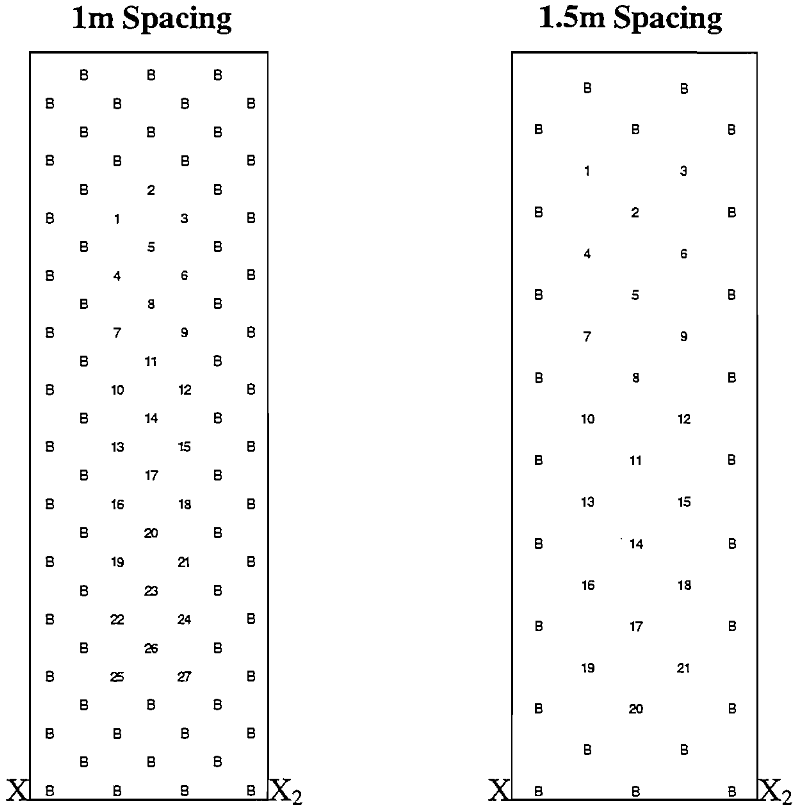
Different treatments were used within each of the trials; these are described in detail in sections 9.2.1, 9.2.2 and 9.2.3. For each treatment there were six replicates of 27 plants each, surrounded by a buffer row of mixed species (see Table 9.1 and Figure 9.1). However, plots of the wide planting density treatment contained only 21 plants. Species in the buffer row were: *C. robusta, C. propinqua, C. grandifolia, P. tenax, Hebe elliptica, Myoporum laetum, Pittosporum eugenioides* and *Leptospermum scoparium*. Within each trial, treatments were allocated randomly to plots. Due to inconsistencies by the contractor in applying weed control methods and difficulties in placing plants uniformly on the overburden dump the intended number of 162 plants per treatment (i.e. 27 plants by 6 plots) varied between treatments.

Table 9.1 Summary of Experiments and Numbers of Replicates and Plants.

Site	Trial	Treatment	Replicates	Plants per Replicate	Plants per Treatment
C.F.	Fertiliser	CKD	6	27	162
		B+B	6	27	162
		No Fertiliser	6	27	162
	Weed Control	Weed Mat	6	27	162
		Hand Weeding	6	27	162
		No Weeding	6	27	162
	Planting Density	1m	6	27	162
		1.5m	6	21	126
O.D.	Fertiliser	CKD	6	27	162
		B+B	6	27	162
		CKD & B+B	6	27	162
		No Fertiliser	6	27	162

Planting was carried out by the contractor during December, 1994 and January, 1995. Seedlings were planted directly from pots. At planting the soil was cultivated to a depth of approximately 30cm in an area 30cm square, then mixed with approximately 4500cm^3 compost. Compost was only used with half of the fertiliser trial seedlings as this trial was a split block design. In all trials (except the wide spacing treatment) plants were placed at 1m x 1m spacing. In the wide spacing treatment of the density trial, plants were placed at 1.5m x 1.5m spacing (see Figure 9.1). Fertiliser application and weed control was undertaken by the contractor.

Figure 9.1: Plot Layout



Key:

1-27	Plant number for data collection purposes.
B	Plant not measured (i.e. buffer)
X	Position of numbered stake.
X_2	Alternative position of stake

Growth of both *C. robusta* and *P. tenax* was determined by measuring the height of the highest point of the plant from the base of the plant in 2cm height classes. Survival of *C. robusta* was determined by the presence of green cambium. Survival of *P. tenax* was determined by the presence of green leaves. The first set of growth and survival measurements were taken at the end of December, 1994 and beginning of January, 1995. Subsequent measurements were taken two, four and eight months after this.

Analysis of variance and Duncan grouping was performed on growth and survival data using Statistical Analysis System (S.A.S.) software version 6.08. Plot data was analysed in groups of treatments with identical variables, except for the variable being considered (e.g. type of weed control, site, etc.). This was done so that, for example, in the fertiliser trial the growth or survival of plants that had received hand weeding were not compared to plants that had received the weed mat. Each analysis group was given a number; treatments within an analysis group were also numbered. Refer to Tables 9.2 to 9.6 for the list of analyses and the treatments included in each analysis. Refer to Table 9.7 for a list of treatments and the variables assigned to each treatment. Plants that had received compost and were adjacent to plants without compost, were considered to have had a different treatment than plants that had received compost and were adjacent to plants that had compost.

Tables of Analyses with Treatment Number:

Table 9.2 Effect of Weed Control

Analysis No.	Weed Mat	Hand Weeding	No Weedin
1	1	2	3
2	4	5	
3	6	7	8
4	9	10	
5	11	13	
6	12	14	
7	17	19	
8	18	20	
9	21	23	
10	22	24	
11	27	29	
12	28	30	
13	44	43	
14	46	45	
15	32	31	
16	34	33	
17	40	39	
18	42	41	

Table 9.3 Effect of Fertiliser

Analysis No.	CKD	B+B	No Fert.	CKD B+B
1	11	15	17	
2	12	16	18	
3	13		19	
4	14		20	
5	21	25	27	
6	22	26	28	
7	23		29	
8	24		30	
9	43	47	51	49
10	45	48	52	50
11	31	35	39	37
12	33	36	41	38
13	32		40	
14	34		42	

Table 9.4 Effect of Compost

Analysis No.	Compost	No Compost
1	11	12
2	13	14
3	15	16
4	17	18
5	19	20
6	21	22
7	23	24
8	25	26
9	27	28
10	29	30
11	43	45
12	44	46
13	47	48
14	49	50
15	51	52
16	31	33
17	32	34
18	35	36
19	37	38
20	39	41
21	40	42

Table 9.5 Effect of Spacing

Analysis No.	1m	1.5m
1	1	4
2	2	5
3	6	9
4	7	10

Table 9.6 Effect of Site

Analysis No.	O.D.	C.F.
1	43	23
2	45	24
3	51	29
4	52	30
5	31	13
6	33	14
7	32	11
8	34	12
9	39	19
10	41	20
11	40	17
12	42	18

Table 9.7 List of Treatments with Variables

N.B. "(split)" denotes plot was of split block design.

Treatment No.	Site	Species	Fertiliser	Weed Control	Compost	Spacing (m)
1	C.F.	C.r.	B+B	weed mat	compost	1
2	C.F.	C.r.	B+B	hand weeding	compost	1
3	C.F.	C.r.	B+B	no weeding	compost	1
4	C.F.	C.r.	B+B	weed mat	compost	1.5
5	C.F.	C.r.	B+B	hand weeding	compost	1.5
6	C.F.	P.t.	B+B	weed mat	compost	1
7	C.F.	P.t.	B+B	hand weeding	compost	1
8	C.F.	P.t.	B+B	no weeding	compost	1
9	C.F.	P.t.	B+B	weed mat	compost	1.5
10	C.F.	P.t.	B+B	hand weeding	compost	1.5
11	C.F.	C.r.	CKD	weed mat	compost (split)	1
12	C.F.	C.r.	CKD	weed mat	no compost (split)	1
13	C.F.	C.r.	CKD	hand weeding	compost (split)	1
14	C.F.	C.r.	CKD	hand weeding	no compost (split)	1
15	C.F.	C.r.	B+B	weed mat	compost (split)	1
16	C.F.	C.r.	B+B	weed mat	no compost (split)	1
17	C.F.	C.r.	No Fert.	weed mat	compost (split)	1
18	C.F.	C.r.	No Fert.	weed mat	no compost (split)	1
19	C.F.	C.r.	No Fert.	hand weeding	compost (split)	1
20	C.F.	C.r.	No Fert.	hand weeding	no compost (split)	1
21	C.F.	P.t.	CKD	weed mat	compost (split)	1
22	C.F.	P.t.	CKD	weed mat	no compost (split)	1
23	C.F.	P.t.	CKD	hand weeding	compost (split)	1
24	C.F.	P.t.	CKD	hand weeding	no compost (split)	1
25	C.F.	P.t.	B+B	weed mat	compost (split)	1
26	C.F.	P.t.	B+B	weed mat	no compost (split)	1
27	C.F.	P.t.	No Fert.	weed mat	compost (split)	1
28	C.F.	P.t.	No Fert.	weed mat	no compost (split)	1
29	C.F.	P.t.	No Fert.	hand weeding	compost (split)	1
30	C.F.	P.t.	No Fert.	hand weeding	no compost (split)	1
31	O.D	C.r.	CKD	hand weeding	compost (split)	1
32	O.D	C.r.	CKD	weed mat	compost (split)	1
33	O.D	C.r.	CKD	hand weeding	no compost (split)	1
34	O.D	C.r.	CKD	weed mat	no compost (split)	1
35	O.D	C.r.	B+B	hand weeding	compost (split)	1
36	O.D	C.r.	B+B	hand weeding	no compost (split)	1
37	O.D	C.r.	CKD & B+B	hand weeding	compost (split)	1
38	O.D	C.r.	CKD & B+B	hand weeding	no compost (split)	1
39	O.D	C.r.	No Fert.	hand weeding	compost (split)	1
40	O.D	C.r.	No Fert.	weed mat	compost (split)	1
41	O.D	C.r.	No Fert.	hand weeding	no compost (split)	1
42	O.D	C.r.	No Fert.	weed mat	no compost (split)	1
43	O.D	P.t.	CKD	hand weeding	compost (split)	1
44	O.D	P.t.	CKD	weed mat	compost (split)	1
45	O.D	P.t.	CKD	hand weeding	no compost (split)	1
46	O.D	P.t.	CKD	weed mat	no compost (split)	1
47	O.D	P.t.	B+B	hand weeding	compost (split)	1
48	O.D	P.t.	B+B	hand weeding	no compost (split)	1
49	O.D	P.t.	CKD & B+B	hand weeding	compost (split)	1
50	O.D	P.t.	CKD & B+B	hand weeding	no compost (split)	1
51	O.D	P.t.	No Fert.	hand weeding	compost (split)	1
52	O.D	P.t.	No Fert.	hand weeding	no compost (split)	1

9.2.1 Fertiliser Trial

Fertiliser was surface applied within one month of planting. On the coastal flat three treatments were used: blood and bone (30 g/plant), cement kiln dust (20 g/plant) and no fertiliser. On the overburden dump the same treatments were repeated as well as a fourth treatment to which both blood and bone (30 g/plant) and cement kiln dust (20 g/plant) were applied. Fertiliser applications were not precise weights as these were applied in an operational manner, approximately one handful of blood and bone was applied per seedling and slightly less cement kiln dust. Within each plot 50% of the plants received compost and 50% did not, i.e. split block design.

9.2.2 Weed Control Trial

This trial was only performed on the coastal flat. There were three treatments hand weeding (i.e. manually pulling out weeds), weed mat ($40cm^2$ of hessian sacking, with a slot cut in from one edge to allow placement and the edges pushed into the soil by spade to hold it in place) and no weeding. All plants received compost in this trial.

9.2.3 Planting Density Trial

This trial was also only performed on the coastal flat. There were two treatments with plants placed at 1m x 1m spacing and at 1.5m x 1.5m spacing. All plants received compost in this trial.

9.3 Determination of Soil Properties

Physical and chemical soil properties were determined for the overburden dump (O.D.), coastal flat (C.F.) and William's Gully (W.G.). Soil profiles were exposed to 60 cm and described. Samples for chemical and physical analysis were taken at 10-20 cm and 50-60 cm depths. Two randomly selected positions were sampled on both the overburden dump and coastal flat sites; while only one randomly selected position was located in William's Gully (refer Table 9.8). One additional position at all three sites was also examined for infiltration rate and resistance to penetration.

Table 9.8: Soil Sampling Locations

Site	Position	Location Description
C.F.	1	Centrally in trials on coastal flat on dune mid-slope.
C.F.	2	Centrally in trials on coastal flat on dune mid-slope.
C.F.	3	Centrally in trials on coastal flat on dune mid-slope.
O.D.	1	Centrally in trials, near centre of plateau of overburden dump.
O.D.	2	Centrally in trials, near centre of plateau of overburden dump.
O.D.	3	Centrally in trials, near edge of overburden dump plateau
W.G.	1	Mid slope of William's Gully under 4 to 6m high canopy.
W.G.	2	Mid slope of William's Gully under 4 to 6m high canopy.

Chemical analysis was conducted by the Soil Fertility Service (New Zealand Pastoral Agricultural Research Institute Limited). Chemical characteristics measured were pH and concentrations of Ca, K, P, Mg, Na, S, NH_4 and NO_3.

Physical characteristics determined were: organic matter, bulk density, resistance to penetration, surface infiltration rate, gravimetric water content, and plastic limit.

- Organic matter was determined by weighing a sample that had been passed through a 2mm sieve and oven dried, muffle furnacing at 550° for two hours, and reweighing.
- Bulk density was determined by calculating the density from the dry weight of sample of known volume. The sample was removed from the soil using a bulk density corer.
- Resistance to penetration was determined by using a F.R.I. (Forestry Research Institute) spring loaded cone penetrometer, the cone diameter was 11.3mm and cone angle 25°. The greatest resistance for each 10 cm depth class was recorded for five points at each position. The penetrometer was recalibrated after taking measurements to check for accuracy.
- Gravimetric water content was determined by oven drying a sample at 105° C for 72 hours and subtracting the dry weight from the initial weight. Gravimetric water content influences resistance to penetration. Therefore gravimetric water content was determined so that if future measurements of resistance to penetration are made it can be ascertained if the two sets of penetration measurements are comparable.
- Surface infiltration rate was determined using two concentric metal rings and a constant head bottle. The water level in the constant head bottle was recorded every five minutes.
- The plastic limit was determined using the method described by Carter (1993). The plastic limit is the gravimetric moisture content at which a soil stops being friable and becomes plastic. Plastic limit was determined only for the overburden dump, as this was considered to be the only area likely to require mechanical manipulation to remedy possible physical limitations.

9.4 Fertilisers

Two fertilisers were used in the trials: blood and bone and cement kiln dust. Blood and bone is an organic fertiliser consisting of a mixture of crushed bone, some dried blood, with a variable proportion of ground waste products of animal origin. The N and P content has been noted to vary. An analysis of 30 samples showed the mean content of N to be 6.1% (range 3.9% to 7.7%), and P to be 6.9% (range 5.8% to 7.8%) (During, 1984). Cement kiln dust is a by-product of the cement making process. Cement kiln dust has high pH and contains less than 2% by weight of nitrogen, phosphorous and potassium (as determined from the data below (Table 9.9) and converting to µg/g as per Cornforth and Sinclair (1984)). Analysis of a sample from Milburn Cement Factory, Westport gave the following results (D. Norton, personal communication, December, 1995):

Table 9.9: CKD Analysis

Analysis	pH	Ca	K	P	Mg	Na	S	O.C.	T.N.
Units	-	Q.T.	Q.T.	Q.T.	Q.T.	Q.T.	Q.T.	%	%
Measurement	12.1	100	300	13	13	155	8800	0.4	0.02

O.C. = organic carbon

T.N. = total nitrogen

Q.T. = M.A.F. Quick Test units

9.5 Seedlings

Seeds were sourced locally and from further afield (e.g. Punakaiki, approximately 50km to the south). Immediately following planting *C. robusta* seedling height ranged from less than 2cm to 31cm and *P. tenax* from less than 2cm to 35cm. Seedlings were raised by the contractor in pots, 8cm high by 5.5cm square, in a nursery approximately 500m from the trial site. Seedlings were one year old and had been hardened outside the nursery enclosure for approximately one month before planting.

10. RESULTS

In the following sections 'significant' means statistically significant at the $p < 0.05$ level.

10.1 Soil Properties

10.1.1 Chemical Properties

Nutrient contents are expressed in quick test units except for ammonium and nitrate which are in parts per million. Chemical analysis of the soil samples from 10-20 cm and 50-60cm are given in Table 10.1 and Table 10.2 respectively.

Table 10.1 Chemical Soil Analysis 10-20cm Depth

Site	pH	Ca	K	Mg	Na	S	P	NH4	NO3
C.F.1	5.1	1	1	6	3	9	49	3	2
C.F.2	5.0	1	3	8	4	13	32	1	2
W.G.	6.4	12	3	25	9	6	1	1	1
O.D.1	7.7	23	3	15	6	101	36	1	1
O.D.2	7.3	8	1	4	4	33	9	2	1

Table 10.2 Chemical Soil Analysis 50-60cm Depth

Site	pH	Ca	K	Mg	Na	S	P	NH4	NO3
C.F.1	5.0	1	0	1	2	4	213	1	1
C.F.2	5.1	0	1	1	1	16	150	1	1
W.G.	5.9	2	2	8	5	13	1	1	1
O.D.1	7.7	11	1	4	5	92	12	1	1
O.D.2	7.5	14	2	9	7	113	24	1	1

Noteworthy points from these measurements are:

- Slight to moderate alkalinity of the overburden dump soil compared to the acid soil of the other two sites.
- Medium to high calcium concentration of overburden dump samples and William's Gully 10 - 20cm sample; compared to the very low calcium concentration of the coastal flat samples and the low concentration in the William's Gully 50 -60cm sample.
- Very low potassium in all samples.
- Magnesium levels in the overburden dump samples were variable; ranging from high to low at both positions, and alternating depths of highest and lowest concentrations. The coastal flat samples both had medium levels of Mg in the 10 - 20cm samples, and low levels in the 50 - 60 cm samples. William's Gully had a high level of Mg in the 10 - 20cm depth and medium level in the 50 - 60cm depth.
- High to very high concentrations of sulphur in the overburden dump soils.
- Very low levels of phosphorous in the William's Gully soil, high to very high in the coastal flat soil and very low to high in the overburden dump soil.
- Higher level of available nitrogen in C.F. 1, 10 - 20 cm depth.

The value ratings used above are those described by Blakemore *et al.* (1987) and in McLaren and Cameron (1993). These ratings indicate the range of values encountered in analysis of New Zealand soils; not what is optimum for indigenous plants.

10.1.2 Physical Properties

10.1.2.1 Soil Profiles

The coastal flat profile was, beginning at the surface; a dark brown nutty layer 10cm to 15cm deep, followed by less dark material to a depth of about 30cm from the surface. Beneath this was a loose, structureless grey sand.

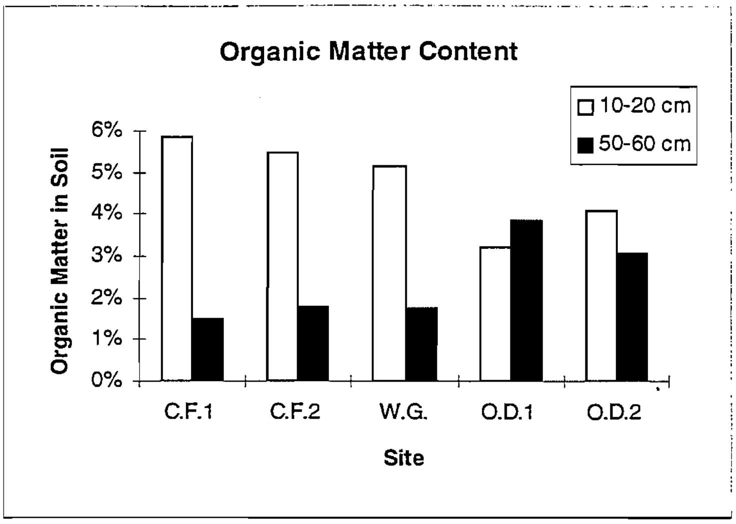
The overburden dump had a dark nutty layer from the surface to about 10cm depth. Beneath this was a layer 20cm thick of light brown blocky iron mottled soil. At the bottom of this layer at position O.D.1 was a perched water table. Beneath this layer was a very hard, platy layer of mixed dark and light soils. Some limestone stones were present.

The soil under forest in William's Gully had a 2cm litter layer beneath which was a nutty friable layer 6cm thick. Beneath this was a dark layer 20cm thick, followed by a 10cm layer of light dark soil. Below about 35cm the soil was light olive grey, structureless and heavily mottled. The water table appeared to be at about 35cm from the surface.

10.1.2.2 Organic Matter

Of the 10-20 cm depth samples, organic matter levels were greatest in the least disturbed soils, i.e. those of the coastal flat and William's Gully (Figure 10.1). Of the 50-60 cm depth sampled, organic matter levels were higher in the overburden dump samples. Differences in organic matter content between depths was greatest in the coastal flat and William's Gully. The overburden dump showed only slight differences in organic matter content between depths.

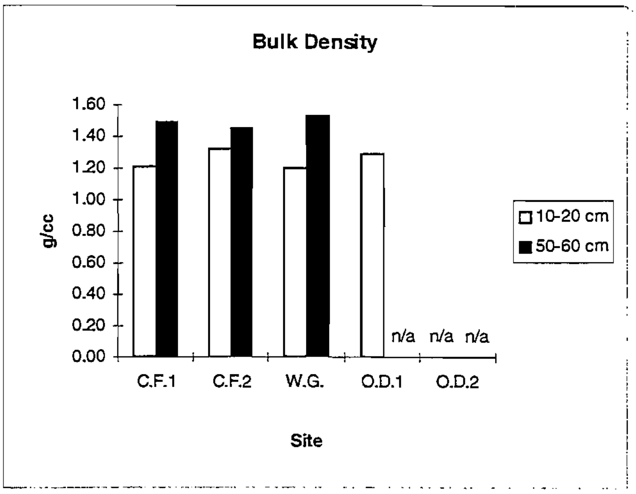
Figure 10.1 Percent Organic Matter



10.1.2.3 Bulk Density

No great variation in bulk density between sites was noted (Figure 10.2). However, bulk density tended to increase with depth at all sites. Due to the presence of large stones encountered in the overburden dump soil only one sample was taken at this site (i.e. at the10-20 cm depth).

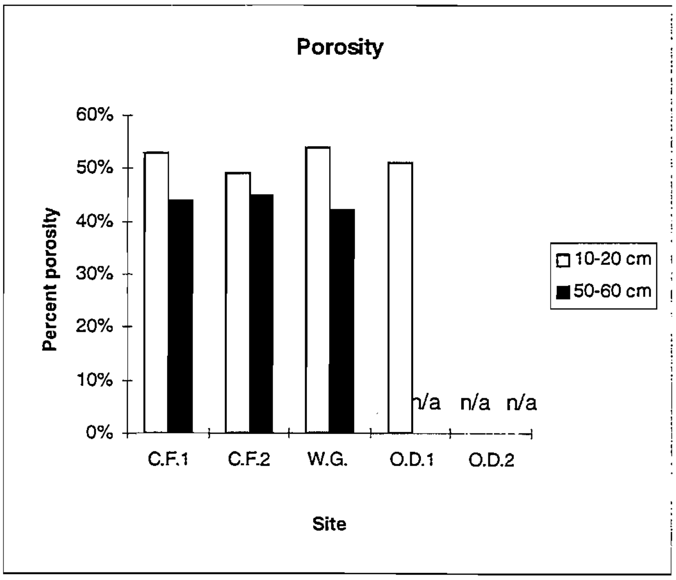
Figure 10.2 Bulk Density



10.1.2.4 Porosity

No great variation in porosity between sites was noted (figure 10.3). However, porosity tended to decrease with depth. Total porosity of all 10 - 20cm depths were medium; and low in the 50 - 60cm depths (ratings as per McDonald and Birrell, 1968). Due to the presence of large stones encountered in the overburden dump soil only one sample was taken at this site (i.e. at the10-20 cm depth).

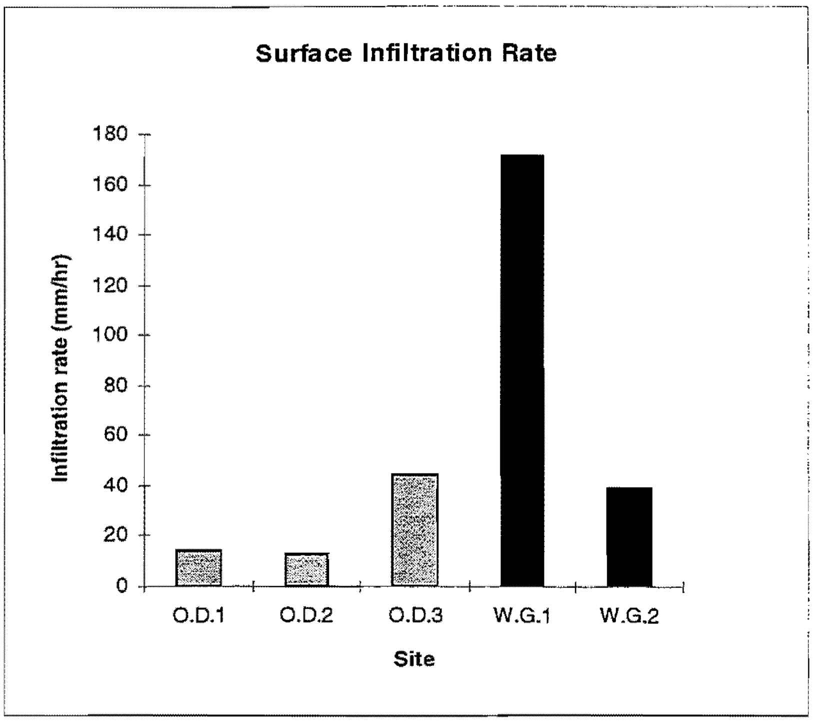
Figure 10.3 Porosity



10.1.2.5 Infiltration Rate

Infiltration rates were classed as: moderately slow for positions O.D.1 and 2; moderate for O.D.3 and W.G.2; rapid for W.G.1 (Figure 10.4). Due to heavy rainfall saturating the soil the night before measuring infiltration rates on the coastal flat this data was considered erroneous and not included in the graph. The infiltration rates recorded for positions C.F. 1, 2 and 3 were slow being four, two and three mm/hr respectively. Classes are as per Bowler (in McLaren and Cameron, 1993). Refer to appendix 2 for details of numerical data and analysis.

Figure 10.4 Surface infiltration Rate

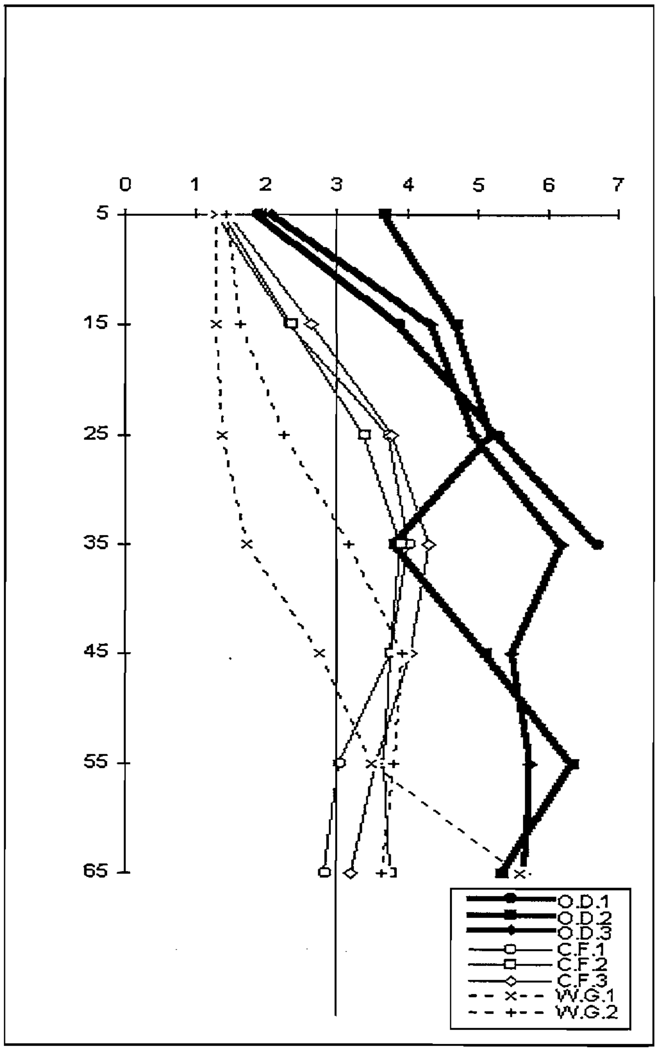


10.1.2.6 Resistance to Penetration

All of the William's Gully and coastal flat positions had significantly less mean resistance to penetration than the overburden dump positions from the surface to 60cm depth (when comparing the same depth class); except for some of measurements from the 35 and 45 cm depth classes (Figure 10.5). Significant differences between William's Gully and the coastal flat were fewer than when comparing the overburden dump with these two other sites (when comparing the same depth class). There were no significant differences between any positions in the 65 cm depth class. Resistance to penetration at position O.D.1 exceeded the capacity for measurement with the equipment used below 40cm.

Resistance to penetration on the overburden dump exceeded the critical 3 MPa limit (refer section 1.2.1) in all measurements; except for positions O.D. 1 and 3 in the 5 cm depth class. Resistance to penetration on the coastal flat exceeded 3 MPa below the 15 cm depth class. Resistance to penetration in William's Gully exceeded 3 MPa below the 25 cm depth class in position W.G.2, and below the 35 cm depth class in position W.G.1. Numerical and statistical data is presented in appendix 3.

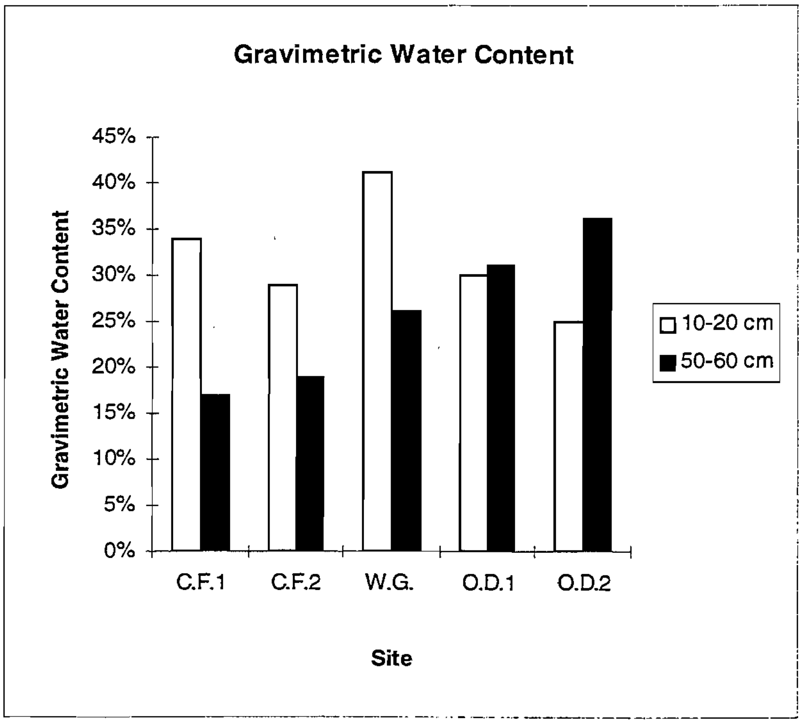
Figure 10.5 Soil Resistance to Penetration



10.1.2.7 Gravimetric Water Content

Gravimetric water content near the surface of the coastal flat and William's Gully tended to be higher than at depth (Figure 10.6). Gravimetric water content on the overburden dump was similar at both depths at O.D.1. At O.D.2 gravimetric water content was higher at depth than near the surface.

Figure 10.6 Gravimetric Water Content



10.1.2.8 Plastic Limit

The plastic limits, in terms of gravimetric water content, determined for the overburden dump samples were as shown in Table 10.3. The O.D. 2 10-20 cm sample was nonplastic because of the high sand content.

Table 10.3 Plastic Limit

Site	O.D.1 10-20 cm	O.D.1 50-60 cm	O.D.2 10-20 cm	O.D.2 50-60 cm
Plastic limit	25%	20%	Nonplastic	22%

10.2 Trials

10.2.1 Introduction

For the following analyses growth is defined as the change in above ground height from planting to the final measurement, i.e. over eight months. Survival at the end of this eight month period is presented. Analysis numbers (A.N.) for the results of the trials are given on graphs to avoid unnecessary cluttering of graphs, in the text these numbers are in brackets where relevant. Details of treatments within an analysis and details of treatments are in Tables 9.2 to 9.6 and Table 9.7 respectively; analysis of variances is in appendix 4.

Predation by cattle or hares of *C. robusta* occurred, and usually resulted in tops (and occasionally side branches) of plants being removed. Chewing patterns on *P. tenax* appeared to be caused by insects or slugs rather than vertebrates. As this was likely to influence growth more than the treatment, these plants were not included in the analysis of growth data. However, plants that had been browsed did not show any decrease in survival and, therefore, were included in the analysis of survival data. There was 67% predation of *C. robusta* seedlings and 8% predation of *P. tenax* seedlings. There were insufficient *C. robusta* alive or not browsed on the overburden dump at the end of the eight month period to allow for analysis of growth data for this species on this site.

10.2.2 Fertiliser Trial

There was a consistent trend of greater growth in plots that had received B+B compared to plots that had received CKD (Figure 10.7). On the overburden dump, there was a trend for plots that had received B+B (either alone or with CKD) to have greater growth than plots that had received only CKD or no fertiliser. In two of ten analyses (A.N. 1 and 2) there was significantly more growth in plots that had received no fertiliser than those that had received only CKD. In one of ten analyses (A.N. 9) there was significantly more growth in plots that had received only B+B than those that had received only CKD.

There was a trend in plots on the coastal flat that had B+B applied to have higher survival than other plots (Figure 10.8). There was significantly higher survival in plots that had received no fertiliser than in plots that had received CKD, in one of fourteen analyses (A.N. 11).

Figure 10.7 Analysis of Fertiliser and Growth

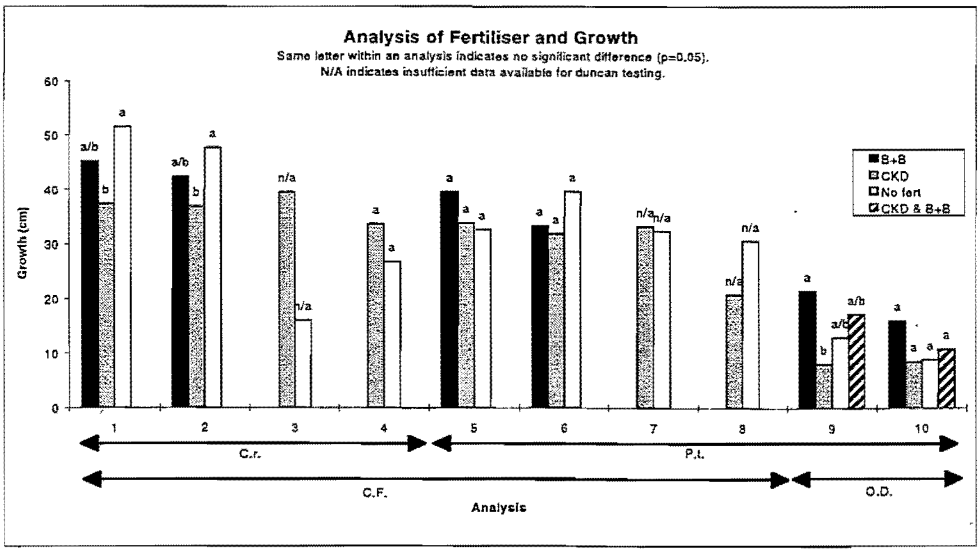
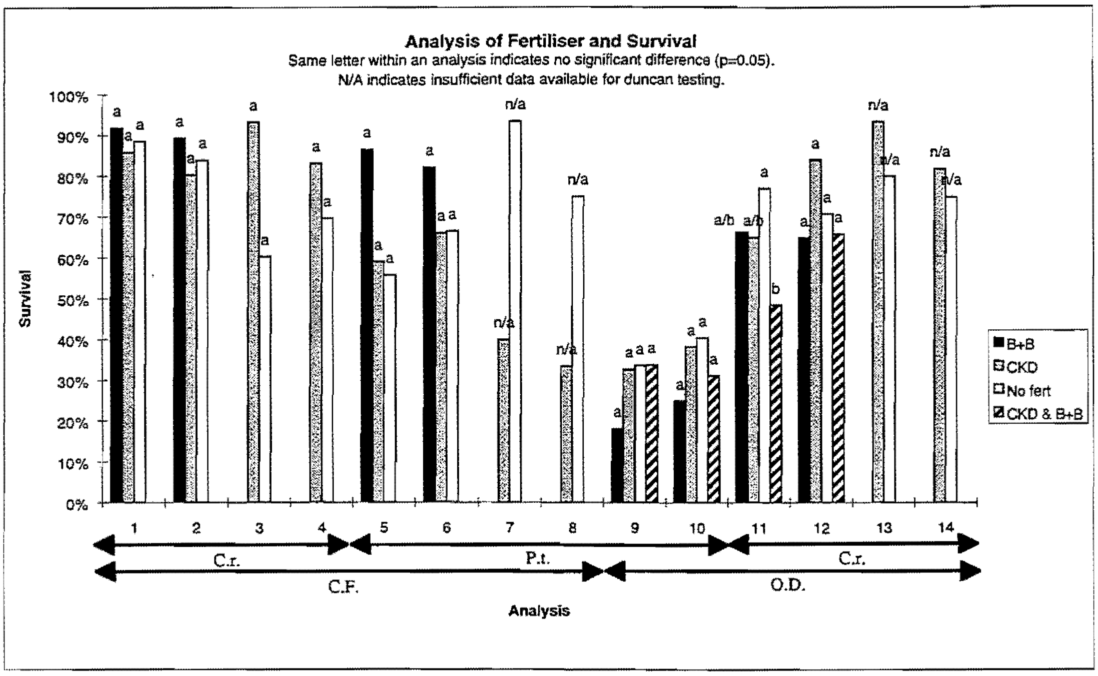


Figure 10.8 Analysis of Fertiliser and Survival



10.2.2.1 Analysis of Compost

Although there were no statistically significant increases in growth in any of the analyses, there was a trend for plants that had received compost to produce more growth (12 of 15 analyses) (Figure10.9). This trend was more apparent on the overburden dump (four of five analyses). Compost had no significant effect on survival, nor were there any obvious trends (Figure 10.10).

Figure 10.9 Analysis of Compost and Growth

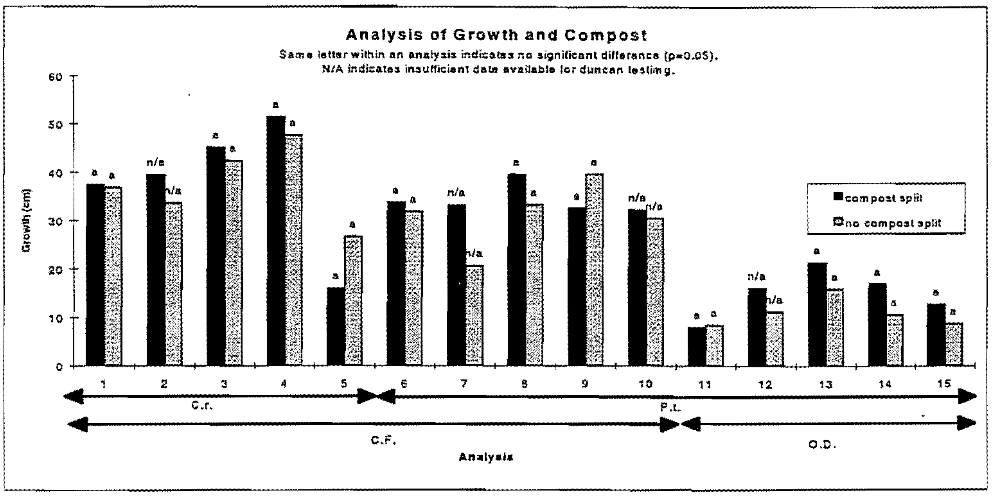
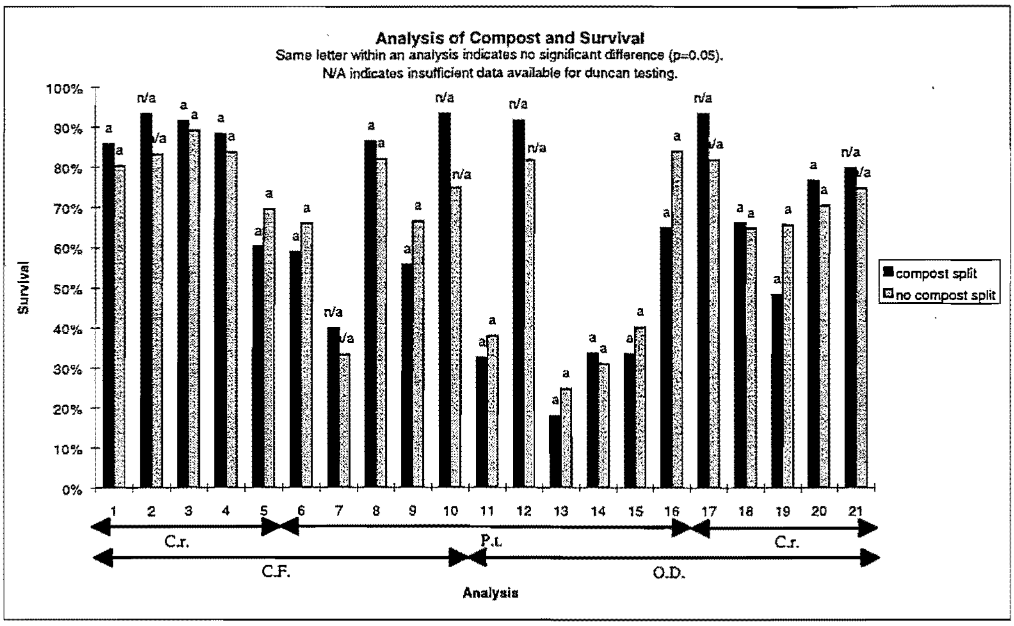


Figure 10.10 Analysis of Compost and Survival



10.2.3 Weed Control Trial

The weed mat initially appeared to control weeds for several months. But thereafter grasses grew through the mat, and after eight months in most cases the mat had decomposed to the point that it did not appear to be effective at inhibiting weeds. Because of this plots that received weed mat were also hand weeded after approximately four months from planting. It was also noted that on 3rd of May that approximately 25% of seedlings were heavily shaded by weeds.

In 12 of 14 analyses there was more growth in plots that had received weed mat than in plots that were hand weeded or not weeded (Figure 10.11). In three analyses (A.N. 3, 8 and 14) there was a significant increase in growth in plots that received weed mat over plots that were hand weeded. There were two analyses (A.N. 1 and 3) that included plots that were not weeded. In one of these analyses (A.N. 1) there was significantly less growth in plots that were not weeded than in plots that had received weed mat; in the other analyses (A.N. 3) there was also less growth, but this difference was not significant.

In two analyses (A.N. 13 and 15), plots that received weed mat had significantly higher survival than plots that were hand weeded (Figure 10.12). In one analysis (A.N. 1) plots that had been hand weeded had significantly higher survival than plots that had not been weeded. But overall there was little obvious pattern in these results. Plots that had received no weeding were only included in two analyses because there was little variation in treatment of these plots and this was therefore sufficient to include all these plots.

Figure 10.11 Analysis of Weed Control and Growth

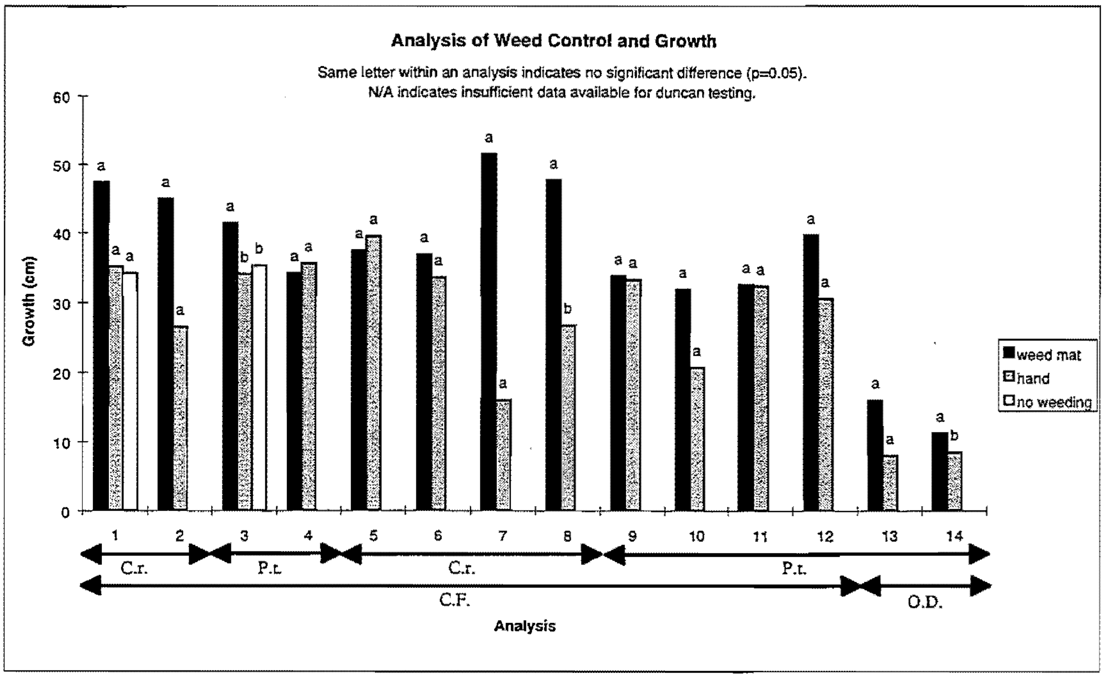
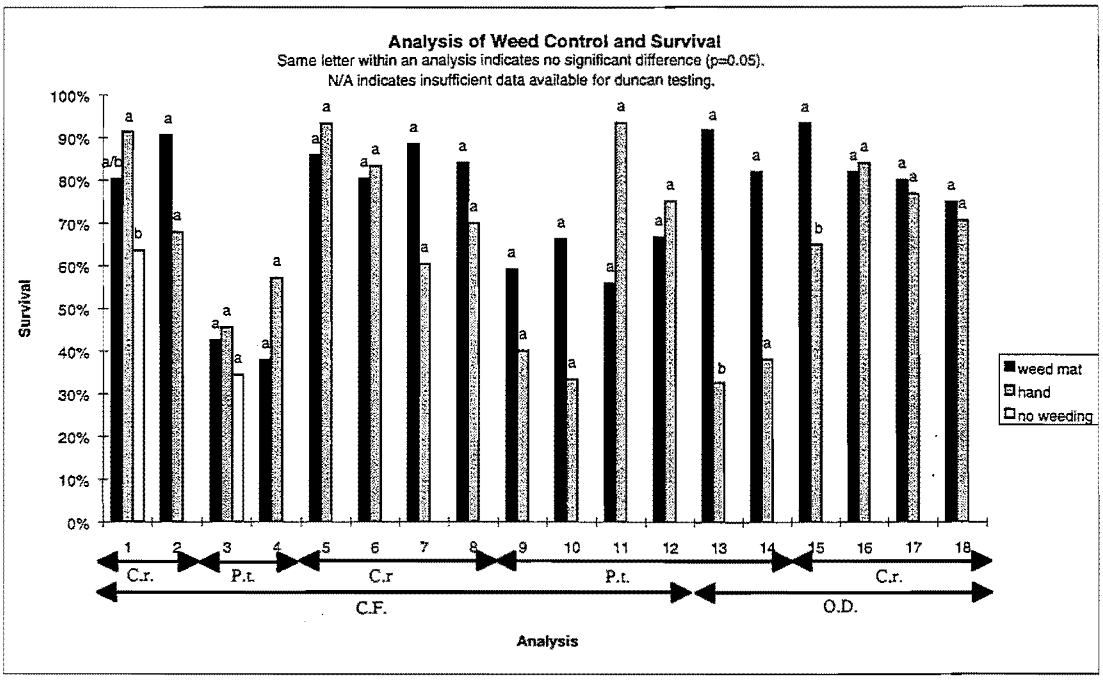


Figure 10.12 Analysis of Weed Control and Survival



10.2.4 Planting Density Trial

Three of four analyses showed greater growth at 1m spacing. This was significant in one analysis (A.N. 3) (Figure 10.13). However, it was observed that the contractor had performed weeding more effectively on plots with 1m spacing than on plots with 1.5m spacing. Workers had become accustomed to the 1m spacing and did not locate plants as well when weeding the 1.5m spacing. This was particularly so for *P. tenax* when surrounded by grass of the same height.

There were no significant differences in survival, or consistent trends, between plots with different interplant spacing (Figure 10.14).

Figure 10.13 Analysis of Planting Density and Growth

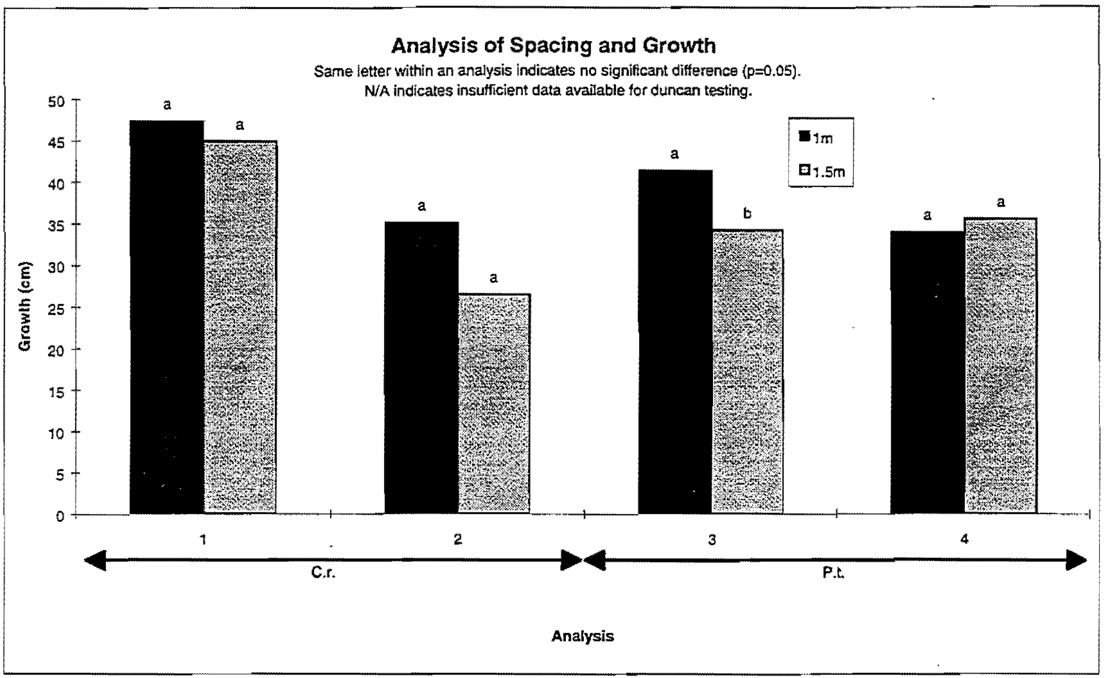
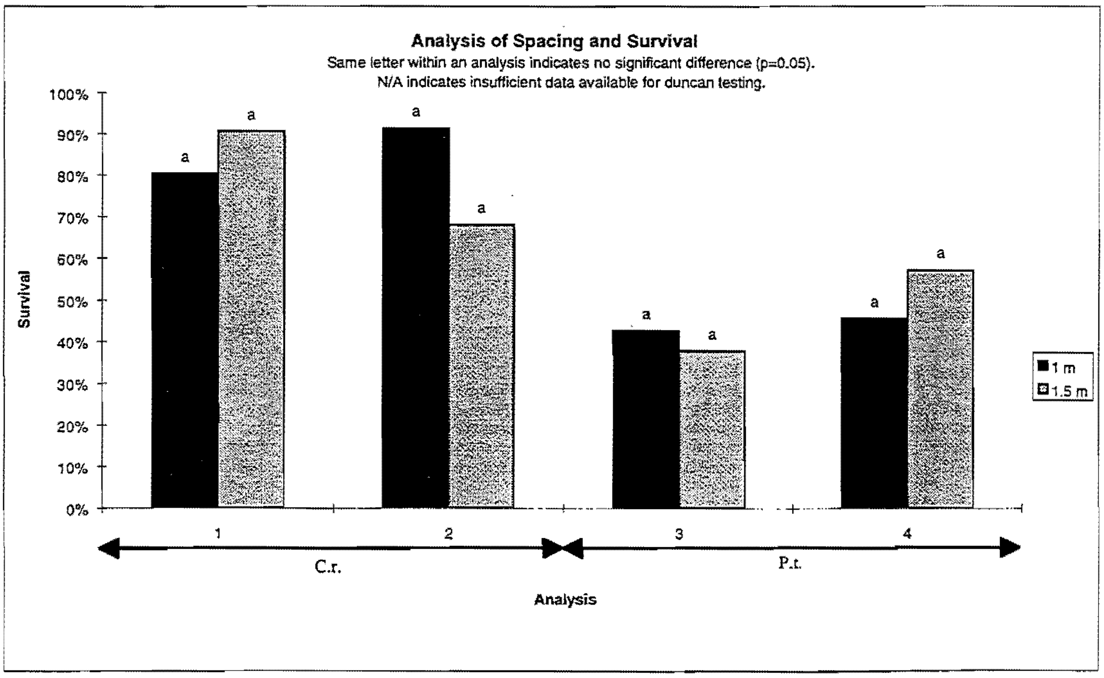


Figure 10.14 Analysis of Planting Density and Survival



10.2.5 Analysis of Site

Growth of *P. tenax* was significantly less on the overburden dump than on the coastal flat in all analyses; differences in the mean growth rates within an analysis ranged from 12 to 25cm (Figure 10.15). *C. robusta* was not included as, mainly as a result of predation, there were insufficient numbers available on the overburden dump for analysis of growth data (see section 10.2.1).

There was little difference in survival between the coastal flat and overburden dump, with six of twelve analyses showing greater survival on the coastal flat than on the overburden dump (Figure 10.16). In only two of the analyses (A.N. 3 and 5) was there a significantly lower survival rate on the overburden dump than on the coastal flat; one of these analyses was of *P. tenax* the other was *C. robusta* . There were no exceptions of significantly higher survival on the overburden dump compared to the coastal flat.

Figure 10.15 Analysis of Site and Growth

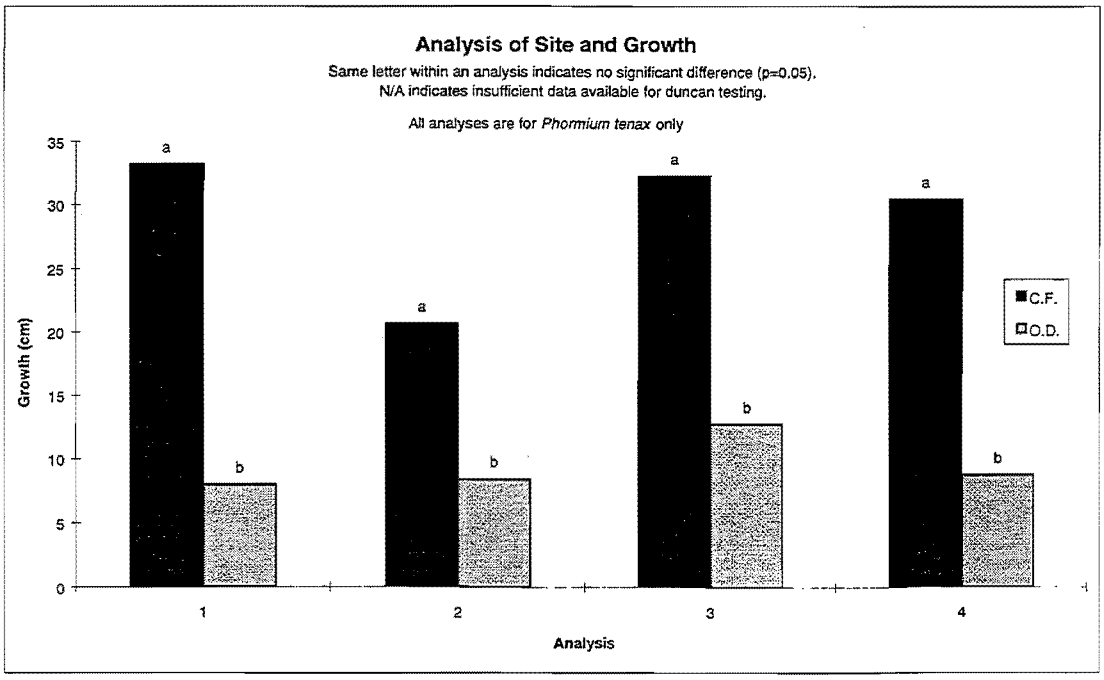
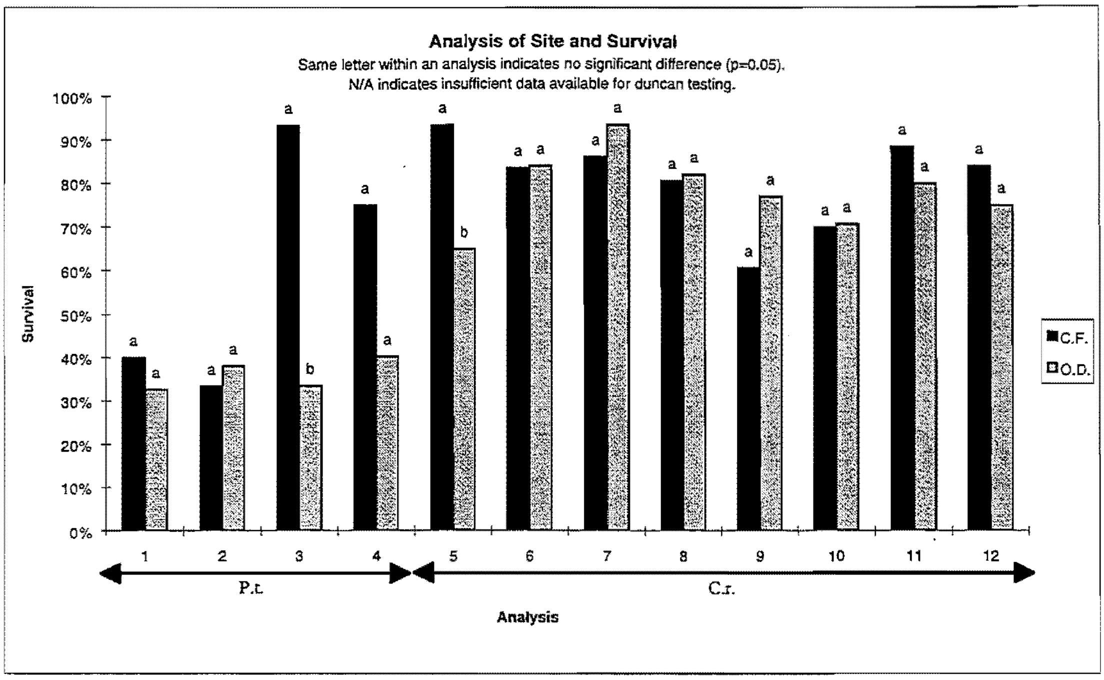


Figure 10.16 Analysis of Site and Survival



10.2.6 Further Analyses

The following analyses were performed by separating data only by seedling site, time, species or height at planting (i.e. growth and survival data from plots was grouped regardless of weed control, fertiliser, spacing and compost regime). This was done to gain an impression of general trends on the sites.

10.2.6.1 Analysis of Planting Height

Where there was less than twenty observations in a height class the height class was not included in the analysis. There were no significant differences in growth when data was grouped by planting height (within the same species and site) (Figure 10.17).

For *P. tenax* on the coastal flat, height classes 26 to 28cm and 30 to 32cm had significantly higher survival than height class 6 to 8cm (Figure 10.18). There was a trend for survival of *P. tenax* to increase with planting size. Survival of *C. robusta* appeared insensitive to planting height.

Figure 10.17 Analysis of Planting Height and Growth

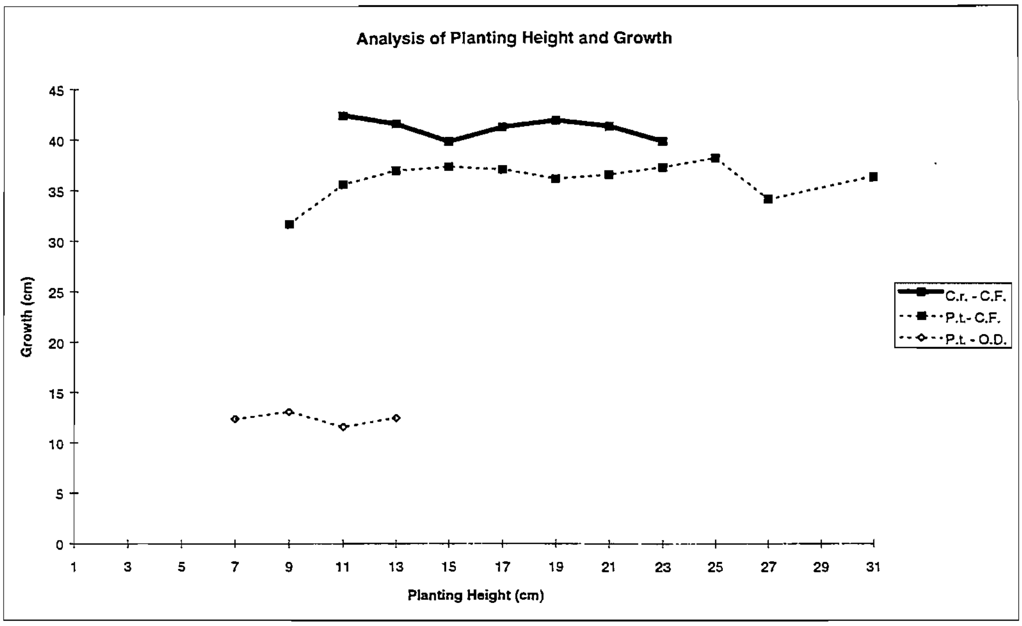
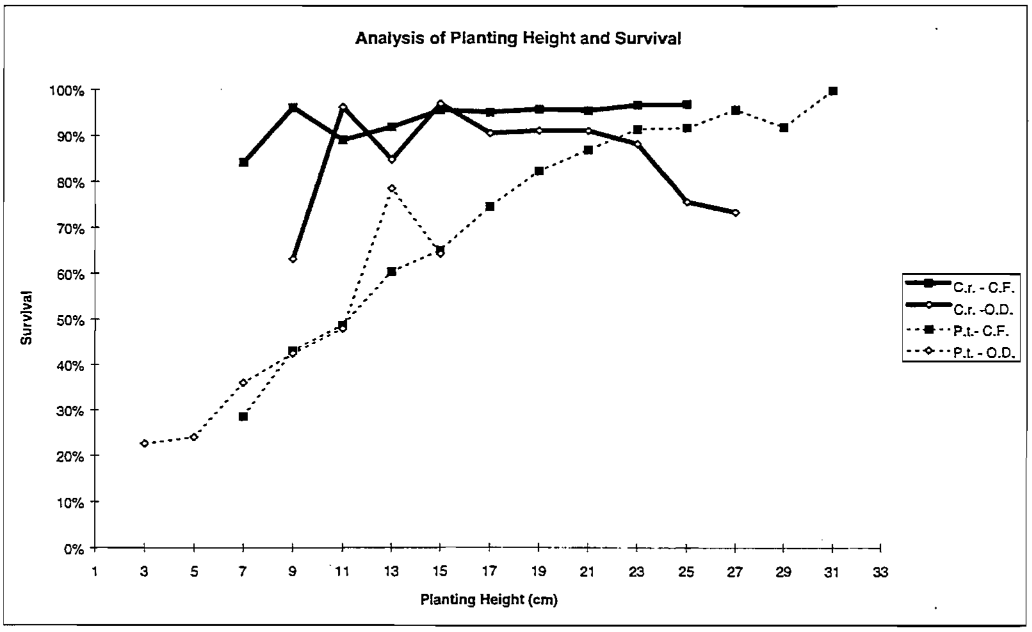


Figure 10.18 Analysis of Planting Height and Survival



10.2.6.2 Analysis of Changes Over Time

For this analysis growth and survival were determined at each measurement in March, May and September. Growth slowed significantly from March through to September (on both sites and for both species) (Figure10.19).

Survival in September was significantly less than survival in March (on both sites and for both species) (Figure 10.20).

Figure 10.19 Analysis of Time and Growth

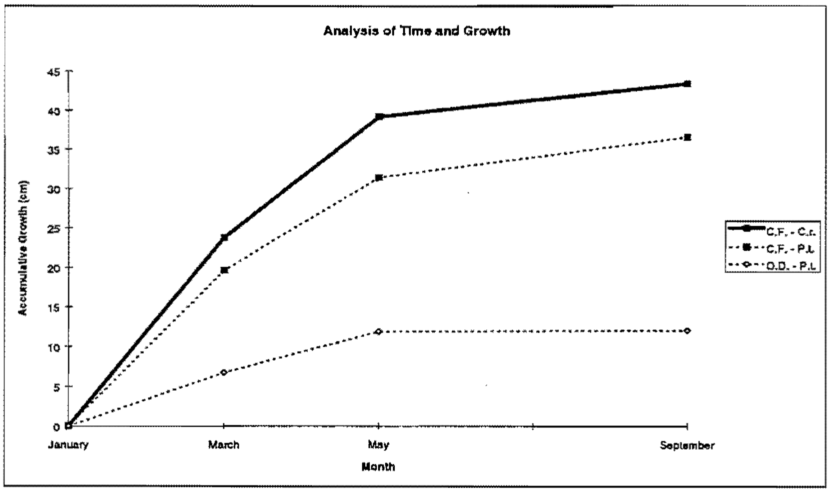
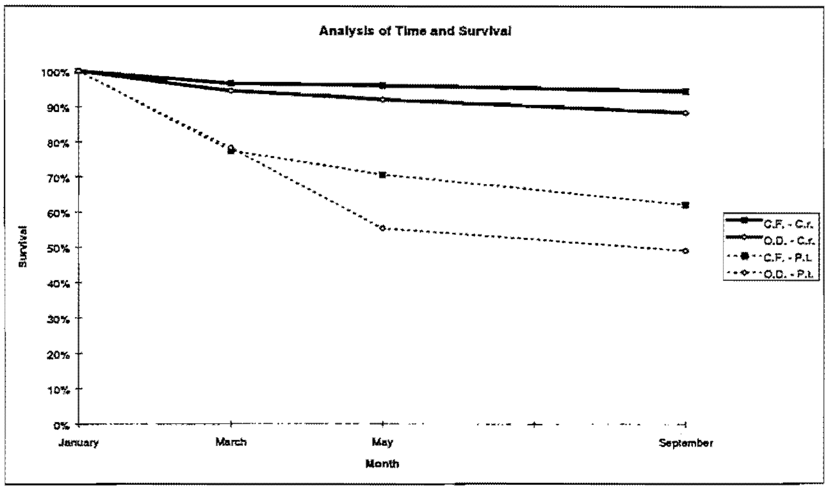


Figure 10.20 Analysis of Time and Survival



10.2.6.3 Analysis of Differences Between Species

Mean growth of *C. robusta* was 4.8cm greater than P. tenax on the coastal flat. This difference was highly significant (Figure 10.21).

Survival of *C. robusta* was higher than *P. tenax* by 29% on the coastal flat; and 36% higher on the overburden dump (Figure 10.22).

Figure 10.21 Analysis of Species Growth

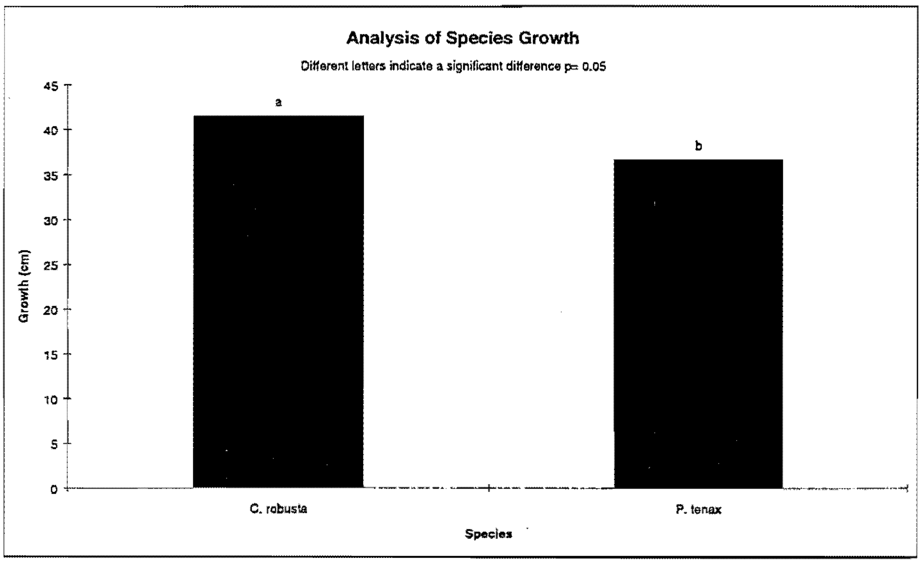
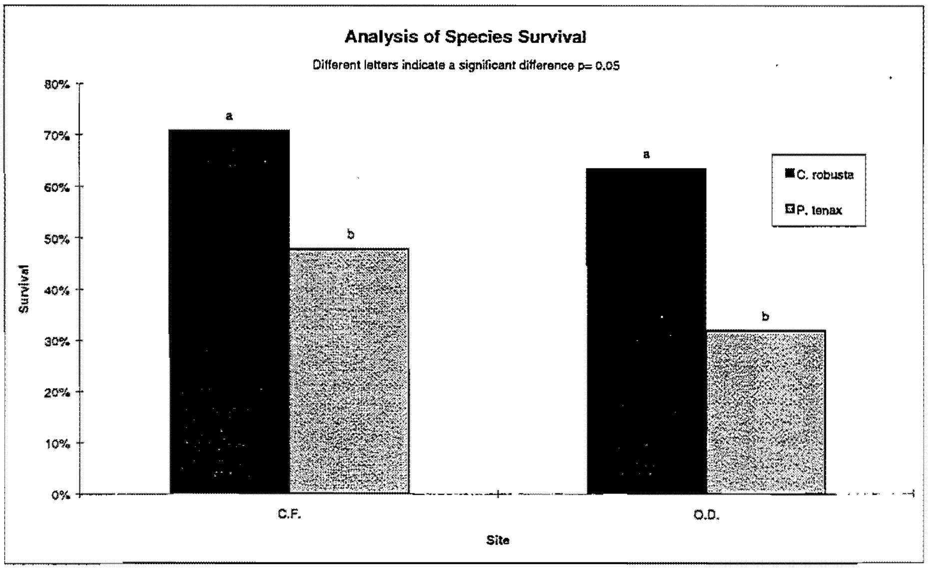


Figure 10.22 Analysis of Species Survival



11. DISCUSSION AND CONCLUSIONS

11.1 Soil Properties

The value ratings for soil nutrient concentrations given by Blakemore (1987) and McLaren and Cameron (1993) indicate the range of values found in New Zealand soil. As such they are not indicators of what are optimum, or normal, for indigenous seedlings. Trials to determine at what soil nutrient levels fertiliser would optimise growth and survival of indigenous seedlings, and at what rates of application, would be useful.

The higher alkalinity of the overburden dump, compared to the other sites, may partially explain the lower growth rates on this site. The higher alkalinity is likely to be caused by a high concentration of calcium carbonate; limestone as fragments, stones and boulders are present on the site. As soils become alkaline some nutrients become less available (particularly phosphorous, iron, zinc, copper, and manganese), this can be overcome by adequate application of fertiliser (Bradshaw and Chadwick, 1980). Also, ammonium at about pH 6.5 and above is subject to volatilisation; if it is near the soil surface. Although no references were found stating optimum pH ranges for indigenous species, optimum ranges for most New Zealand crops lie between pH 4.8 and 7.5 (McLaren and Cameron, 1993). Potassium is also very low on both sites. Thus high pH on the overburden dump resulting in low availability of some nutrients, and low potassium on both sites, may be soil chemical factors limiting optimum growth and survival.

Foliar analysis of nutrient content of the planted seedlings may reveal nutrient deficiencies. However, a range of foliar nutrient concentrations would have to be determined for healthy and unhealthy plants for comparison purposes. Nutrients of particular importance to analyse would be phosphorus, nitrogen, potassium, manganese, iron, copper and zinc.

The low levels of P in the soil under the forest canopy in William's Gully, compared to the other sites, is likely to be due to that most of the phosphorous pool in forests with a closed canopy is in the trees (Brockie, 1992).

Organic matter near the surface of the overburden dump is lower than that of the coastal flat and William's Gully. This may reflect the younger age and poorer conditions for plant growth on the overburden dump.

Neither bulk density nor porosity were found to be at levels that have been noted to be detrimental to plant growth. However, samples from 50 - 60cm were not taken from the overburden dump for these analyses. Due to heavy vehicle traffic on the overburden dump, bulk density and porosity at this depth may be such that plant growth may be limited.

Although infiltration rate on the coastal flat was considered erroneous, because of heavy rainfall the night before measuring, surface infiltration on sandy loams is usually rapid (McLaren and Cameron, 1993) and so only limiting to plant growth and survival where rainfall is low.

Infiltration rates measured on the central area of the overburden dump plateau were moderately slow, however the infiltration rate recorded near the edge of plateau was moderate. This may be because when the overburden was placed heavy vehicle traffic (which can reduce infiltration rate through compaction) would likely to have been greatest on the centre of the plateau rather than the edge. This situation appears to have been exacerbated by cattle pugging the surface. Low infiltration rate on some areas of the overburden dump, and high rainfall, resulted in depressions and holes dug for plants were often filled with water for long periods of time. Compared to the coastal flat where the soil drained rapidly and water was not observed to pond for long periods. Poor drainage (as shown by long periods of surface ponding, slow infiltration rate and observation of a perched water table only 30cm from the surface) is likely to be an important factor limiting growth and survival on the overburden dump.

The infiltration rate recorded on the edge of the overburden dump plateau was similar to one of the infiltration rates measured in William's Gully. This may indicate that, with careful placement of soil and adequate vegetation development, surface infiltration rate on an overburden dump may attain that found under a forest canopy.

Resistance to penetration is above the critical 3 MPa limit (refer section 1.2.1) in most measurements on the overburden dump. However, on the coastal flat and William's Gully resistance to penetration did not exceed this limit until below 20cm and 30cm depth, respectively. The high penetration resistance of the overburden dump soil is likely to result in poor root growth of seedlings beyond the cultivated soil of planting holes. This will limit the volume of soil explored by the roots of seedlings and so result in less nutrients being available to plants on this site; and may already account for some of the reduced growth observed on this site, compared to coastal flat.

Mechanical operations on the overburden dump soil should not be performed when the gravimetric soil water content is over 20-25%, as this was determined as the plastic limit for this soil where sand did not dominate.

The soil problems discussed above are likely to be resolved by the following actions:

- Foliar analysis of seedlings to determine soil chemical deficiencies; followed by experimental determination of optimum fertiliser application rates (based on foliar analysis results), implementation of optimum fertiliser regime.
- Ripping to relieve resistance to penetration.
- Drainage to reduce waterlogging of the soil.

11.2 Trials

11.2.1 Fertiliser

Plots that had received cement kiln dust had significantly less growth than the control (i.e. no fertiliser) in two analyses, and, significantly less survival in one analysis. Cement kiln dust is very alkaline (pH 12), and on some plants was observed at the base of the stem of seedlings. Placing this very alkaline substance so close to the seedlings may have been the cause of the observed decrease in growth and survival. Placing urea too close to the stem of seedlings has been noted to result in a high mortality, and blood and bone placed too near the stem has been noted to decrease survival by 10 to 30% (Moberly *et al.*, 1975).

On the overburden dump, in one analysis, there was significantly more growth in plots that had received only blood and bone than those that had received only cement kiln dust. This may be a result of the combined detrimental effects of cement kiln dust and beneficial effect of blood and bone.

In trials by other authors no response in growth and survival of indigenous species was found on a soil, with topsoil, at a fertiliser application rate of 7g N, 17g P and 6g K per seedling (Guest, 1985). However, a highly significant response was observed on a mineral soil with slightly lower rates of N, P and

K (Dakin, 1976a, 1976b, 1977). Also a significant response (at p=0.05) was found at a rate of 20g N and 17g P per seedling on an overburden dump (Davis and Langer, 1994). The application rates in this trial of blood and bone were 2g N and 2g P per seedling; and negligible for cement kiln dust. Therefore, the low rates of fertiliser application in this trial could explain the lack of significant growth and survival increases in fertilised plots over the control plots. However, Moberly *et al.* (1975) found an increase in seedling growth when applying blood and bone at the rates used in this trial. The species used by Moberly *et al.* (1975) was *Eucalyptus delegatensis* which may be more sensitive to fertiliser.

Placement of fertiliser in a slot 15cm from a seedling has been shown to increase growth more than surface application (Ballard, 1969a in Ballard, 1978). Given the high rainfall of this area and the potential for fertiliser to be removed in run off, applying the fertiliser in a slot might increase the response from fertiliser application.

11.2.2 Weed Control

Weed control has been shown to increases growth and survival by many authors (e.g. Berg, 1975; Nambiar and Zed, 1980, Balneaves and Henley, 1992; Menzies and Chavasse, 1982). The main influences in some of these experiments has been competition for water (e.g. in Canterbury) or frost reduction through exposure of black bare soil (e.g. in central North Island). However in this experiment water deficit and frosts likely to be negligible influences (see locality description, section 9.1). Weeds in this experiment are more likely to influence seedling growth and survival through competition for nutrients and light.

In several analyses there was significantly greater growth and survival in plots receiving weed mat than plots receiving hand weeding or no weeding. Therefore it is likely that the weed mat reduced growth of weeds sufficiently to reduce competition for light and nutrients so that growth of seedlings in some plots was increased.

Hand weeding resulted in similar growth, but higher survival, as not weeding. This may be because the method of hand weeding involved removing the above ground part of weeds, leaving the roots of weeds intact. Although this reduced competition for light it probably did not reduce competition for nutrients. This may explain the observed lack of differences in growth between hand weeding and no weeding. Alternatively, in some plots that were not weeded it was observed that hares had grazed weeds to a lower height than in plots that had been weeded. This might also account for the lack of significant differences in the growth analyses.

Although hand weeding did not influence growth, compared to not weeding, it did influence survival. In one analysis there was significantly less in plots that had not been weeded than in plots that had been hand weeded. Therefore, it may be that survival is more influenced by competition for light and nutrients than growth. Alternatively, differences in survival may have been more pronounced than in growth because of the microclimate created in plots not weeded. The microclimate around seedlings not weeded may have been more conducive to fatal pests and diseases than the more open environment around seedlings in plots that had been hand weeded.

The weed methods used did not influence growth and survival as consistently as expected. Controlling weeds more effectively, with either a more effective weed mat or herbicides, may result in improved growth and survival.

11.2.3 Planting Density

Greater growth of 1m spaced *P. tenax* in one analysis was the only significant difference found in this trial. However, it was observed that weeding was not performed as effectively on the 1.5m spaced plots as the 1m spaced plots.

Workers had become accustomed to the 1m spaced plots and did not locate plants as well when weeding the 1.5m spaced plots. This was particularly so for *P. tenax* when surrounded by grass of the same height. This observation may account for the one significant difference in this trial. The paucity of significant differences in this trial is probably due to seedlings not yet being of a sufficient size to influence neighbouring seedlings.

11.2.4 Site

Growth of *P. tenax* was significantly less on the overburden dump than on the coastal flat in all analyses; and in two analyses survival of both species was significantly less on the overburden dump than on the coastal flat. The overburden dump is adjacent to the coastal flat and is likely to have a nearly identical climate. Thus it is likely that soil conditions are the main cause for differences in growth and survival. The soil differences between the two sites has been discussed above in section 11.1. It is possible that, given sufficient time, problems resulting from compaction and alkalinity may be resolved naturally. How long this will take could be several decades or longer. Solutions to the soil problems of the overburden dump are outlined in section 11.1 above.

11.3 Planting Height

In agreement with the findings of Ballard (1974) growth appeared to be insensitive to planting height.

Shiver *et al.*, (1990) found the survival of tree seedlings under 15cm at planting to be significantly less than that of seedlings over 30cm. This is similar to what was found for *P. tenax*, in that the seedlings that were smallest at planting (i.e. under 8cm) had significantly less survival than those that were largest at planting (i.e. over 30cm). However, survival of *C. robusta* was found to be insensitive to planting height.

The observation of heavy shading by weeds of approximately 25% of seedlings on the 3rd of May could explain the differences of sensitivity in planting height to survival, between *C. robusta* and *P. tenax.* Although *C. robusta* is usually a plant of forest margins Pollock (1986) notes that it tolerates shade. Therefore if *C. robusta* seedlings were above or below the shading effect of weeds it would have possibly made little difference to survival. No references were found on the shade tolerance of *P. tenax,* but is rarely found in shaded positions and the author assumes it to be light demanding. *P. tenax* seedlings taller than the weeds could have grown normally. While the smaller seedlings of *P. tenax,* i.e., those in the shade of weeds, would have experienced conditions in which *P. tenax* normally does not survive.

11.4 Time

As could reasonably be expected most of the growth occurred over summer and decreased over autumn and winter. Growth of *P. tenax* on the overburden dump almost stopped over winter, mean growth was less than 0.2cm from May to September. This was possibly a result of nearly continuous water logging over this period.

Incidences of mortality decreased after two months. Mortality was still occurring at the final measurement in September, but significantly less frequently than in the first two months.

11.5 Species

C. robusta had significantly more growth and higher survival than *P. tenax.* The growth analysis agrees with Rennison and MacLeod (1981) who note that at age three *C. robusta* is likely to be 25cm higher than *P. tenax*. *C. robusta* is also higher at maturity, 6m , compared to *P. tenax* at maturity, 2-3m (Pollock, 1986). The lower survival of *P. tenax* (which was greater on the overburden dump) may have been attributed largely to Phormium yellow-leaf virus. The description of symptoms given by Metcalf (1987) for this virus describe accurately that which was observed to occur on many of the *P. tenax* seedlings. No reference were found describing the occurrence of this virus on *C. robusta*.

P. tenax occurs naturally around Tauranga Bay. However, *C. robusta* was not observed in William's Gully (see Botanical Survey appendix 5) and does not appear on a list of vascular plants observed at the Milburn Cement Cape Foulwind Quarry prepared by D. Norton (D. Norton personal communication, December, 1995). Thus, it may be that pests and diseases of *P. tenax* could already be established on the sites in existing populations of *P. tenax*. However, as *C. robusta* is absent populations of pests and diseases of this shrub may not be present. It is important to note that *C. lucida* has been observed at Cape Foulwind (D. Norton personal communication, December, 1995) and fungal pathogens fatal to *C. lucida* have shown to be equally infectious to *C. robusta* (Forbes and Pearson, 1987). If diseases of *C. robusta* were present they do not appear to have influenced survival of *C. robusta* as much as *P. tenax* was influenced.

11.6 Sources of Error

On the overburden dump, where uncultivated soil beyond planting holes was usually too hard for roots to penetrate, variation in hole size would have influenced the volume of soil (and therefore nutrients) available to seedlings and so probably growth and survival. Therefore, on such a soil consistent hole size is likely to be an important consideration. However, digging holes to a specific size is time consuming, and this would not be compatible with the objectives of a commercially operated restoration project. Another source of variation could have been the greater variation in soil nutrient concentrations observed in the overburden dump than in the coastal flat soil.

P. tenax leaves are temporal structures and in the early stages of growth each successive leaf grew larger than the previous ones. Also, the leaves changed from a firmly upright posture to bent over within about two months. Such a variable form resulted in highly variable results. A method that estimates total above ground biomass, without destroying the plant, would be more suitable. Especially as much of the growth produced by both species appeared in some cases to be equally lateral as vertical. E. Mason (personal communication, December, 1995) is developing a method that estimates above ground biomass from an analysis of a video picture of a seedling, by computer software. This method may be well suited to this experiment.

Predation by cattle and hares and inconsistency in weed control by the contractor reduced the number of plants that could have been included in an analysis. If more plots could have been included within an analysis more significant differences may have been observed.

Seedling condition (both morphological and physiological) at time of planting may have had a strong influence on growth and survival. There was considerable variation in height of seedlings and this may have influenced results in survival analyses of *P. tenax,* if plants were not evenly distributed. Also, a wide variation in water potentials of seedlings was observed, which also may have influenced growth and survival.

11.7 Recommendations

1) Trial subsoiling and drainage on overburden dump to determine if this can improve growth and survival.
2) Undertake a foliar analysis survey of a range of healthy and unhealthy plants to determine optimum foliar nutrient contents. Compare with those

on the planting site so that nutrient deficiencies on the site can be more readily identified and rectified.

3) Repeat fertiliser trials with higher rates of N and P and inorganic fertilisers.
4) Discontinue use of cement kiln dust.
5) Trial a weed control regime that effectively removes above and below ground competition (e.g. herbicide or a more effective weed mat).
6) Continue measurements of planting density trial for at least two more years.
7) Immediately implement program to reduce browsing; e.g. shooting or application of repellent.
8) Set minimum planting height for seedlings. This is not so critical for one year old *C. robusta,* but for *P. tenax* this should be about 20cm.
9) Compare growth and survival for a wider range of species. Particularly salt tolerant species which occur in the locality, for example ngaio (*Myoporum laetum*) and taupata (*Coprosma repens).*

12. SUMMARY

Higher rates of N (balanced with adequate P) may be necessary to observe a significant response from fertiliser than was applied in this experiment. Cement kiln dust was shown to reduce growth. The true potential for cement kiln dust as an aid to growth and survival of plants is perhaps in increasing the pH of acid soils rather than as a supplier of nutrients. Compost did not significantly influence growth or survival. Weed mat improved growth in some instances. A greater response in growth and survival may result from more thorough weed control methods. It is probably to early to know if varying planting density will influence growth and survival.

The overburden dump has poor physical soil conditions which may be alleviated by ripping and drainage. Also, there may be chemical deficiencies on the overburden dump as result of high pH. It may be possible to detect these with foliar analysis and comparison to healthy specimens.

APPENDICES

Appendix 1. Diary

8/12/**94** Two Tui sighted in quarry area.
15/12 Keruru sighted in quarry area.
17/12 Total hare damage to date 3x *C. robusta*, 1x *M. lateum*.
17/12 Pair of keruru east of quarry area.
27/12 First measurement of coastal flat and overburden dump plots.
1/3/**95** Cattle broke into overburden dump.
2/3 Pair of keruru east of quarry area.
2-6/3 Measurement 2.
5/3 Of plots not yet weeded obvious that *C. robusta* not persisting when covered by weeds, but *P. tenax* appears to be.
6/3 Grass green and growing beneath hessian sacking.
29/4 - 4/5 Measurement 3.
29/4 Nursery spider nest on *C. robusta* on overburden dump.
30/4 Pair of paradise ducks flying overhead.
1/5 Harrier hawk over escarpment.
3/5 Estimate 25% of plants are heavily shaded by weeds on the coastal flat .
4/5 CKD pellets visible on surface at base of plant.
6-10/5 Botanical survey.
3-6/9 Measurement 4.
7-9/10 Soil measurements.

Appendix 2. Infiltration data

Position	mm/hr	Slope	r^2
C.F.1	14	0.024	0.956
C.F.2	13	0.022	0.991
C.F.3	45	0.074	0.999
O.D.1	4	0.006	0.978
O.D.2	2	0.003	0.872
O.D.3	3	0.005	0.987
W.G.1	171	0.285	0.994
W.G.2	39	0.065	0.998

Appendix 3. Penetration Data

Site	Depth (cm)	Duncan Grouping		Mean (MPa)	N	F Value	Pr > F
O.D.2	5		A	3.7	5	16.34	0.0001
O.D.3	5		B	2.1	5		
O.D.1	5		B	1.9	5		
C.F.3	5		C	1.5	5		
W.G.2	5		C	1.4	5		
C.F.2	5		C	1.4	5		
W.G.1	5		C	1.3	5		
C.F.1	5		C	1.3	5		
O.D.2	15		A	4.7	5	30.50	0.0001
O.D.3	15	B	A	4.3	5		
O.D.1	15	B		3.9	5		
C.F.3	15		C	2.6	5		
C.F.2	15		C	2.3	5		
C.F.1	15	D	C	2.3	5		
W.G.2	15	D	E	1.6	5		
W.G.1	15		E	1.3	5		
O.D.1	25		A	5.3	5	20.00	0.0001
O.D.2	25		A	5.2	5		
O.D.3	25		A	5.0	5		
C.F.3	25		B	3.8	5		
C.F.1	25		B	3.7	5		
C.F.2	25		B	3.4	5		
W.G.2	25		C	2.3	5		
W.G.1	25		C	1.4	5		
O.D.1	35		A	6.7	5	19.11	0.0001
O.D.3	35		A	6.2	5		
C.F.3	35		B	4.3	5		
C.F.1	35		B	4.0	5		
C.F.2	35		B	3.9	5		
O.D.2	35		B	3.8	3		
W.G.2	35		B	3.2	5		
W.G.1	35		C	1.7	5		
O.D.3	45		A	5.5	3	3.50	0.0125
O.D.2	45	B	A	5.1	3		
C.F.3	45	B	C	4.0	5		
W.G.2	45	B	C	3.9	5		
C.F.1	45	B	C	3.8	5		
C.F.2	45	B	C	3.7	5		
W.G.1	45		C	2.7	5		
O.D.2	55		A	6.3	3	3.31	0.0178
O.D.3	55		A	5.7	2		
W.G.2	55		B	3.8	4		
C.F.2	55		B	3.7	5		
C.F.3	55		B	3.5	5		
W.G.1	55		B	3.5	5		
C.F.1	55		B	3.0	5		
O.D.3	65		A	5.7	1	2.40	0.0676
W.G.1	65		A	5.6	5		
O.D.2	65		A	5.3	2		
C.F.2	65		A	3.7	5		
W.G.2	65		A	3.6	3		
C.F.3	65		A	3.2	5		
C.F.1	65		A	2.8	5		

Appendix 4. Analysis of Variance

'n/a' in the df column indicates that analysis was not performed.
'n/a' in the F Value and Pr>f column indicates that there was insufficient data available to perform that analysis.

Fertiliser Trial Analysis

Analysis	Growth Analysis			Survival Analysis		
No.	**df**	**F Value**	**Pr > F**	**df**	**F Value**	**Pr > F**
1	10	4.38	0.0519	14	0.15	0.8612
2	8	3.86	0.0836	14	0.27	0.7653
3	1	n/a	n/a	3	1.9	0.3016
4	2	0.44	0.6273	3	0.25	0.6663
5	13	0.74	0.5012	14	2.3	0.143
6	13	0.5	0.6216	14	0.69	0.5191
7	1	n/a	n/a	1	n/a	n/a
8	1	n/a	n/a	1	n/a	n/a
9	16	2.83	0.0795	19	0.73	0.5485
10	18	0.66	0.5876	19	0.44	0.7242
11		n/a	n/a	17	2.3	0.1221
12		n/a	n/a	17	0.78	0.5256
13		n/a	n/a	1	n/a	n/a
14		n/a	n/a	1	n/a	n/a

Compost Analysis

Analysis	Growth Analysis			Survival Analysis		
No.	**df**	**F Value**	**Pr > F**	**df**	**F Value**	**Pr > F**
1	7	0.02	0.901	11	0.17	0.688
2	1	n/a	n/a	1	n/a	n/a
3	6	0.63	0.4645	11	0.07	0.8021
4	4	0.52	0.5219	5	0.07	0.8014
5	2	1.05	0.4917	5	0.18	0.6918
6	9	0.12	0.7355	9	0.34	0.5744
7	1	n/a	n/a	1	n/a	n/a
8	9	0.93	0.3626	9	0.26	0.6219
9	7	0.51	0.5011	9	0.16	0.6972
10	1	n/a	n/a	1	n/a	n/a
11	5	0.18	0.6918	5	0.1	0.7681
12	1	n/a	n/a	1	n/a	n/a
13	9	0.39	0.552	11	0.54	0.4778
14	8	2.42	0.1636	9	0.04	0.8531
15	10	1.74	0.2198	11	0.16	0.6943
16	n/a			7	1.81	0.2275
17	n/a			1	n/a	n/a
18	n/a			7	0.02	0.9047
19	n/a			9	1.28	0.2899
20	n/a			9	0.32	0.5879
21	n/a			1	n/a	n/a

Analysis of Weed Trial

Analysis	Growth Analysis			Survival Analysis		
No.	**df**	**F Value**	**Pr > F**	**df**	**F Value**	**Pr > F**
1	18	2.15	0.1489	24	5.65	0.0105
2	2	4.56	0.2787	5	0.95	0.3841
3	22	4.3	0.028	22	0.49	0.6201
4	5	0.04	0.8441	5	0.4	0.5594
5	5	0.07	0.8036	6	0.19	0.6844
6	3	0.62	0.5145	6	0.01	0.9215
7	2	28.8	0.1173	5	1.35	0.3096
8	4	10.97	0.0453	5	0.95	0.3846
9	5	0.01	0.9163	5	0.53	0.5058
10	5	0.78	0.4283	5	2.71	0.1748
11	4	0	0.9879	5	1.37	0.3063
12	4	0.34	0.6	5	0.03	0.8636
13	3	15.43	0.0591	3	348.83	0.0029
14	3	39.85	0.0242	3	2.4	0.2615
15	n/a			4	21.21	0.0193
16	n/a			4	0.01	0.9421
17	n/a			5	0.05	0.8307
18	n/a			5	0.04	0.8569

Analysis of Spacing Trial

Analysis	Growth Analysis			Survival Analysis		
No.	**df**	**F Value**	**Pr > F**	**df**	**F Value**	**Pr > F**
1	5	0.1	0.7725	10	0.85	0.3806
2	10	0.67	0.4338	13	3.04	0.1069
3	10	5.66	0.0413	10	0.09	0.7709
4	11	0.11	0.7508	11	0.3	0.5944

Analysis of Site

Analysis No.	Growth Analysis			Survival Analysis		
	df	F Value	Pr > F	df	F Value	Pr > F
1	3	153.09	0.0065	3	3.25	0.2132
2	3	756.25	0.0013	3	0.02	0.9039
3	5	11.75	0.0266	6	12.63	0.0163
4	6	17.17	0.009	6	1.12	0.3379
5	n/a			4	21.21	0.0193
6	n/a			4	0	0.9842
7	n/a			6	0.19	0.6844
8	n/a			6	0	0.9625
9	n/a			7	1.43	0.2768
10	n/a			7	0	0.9636
11	n/a			3	0.06	0.8259
12	n/a			3	0.69	0.4942

Analysis of Species

Site	Growth Analysis			Survival Analysis		
	df	F Value	Pr > F	df	F Value	Pr > F
C.F.	884	32.7	0.0001	2516		0.0001
O.D.	n/a			997	151.11	0.0001

Analysis of Planting Height

Site	Species	Growth Analysis			Survival Analysis		
		df	F Value	Pr > F	df	F Value	Pr > F
C.F.	C.r.	348	0.76	0.6665	1313	1.39	0.1569
C.F.	P.t.	546	0.87	0.6016	1202	11.86	0.0001
O.D.	C.r.	n/a			483	1.9	0.0285
O.D.	P.t.	124	1.79	0.0773	513	4.56	0.0001

Analysis of Time

Site	Species	Growth Analysis			Survival Analysis		
		df	F Value	Pr > F	df	F Value	Pr > F
C.F.	C.r.	893	639.27	0.0001	5255	105.82	0.0001
C.F.	P.t.	1619	297.88	0.0001	4767	426.45	0.0001
O.D.	C.r.	n/a			1939	62.39	0.0001
O.D.	P.t.	365	55.75	0.0001	2063	277.15	0.0001

Appendix 5. Botanical Survey

The survey was conducted in William's Gully and included only vascular plants. A total of forty five 25 m^2 plots were surveyed at 25 m intervals along transects spaced 50 m apart. The first transect and first plot of each transect were placed at a random distance from the survey area perimeter. Importance value (I.V.) was determined by combining abundance cover (weighted by strata) of each species from all plots.

Species	I.V.	I.V. % of	Species	I.V.	I.V. % of total
Coprosma grandifolia	601.18	21.1%	Asplenium bulbiferum	3.56	0.1%
Dicksonia squarrosa	578.27	20.3%	Metrosideros diffusa	3.48	0.1%
Melicytus ramiflorus	424.30	14.9%	Metrosideros perforata	3.44	0.1%
Macropiper excelsum	206.61	7.3%	Asplenium flaccidum	3.26	0.1%
Ulex europaeus	150.92	5.3%	Blechnum discolor	2.34	0.1%
Aristotelia serrata	145.21	5.1%	Coprosma robusta x propinqua	1.76	0.1%
Myrsine salicina	114.00	4.0%	Rubus cissoides	1.53	0.1%
Coprosma propinqua	63.56	2.2%	Coprosma areolata	1.26	0.0%
Weinmannia racemosa	54.54	1.9%	Lotus pendunculatus	1.15	0.0%
Rhopalostylis sapida	44.02	1.5%	Coprosma rhamnoides	1.12	0.0%
Leycesteria formosa	43.77	1.5%	Blechnum chambersii	0.83	0.0%
Schefflera digitata	43.43	1.5%	Lastreopsis glabella	0.71	0.0%
Fuchsia excorticata	43.17	1.5%	Asplenium polyodon	0.57	0.0%
Pinus radiata	38.61	1.4%	Adiantum fulvum	0.57	0.0%
Dacrydium cupressinum	27.25	1.0%	Freycinetia baueriana	0.35	0.0%
Ripogonum scadens	25.25	0.9%	Ileostylus micranthus	0.31	0.0%
Rubus fruiticosus	24.90	0.9%	Asplenium lyallii	0.22	0.0%
Brachyglottis repanda	24.40	0.9%	Coprosma repense	0.22	0.0%
Dacrycarpus darcydioides	24.00	0.8%	Tmesipteris elongata	0.22	0.0%
Senecio mikanoides	22.23	0.8%	Asplenium oblongifolium	0.20	0.0%
Hedycarya arborea	19.08	0.7%	Astelia fragrans	0.20	0.0%
Pteridium esculentum	15.00	0.5%	Diplazium australe	0.20	0.0%
Muehlenbeckia australis	14.97	0.5%	Solanum sublobatum	0.20	0.0%
Ilex aquifolium	11.07	0.4%	Epilobium sp.	0.12	0.0%
Blechnum capense	9.30	0.3%	Lastreopsis hispida	0.12	0.0%
Holcus lanatus	7.25	0.3%	Pteris macilenta	0.12	0.0%
Nasturtium sp.	5.42	0.2%	Asplenium obtusatum	0.08	0.0%
Juncus sp.	5.35	0.2%	Blechnum fluviatile	0.08	0.0%
Cyperus ustulatus	5.19	0.2%	Uncinia sp.	0.08	0.0%
Carpodetus serratus	4.90	0.2%	Acaena anserinifolia	0.04	0.0%
Parsonsia heterophylla	4.81	0.2%	Centella uniflora	0.04	0.0%
Rununculus repense	4.51	0.2%	Plantago lanceolata	0.04	0.0%
Phymatosorus diversifolius	4.19	0.1%	Cyperus spp.	0.04	0.0%
Pnuematoptreris pennigira	3.87	0.1%	Senecio minimus	0.04	0.0%

Species observed but not located in plots were: *Ascarina lucida, Cordyline australis, Griselinia lucida, Metrosideros fulgens, Crocosmia x crocosmiifolia, Phormium tenax.*

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