REHABILITATION OF NATIVE FOREST SPECIES AFTER MINING IN WESTLAND

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ABSTRACT

Rehabilitation techniques for native forest were investigated at an opencast coal mine site in cut-over beech (*Nothofagus*) forest on alluvial river terraces at Giles Creek near Reefton, Westland. Annual precipitation at the site was 2900 mm and soils were dominantly Allophanic and Acid Brown Soils. The survival and growth of 11 nursery-raised native woody species, and natural regeneration, were examined in three covering treatments consisting of (1) overburden gravel, (2) mixed-horizon forest soil, and (3) layered-horizon forest soil. Underlying gravels were either not ripped or ripped to a depth of 80 cm.

Survival of bare-root and container-grown plants 4.5 years after planting was better in overburden gravel than in both mixed and layered soil, largely because of poor survival of beech species in soil. Plant height growth in overburden gravel, however, was minimal because of nitrogen deficiency. Height growth after 4.5 years in layered soil was nearly twice that in mixed soil, the better growth in layered soil being due to improved drainage and improved nitrogen nutrition. Poor survival of the beeches in forest soil is attributed to root-rot pathogens. Ripping of underlying overburden gravel had no influence on plant survival or growth in any of the three covering materials.

In the fifth year of the trial, ground cover in the two soil treatments was 38–40%, but cover in overburden gravel never exceeded 1%. Tall-growing adventive rushes (*Juncus* sp.) dominated in mixed soil, reflecting poor drainage, whereas native and adventive herb species dominated in layered soil. Few native species, especially woody species, were introduced from the original forest through soil replacement. Research is required to determine optimum timing of earthmoving operations in relation to natural seed dispersal.

Keywords: mineland rehabilitation; native forest; ripping; natural regeneration; nutrients; soil replacement.

INTRODUCTION

In New Zealand, site restoration or rehabilitation is a general requirement of mining under Clause 17 of the Resource Management Act (1991). Most efforts to reclaim mined land have focused on the establishment of pasture or exotic plantation forestry. However, significant mineral and coal deposits under or adjoining areas of indigenous forest are being mined or prospected within the conservation estate, administered by the Department of Conservation, especially in the Coromandel and West Coast regions. Rehabilitation to indigenous forest is now a consent requirement for many mining licences, particularly on conservation estate land. Information is available on methods for establishment of native forest species on sites where there has been little soil disturbance (Beveridge *et al.* 1981, 1985; Evans 1983; Porteous 1993), but is lacking for mined sites where soil disturbance has been catastrophic.

In earlier episodes of mining in the region soil was generally not salvaged and replaced on overburden materials or tailings after mining, a practice which is considered to have substantially slowed the regeneration of native forest (Fitzgerald 1987). There are no reports of studies for Westland or elsewhere in New Zealand, however, which have compared the performance of native forest species on overburden materials with that where soil has been replaced. With pasture and crop species, studies have generally shown greater productivity where soils have been replaced as separate layered horizons (topsoil over subsoil) than as mixed horizons (Widdowson & McQueen 1990; Power *et al.* 1981; Simcock 1993), though not invariably (Simcock 1993). In the present study the survival, growth, and nutrition of nursery-grown plants of locally occurring native tree and shrub species on mine overburden gravels without soil replacement was compared with that where soil was replaced, either as mixed or as layered horizons. Most of the species used were recommended by Norton (1991) as potential species for restoration of alluvial or glacial outwash surfaces disturbed by mining in the Grey-Inangahua bioclimatic region. In addition to the planted stock, the development of natural regeneration was studied to provide a further indicator of the effect of the different soil replacement treatments. The effect of deep ripping of overburden gravels which had been compacted by machinery during replacement was also examined.

METHODS

Study Site

The study area was located on alluvial river terraces at the Giles Creek coal mine, operated by Dunollie Mining Company Limited, Inangahua catchment, North Westland. Elevation at the mine site was 200 m and annual rainfall was 2900 mm. The forest was cut over in the early 1980s for podocarps, (mainly miro (*Prumnopitys ferruginea* (D.Don) de Laub.) and rimu (*Dacrydium cupressinum* Lamb.)), red beech (*Nothofagus fusca* (Hook.f.) Oerst.), and some silver beech (*N. menziesii* (Hook.f.) Oerst.). A forest structure was still present prior to mining. Beech species dominated the canopy and sub-canopy of forest adjoining the mine site, with silver beech being the dominant species, but red and mountain beech (*N. solandri* var. *cliffortioides* (Hook.f.) Poole) were also abundant. Prominent species in the lower tiers included lancewood (*Pseudopanax crassifolius* (A.Cunn.) C.Koch), wineberry (*Aristotelia serrata* (Forst.) Oliver), pepperwood (*Pseudowintera colorata* (Raoul) Dandy), small-leafed *Coprosma* species, mountain toatoa (*Phyllocladus aspleniifolius var. alpinus* Hook.f.), and Hall's totara (*Podocarpus hallii* Kirk).

Soils were dominantly Allophanic Brown Soils of the Ahaura series, with Acid Brown Soils of the Ikamatua series on younger terraces, and Acid Gley Soils of the Maimai series occurring in poorly drained sites (soil nomenclature follows Hewitt 1992). The soil organic and topsoil layers had an average depth of 30 cm, and overlay subsoil layers of similar total thickness. The soils overlay varying thicknesses of alluvial gravels which in turn overlay the coal seams. Mudstone and sandstone layers were associated with the coal seams.

Covering Treatments

The area selected for the trial site consisted of alluvial gravel overburden material arising from the mining operation, which had been transported and dumped on the site to a depth of approximately 10 m and levelled to form a platform prior to 1991. The material had been compacted by earthmoving machinery. Three plots of approximately 0.1 ha were defined, and in February 1991 one-half of each plot was ripped at 1.5-m intervals to a depth of 80 cm.

Using a hydraulic excavator, soil was stripped from logged forest ahead of the mining front after tree stumps had been removed. The stripping was achieved in two ways: either all O, A, B, and a minimal amount of C horizon material was removed as a mixture, or the O and A horizon material was removed separately from the B and C material.

Between February 1991 and February 1992, each 0.1-ha plot was covered with one of the following:
(1) Overburden gravel, to a depth of 60 cm
(2) Mixed soil, to a depth of 60 cm
(3) Layered soil: 30 cm of O + A horizon material over 30 cm of B + C horizon material.
Open drains, 1 m deep, were dug round each plot to intercept run-off water from the surrounding area and to prevent water movement between plots.

Chemical characteristics of the stripped soil materials, sampled from the trial plots prior to planting, and of *in situ* Ahaura soil were determined using methods described by Blakemore *et al.* (1987). Comparisons are presented in Table 1.

Species and Planting Stock

Within each of the ripping treatments in each covering treatment, two replicates, each of 17 species-planting stock combinations (Table 2), were planted in early September 1992. Within replicates, species-planting stock combinations were planted in rows containing either 12 or 13 individual plants spaced at 1-m intervals. Rows were spaced 1 m apart.

With the exception of kahikatea (*Dacrycarpus dacrydioides* (A.Rich.) de Laub.) and totara (*Podocarpus totara* D.Don), plants for the trial were raised from seed collected from the Maimai Ecological District (North Westland Ecological Region—McEwen 1987) in autumn 1990. Plants of the two podocarp species were 4-year-old seedlings obtained from a nursery and were not of Westland origin. Seed of the other species was germinated in seed trays in October 1990 and subsequently transplanted into "root trainers" and grown on prior to transplanting into polythene bag containers (container stock), or into field nursery beds (bare-root stock) producing 2-year-old seedlings. Not all species were grown as both container and bare-root stock (Table 2). Because of the different nursery growing conditions, different stock types of the same species differed in size at the time of planting (Table 2).

TABLE 1–Chemical characteristics of *in situ* Ahaura soil, and of the three covering treatments.

Soil	Horizon	Depth (cm)	pH (H_2O)	Carbon (%)	Nitrogen (%)	CEC (me/100 g)	Exchangeable cations (me/100 g)				Olsen-P (µg/g)	Bray-P (µg/g)	SO_4-S (µg/g)
							Ca	Mg	K	Na			
In situ Ahaura	O	12–0	4.1	27.7	0.71	43.2	6.59	1.84	1.13	0.23	12	12	12
	Ah	0–22	4.5	6.5	0.23	18.4	0.15	0.17	0.08	0.03	0	3	2
	Bs	22–50	5.2	2.4	0.06	11.6	0.02	0.01	0.02	0.02	0	4	46
	BC	50–70	5.3	0.63	0.02	4.6	0.00	0.00	0.01	0.01	1	46	23
Overburden gravel	C	0–60	5.6	0.19	0.01	3.1	0.08	0.04	0.06	0.01	11	166	10
Mixed soil	O+Ah+Bs+BC	0–50	5.0	2.8	0.09	10.5	0.18	0.09	0.08	0.04	1	14	42
Layered soil													
topsoil	O+Ah	0–30	4.3	12.1	0.36	28.6	2.71	1.56	0.54	0.13	3	5	8
subsoil	Bs+BC	30–60	5.1	3.2	0.09	11.3	0.09	0.08	0.07	0.00	0	5	53

TABLE 2–Species planted, and heights (cm) of bare-root and container-grown stock at planting. Values in parentheses are standard errors.

			Bare-root	Container
Trees	*Carpodetus serratus*	Marbleleaf	–	20 (0.6)
	Dacrycarpus dacrydioides	Kahikatea	72 (1.9)	98 (2.1)
	Nothofagus fusca	Red beech	39 (1.6)	43 (1.4)
	Nothofagus solandri var. *cliffortioides*	Mountain beech	43 (0.8)	30 (0.8)
	Podocarpus totara	Totara	67 (1.5)	–
Shrubs	*Aristotelia serrata*	Wineberry	–	38 (1.5)
	Coprosma robusta	Karamu	38 (1.3)	25 (1.4)
	Coriaria arborea	Tree tutu	16 (2.0)	23 (1.1)
	Fuchsia excorticata	Fuchsia	–	30 (0.5)
	Hebe salicifolia	Koromiko	31 (0.9)	33 (1.2)
	Leptospermum scoparium	Manuka	–	45 (2.2)

Seven of the species used were recommended by Norton (1991) as potential species for restoration of alluvial or glacial outwash surfaces disturbed by mining. Three additional species, namely koromiko (*Hebe salicifolia* (Forst.f.) Pennell), fuchsia (*Fuchsia excorticata* (Forst.f.) L.f.), and kahikatea, were included because of their occurrence as either seral or tall forest species on alluvial terraces in the immediate vicinity of the trial site. One additional species (totara) was included because of its widespread occurrence on young alluvial terraces in the region prior to its removal by logging. Beeches were included because they were a dominant component of the stripped forest, even though survival of nursery-raised stock has often been poor (Wardle 1984).

All plants were sprayed with "Treepel" (egg powder mixed with acrylic resin sticker) animal repellent at planting and again at 3 months after planting. Some hand-weeding of white clover (*Trifolium repens* L.) which developed around the base of container-grown stock was also undertaken. Apart from hand-weeding of occasional gorse (*Ulex europaeus* L.) and broom (*Cytisus scoparius* L.) plants, no other weed control was carried out.

The height of all plants was measured at planting, and survival and height were measured in spring and autumn for the first 2 years, and thereafter in autumn. Current-season foliage of species with good survival on all three covering treatments was collected in April 1994 for determination of nutrient concentrations. Collections for three species (koromiko, karamu (*Coprosma robusta* Raoul), kahikatea) were made from both types of planting stock, while collections for a further four species (manuka (*Leptospermum scoparium* J.R. et G.Forst.), wineberry, marbleleaf (*Carpodetus serratus* J.R. et G.Forst), totara) were from plants from one stock type only. Foliar nutrient concentrations were determined at the Invermay AgResearch laboratory.

Both beech species included in the trial suffered severe mortality in mixed and layered soil. Six mountain beech and two red beech plants ranging from relatively healthy to recently dead, were excavated from the layered soil treatment in July 1994 and examined for the presence of pathogens.

Natural Regeneration

Twenty 0.25-m^2 rectangular plots were established along four transects located midway between randomly selected planted rows in the ripped half of each covering treatment, to examine the effect of covering treatment on natural regeneration of native and exotic species. Plots were located at 2-m intervals along the transects, unless rocks or woody debris prevented insertion of the metal pegs used to locate the plot corners; in such instances plots were sited at the nearest point along the transect where pegs could be inserted. Ground cover and the plant species present in each plot were recorded annually in summer or autumn, and the frequency of occurrence of each species was calculated.

RESULTS

Survival and Growth of Nursery-grown Plants in Different Covering Materials

Plant survival

After 4.5 years, mean plant survival of both container-grown and bare-root stock in overburden gravel exceeded that in mixed soil, while survival in layered soil was intermediate (Fig. 1). The better overall survival in overburden gravel was due largely to high mortality of the beeches in both soil covering treatments, while they survived relatively well in overburden gravel (Fig. 2a). In contrast, some species (kahikatea, totara, koromiko, marbleleaf, karamu, manuka) survived well in all three covering materials, while others (tree tutu (*Coriaria arborea* Lindsay), fuchsia) survived poorly (Fig. 2a,b). In one species (wineberry) survival after 4.5 years was higher in layered soil than in overburden gravel or mixed soil. Most mortality in the beeches, tree tutu, and fuchsia occurred during the first 2 years (Fig. 2a, b), and in the beeches and fuchsia most mortality in soil occurred over the summer periods, indicating that the mortality in these species may have been associated with moisture stress. While overall survival was high in overburden gravel, there was some indication of increasing mortality in some species (marbleleaf, karamu) in that material in the fifth year of the trial (Fig. 2a, b).

Plant growth

Plant growth in the different covering materials was compared using species which survived well in all three substrates. Karamu was omitted from the comparison as, although it had high survival (Fig. 2b), it was frequently and heavily browsed by hares.

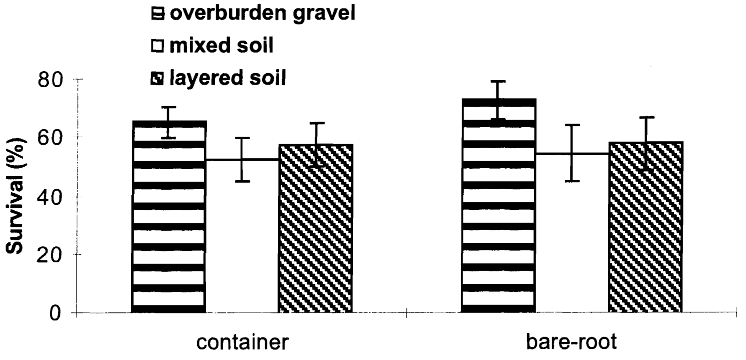

FIG. 1—Survival of container-grown and bare-root plants in three covering treatments, 4.5 years after planting. Values are means of ripped and unripped plots and of 10 and 7 species for container and bare-root plants respectively. Bars show ± 1 se.

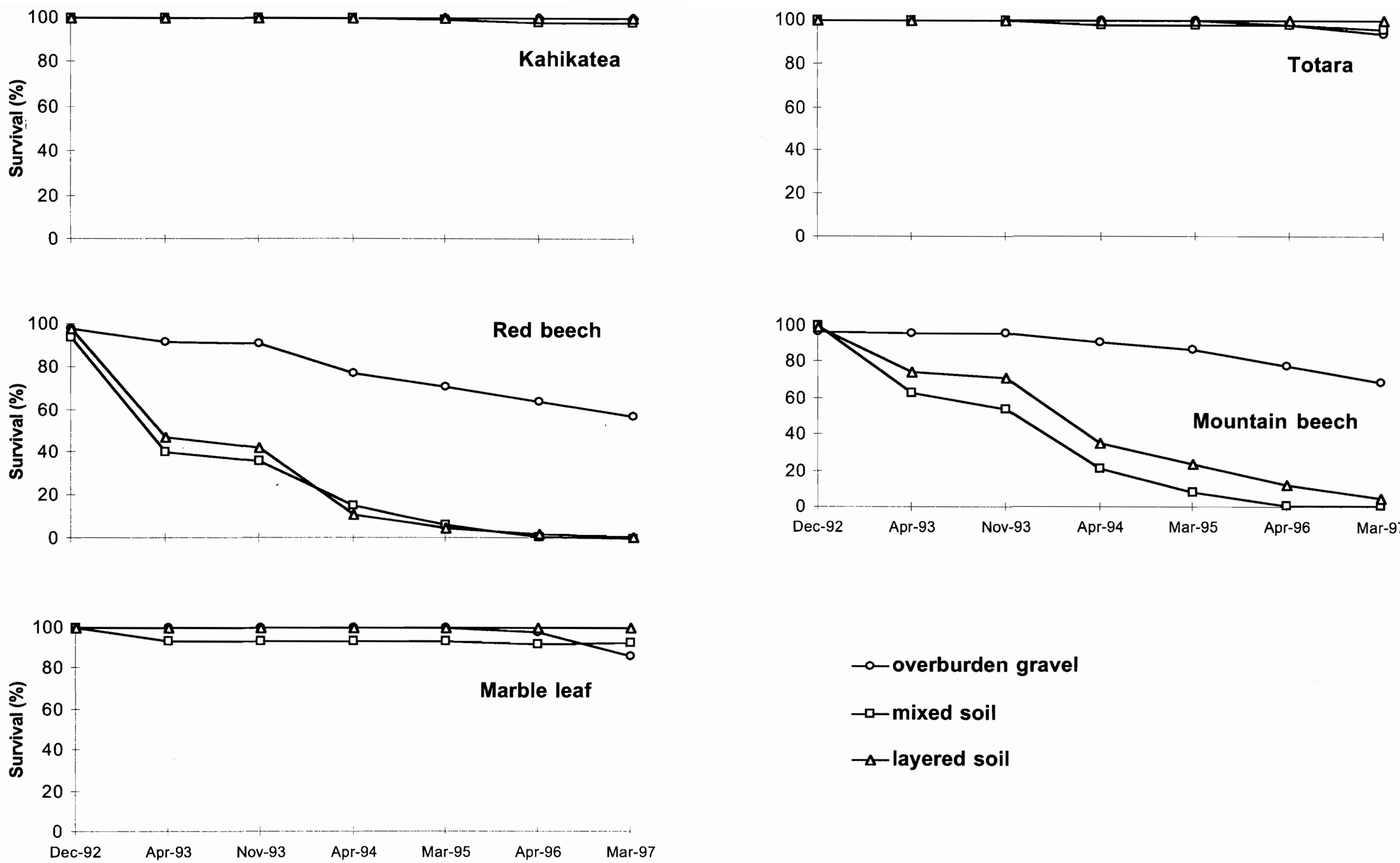

FIG. 2a–Survival of tree species in three covering materials after 4.5 years. Values are means of bare-root and container-grown stock, and of ripped and unripped plots.

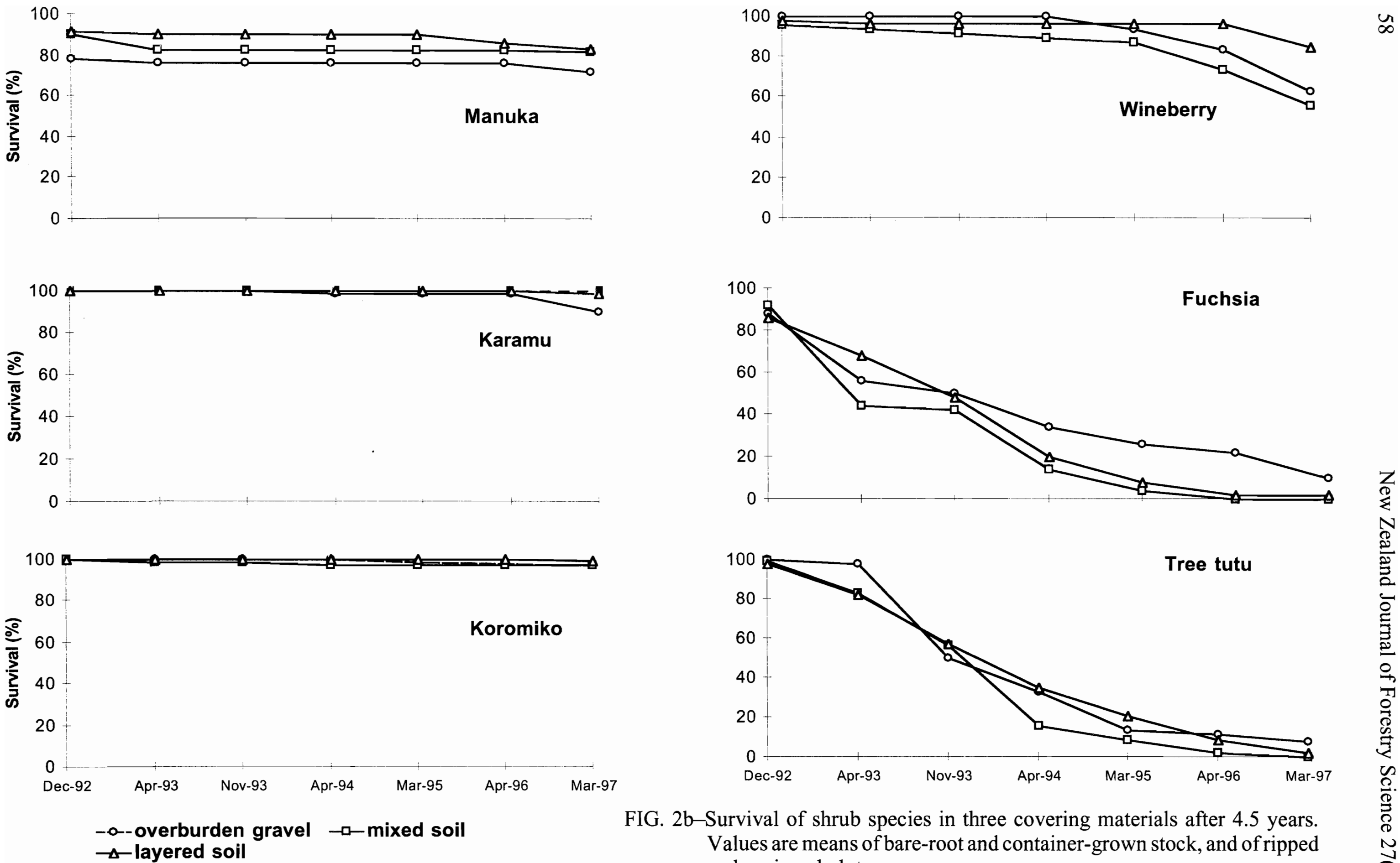

FIG. 2b–Survival of shrub species in three covering materials after 4.5 years. Values are means of bare-root and container-grown stock, and of ripped and unripped plots.

Mean plant height of both container-grown and bare-root stock in layered soil exceeded that in mixed soil, which in turn exceeded that in overburden gravel (Fig. 3). The difference between layered and mixed soil was apparent in all species and stock type combinations, and for the tree species increased with time (Fig. 4). In contrast to bare-root stock, the height of container-grown kahikatea and koromiko in mixed soil did not exceed that of plants in overburden gravel (Fig. 4). Mean height growth over the duration of the trial was 10 cm in overburden gravel, 49 cm in mixed soil and 96 cm in layered soil. A few container-grown plants of the nitrogen-fixer tree tutu survived and appeared healthy in overburden gravel, but did not exceed a height of 60 cm as summer growth was cut back over the winter period (data not shown).

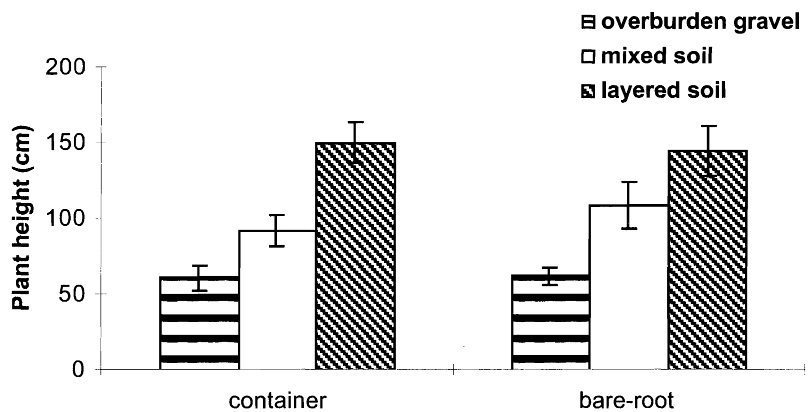

FIG. 3–Height of container-grown and bare-root plants with more than 50% survival in all covering treatments, 4.5 years after planting. Karamu is omitted because of browsing. Values are means of five and three species for container and bare-root plants respectively. Bars show ± 1 se.

Foliar Nutrient Concentrations of Nursery-grown Plants in Different Covering Materials

Mean foliar nutrient concentrations of nitrogen, sulphur, potassium, and copper in both mixed and layered soil exceeded those in overburden gravel (Fig. 5). In contrast, mean concentrations of phosphorus, calcium, and manganese, and also of aluminium, which is potentially toxic, were lower in plants growing in soil than in overburden gravel. Only the mean concentration of nitrogen in layered soil substantially exceeded that in mixed soil, while the converse was true for iron. Mean concentrations of phosphorus, sulphur, potassium, calcium, magnesium, boron, zinc, copper, manganese, and aluminium were generally similar in the two soil treatments.

Effect of Ripping on Nursery-grown Plants

Ripping of the underlying overburden material to a depth of 0.8 m had no influence on mean plant survival or height of container-grown or bare-root stock in any of the three covering materials, and had no effect on foliar nutrient concentrations.

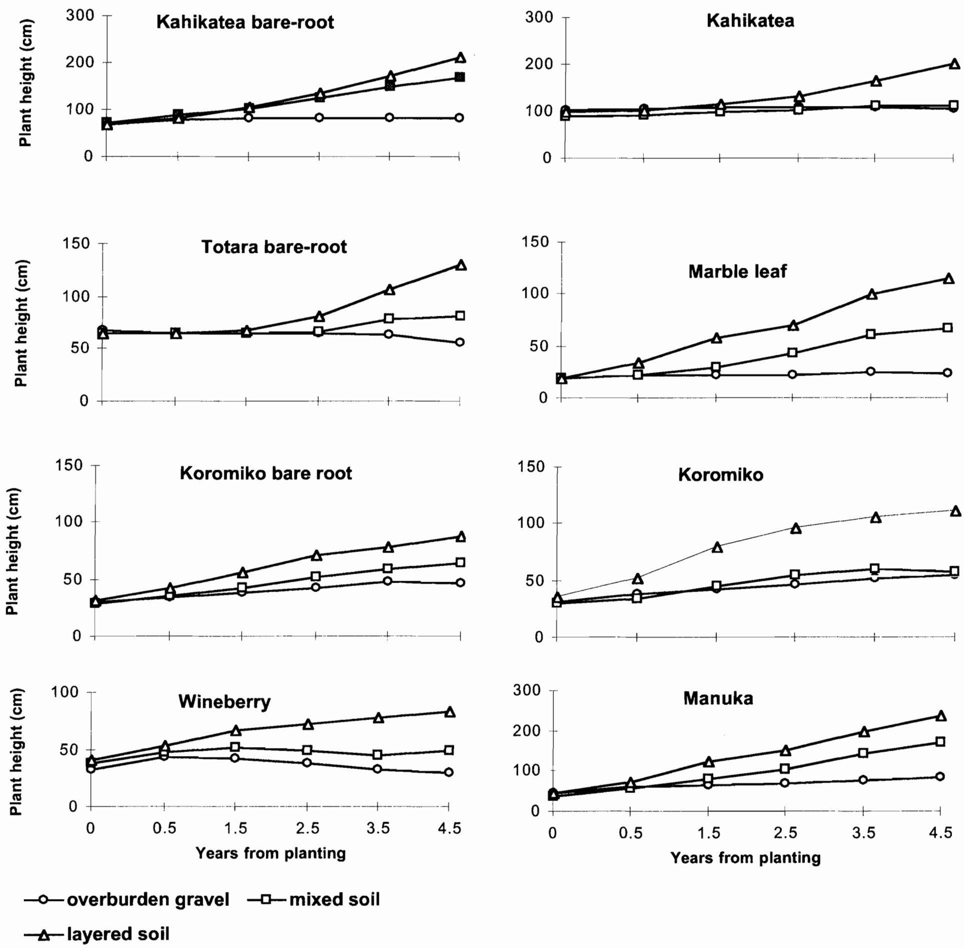

FIG. 4–Height growth at 4.5 years of six species with more than 50% survival in three covering materials. Values are for container-grown stock unless shown otherwise, and are means of ripped and unripped plots.

Development of Natural Regeneration in Different Covering Materials

Little vegetative cover had developed on any of the substrates by the end of the first year after plot construction (Fig. 6). Cover developed more rapidly over the following 3 years in layered than in mixed soil, but in the fifth year declined markedly in layered and increased in mixed soil, so that the two treatments had similar amounts of cover (*c.* 38–40%) 5 years after plot construction. Plant invasion in overburden gravel was negligible, with ground cover remaining at less than 1% after 5 years.

The adventive flatweed species, *Hypochoeris radicata* L., occurred at highest frequency in both mixed and layered soil in the fifth year of the trial (Table 3). In mixed soil, however, tall-growing adventive rushes (*Juncus* sp.) were physiognomically dominant (Fig. 7a). The

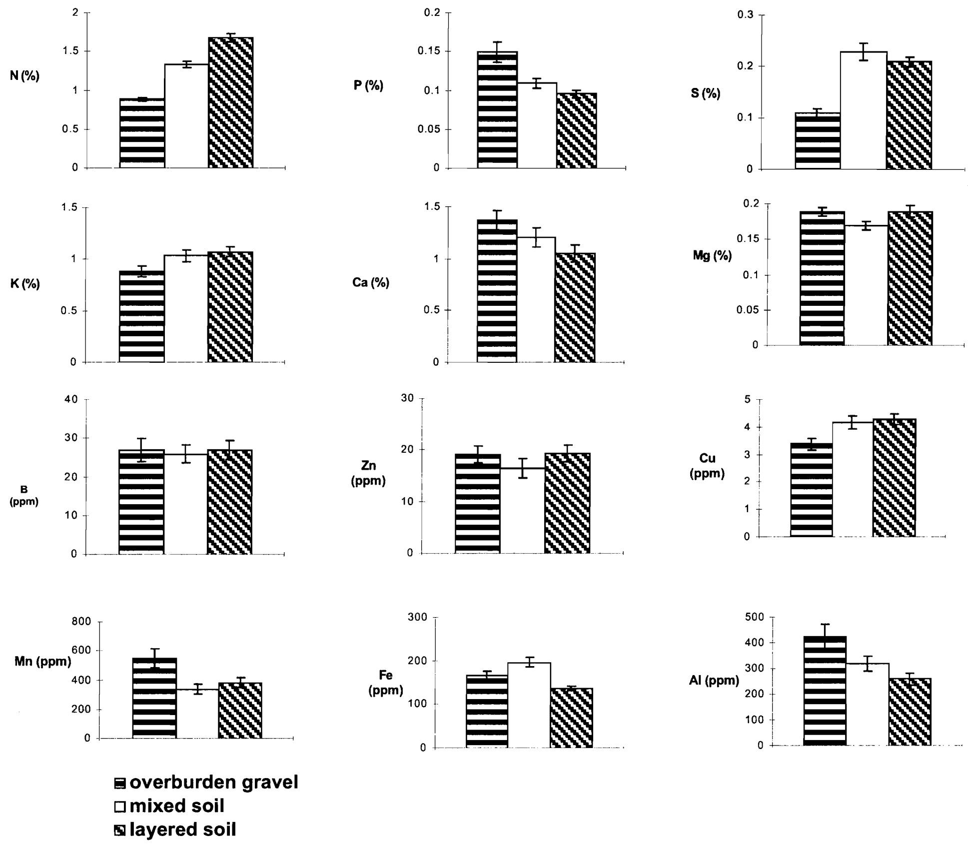

FIG. 5–Mean foliar nutrient concentrations in three covering materials. Values are for current-season foliage and are means of ripped and unripped plots, and of 10 species × planting stock combinations. Bars show ± 1 se.

trailing native herb *Nertera depressa* Banks & Sol.ex Gaertn. occurred at high frequency in both mixed and layered soil, and provided much of the ground cover in the latter treatment. Thus the invading vegetation in layered soil was of lower stature than in mixed soil; in mixed soil 75% of plots had vegetation (mainly rush species) exceeding 50 cm in height, whereas only 15% of plots in layered soil had vegetation over 50 cm. The total number of adventive and exotic species invading the plots was similar in the two treatments (Table 3).

Excluding seedlings arising from planted stock, only two seedlings of indigenous woody species (*Gaultheria antipoda* Forst.f. and a small-leafed *Coprosma* species) were present in the regeneration plots after 5 years, and both were present in layered soil only (Table 3). However, a number of mountain toatoa seedlings established in layered soil outside of the regeneration plots. No beech or podocarp seedlings other than mountain toatoa were present in the regeneration plots, or have been noted in the wider plot area. A few small silver beech plants, however, survived the soil stripping and replacement process, in layered soil only, and established well. Seedlings of the adventive woody shrub, Himalayan honeysuckle (*Leycesteria formosa* Wall.) established in regeneration plots in both layered and mixed soil (Table 3).

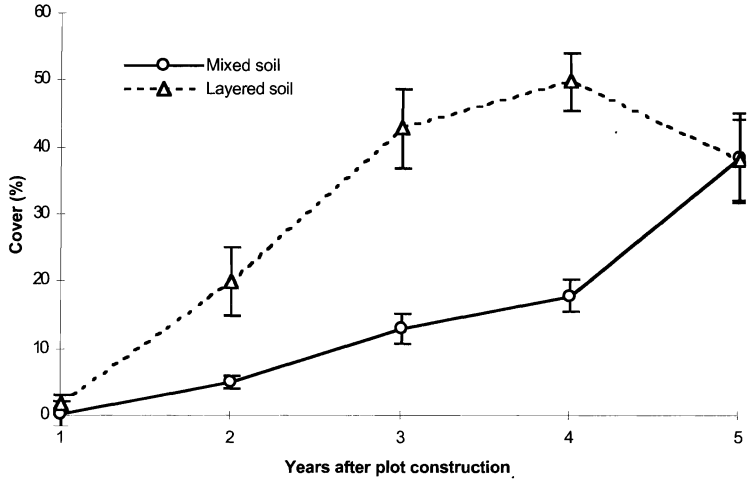

FIG. 6—Development of ground cover from natural regeneration in mixed and layered soil. Values are means of ripped plots only, n = 20. Ground cover in overburden (not shown) did not exceed 1%. Bars show ± 1 se

By the end of the third growing season substantial numbers of koromiko and manuka seedlings were present around the base of planted stock in both layered and mixed soil, but not in overburden gravel material. The most vigorous seedlings in mixed soil were present in potting soil in planting sites of container-grown plants. No seedlings of other planted species were noted.

DISCUSSION

Effect of Soil Covering and Ripping on Nursery-raised Plants

The unsorted overburden gravel contained a high proportion of coarse material which allowed good drainage. Ripping of underlying overburden gravel had no significant impact on the survival, growth, or nutrition of either bare-root or container-grown plants. Ripping had only a small effect on water potential in overburden gravel, and no effect on oxygen diffusion rate (R.J.Jackson unpubl. data).

Apart from the beech species, survival of planted stock was generally similar in the three covering materials. Growth of surviving plants, however, was poorest in overburden gravel, probably because of nitrogen deficiency. Mean foliar nitrogen and sulphur concentrations were substantially lower in plants growing in overburden gravel than in those in both layered and mixed soil, while potassium and copper concentrations were marginally lower. A glasshouse fertiliser trial with red beech and karamu, however, showed that phosphorus was the only macro-nutrient other than nitrogen likely to be deficient in overburden gravel (Davis & Langer 1997). The available phosphorus levels in overburden gravel (Table 1), and foliar phosphorus concentrations of plants growing in that material, indicated that phosphorus deficiency was unlikely to have limited growth there. No fertiliser trial or foliar diagnostic information was available to determine whether copper deficiency may have limited plant growth in overburden gravel. Foliar concentrations of the potentially toxic element, aluminium, in plants from overburden gravel exceeded those in both soils, but again it was

TABLE 3–Species frequency (%) on natural regeneration plots, 5 years after plot construction (n = 20)

	Overburden	Mixed soil	Layered soil
Native species			
Blechnum fluviatile *			5
Carex dissita			20
Carex geminata		10	15
Carex secta		5	
Carex testacea		5	
Centella uniflora			15
Coprosma robusta †		5	
Coprosma sp.			5
Epilobium sp.		5	
Gahnia rigida		15	
Gaultheria antipoda			5
Gnaphalium ensifer		5	
Hebe salicifolia *†		5	15
Helichrysum bellidioides		5	
Histiopteris incisa *			20
Leptospermum scoparium *†		25	20
Nertera depressa *		65	80
Oreobolus impar			5
Paesia scaberula *			30
Pseudo gnaphalium luteo-album		5	
Raoulia tenuicaulis	10		
Rytidosperma sp.		10	10
Thelymitra venosa		10	5
Adventive species			
Anthoxanthum odoratum			15
Crepis capillaris			10
Digitalis purpurea *			5
Hieracium pilosella		5	
*Holcus lanatus**		30	55
Hypochoeris radicata *	15	100	95
Juncus canadensis		90	5
Juncus effusus		35	
Juncus sp.		5	
Lycesteria formosa *		10	20
Lotus pedunculatus	5		30
Senecio jacobaea *		30	15
Senecio sylvaticus		5	
Trifolium repens	10		

* Recorded as present in forest immediately adjoining the mine site
† Seedlings from planted stock

not possible to determine whether aluminium toxicity limited growth in overburden gravel. Tree tutu was the only nitrogen-fixing species included in the trial, and the few plants of this species which survived the establishment phase were the only plants of any species that appeared vigorous in overburden gravel, further suggesting that nitrogen deficiency was the primary factor limiting growth in that substrate.

Despite the location of the trial site in a high rainfall zone, short periods of drought may occur near the surface of the free-draining overburden material during summer, which could reduce growth over an initial growing season before plant roots extended to deeper layers (Jackson unpubl. data). Water balance data showed, however, that dry periods were restricted during the first growing season of the present trial (Jackson unpubl. data), and were unlikely to have contributed to the poorer growth in overburden gravel.

Growth of both bare-root and container-grown plants was consistently better in layered than in mixed soil. Poor drainage is likely to have contributed to the inferior growth in mixed soil; the forest subsoil material had little structure, and even when it was mixed with topsoil and organic material from the forest floor, drainage remained restricted. Tensiometer and oxygen diffusion measurements showed that the mixed soil treatment remained saturated with water and deficient in oxygen for long periods after rainfall events, in contrast to the layered soil treatment (Jackson unpubl. data). The dominant rush cover which developed reflects the poor drainage in mixed soil (compare Fig. 7a and 7b).

Improved nitrogen nutrition was also likely to have contributed to the better growth in layered soil. Nitrogen was the only nutrient for which foliar concentrations were significantly greater in layered than in mixed soil. Two species (marbleleaf and kahikatea) responded to nitrogen at planting in an adjoining field fertiliser trial in mixed soil, and one of these (kahikatea) responded to additional nitrogen applied at the beginning of the third growing season (unpubl. data). Neither species responded to superphosphate, indicating that neither phosphorus nor sulphur deficiency limited plant growth in mixed soil. Since the foliar concentrations of the other nutrients and of aluminium were generally similar in the two soil-covering treatments, improved nitrogen availability appears to be the main nutritional benefit of replacing soil as layered rather than as mixed horizons.

Widdowson & McQueen (1990) compared the effect of loessial soil replacement treatments on pasture growth after simulated coal mining in Southland. Over a 5-year monitoring period, pasture production where soil was replaced in layered horizons amounted to 95% of that in an undisturbed control. Mixing topsoil and subsoil resulted in a 24% reduction in pasture growth. The differences in pasture productivity were most evident in the first year and declined with time. Deep ripping and nitrogen fertiliser compensated for the adverse effects of soil mixing, the effect of nitrogen being consistent with the present study. In the southern North Island, after aggregate mining, Simcock (1993) reported that pasture establishment on a poorly drained silt loam soil was better where horizons were stripped and replaced separately than where horizons were mixed, but the same advantage was not evident in free or excessively drained soils. Further, there was no long-term advantage in stripping and replacing horizons separately for any of the three soils examined. In the present study, mean cumulative height growth in layered soil was nearly double that in mixed soil after 5 years, and the difference between mixed and layered soil increased as the trial progressed, especially in the tree species. The greater benefit obtained from replacement of soil in layered horizons at Giles Creek than in the Southland and southern North Island trials may be due largely to the substantially greater precipitation at Giles Creek (2900 mm compared with *c.* 1000 mm).

The present results raise the question as to whether subsoil horizons need to be salvaged and replaced in high rainfall environments. In lower rainfall zones the water storage capacity of subsoils is likely to be important for plant survival and growth. Studies with crop species in North America have demonstrated the value of subsoil replacement in low- and medium-

(a)

(b)

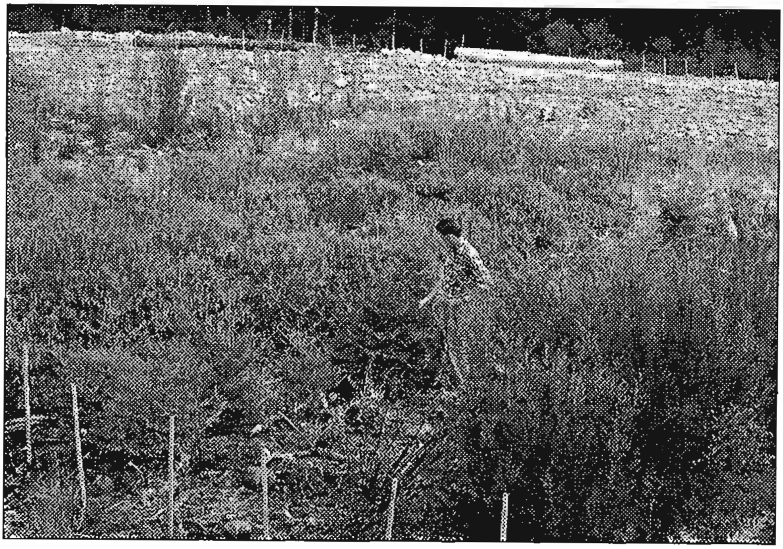

FIG. 7–Mixed (a) and layered (b) soil plots at Giles Creek. Photos taken in September 1997, 5 years after planting of native species. Note the dominance of rush species in mixed soil. Prominent species in layered soil include manuka, marbleleaf, and koromiko.

rainfall environments (Fehrenbacher *et al.* 1982; Halvorson *et al.* 1986), but there have been no studies conducted where precipitation approaches that at Giles Creek.

Survival of nursery-raised beech seedlings in other studies has often been poor, the causes of failure being attributed to smothering by grass, browsing by rabbits and hares, drought during the first summer, and unseasonal frosts (Wardle 1984, p.280). In the present study smothering (or competition from other species) and browsing were not factors, and the high survival of both species in overburden gravel indicated that frosting also could be discounted.

Most mortality occurred over the summer months, suggesting that the poor survival was likely to be due to moisture stress. Since moisture stress would be expected to be greater in the freer-draining overburden gravel, the summer mortality in the replaced soils suggested a problem with water uptake, rather than with water availability, possibly caused by root-rot pathogens in those substrates. Three species of root-rot fungi, *Phytophthora cinnamomi, Pythium acanthium,* and *Pythium ultimum*, were isolated from the roots of the plants excavated from layered-horizon soil and examined for pathogens in July 1994. All plants were infected by one or the other of the three species, predominantly *Ph. cinnamomi*, and one plant was infected by both species of *Pythium*. *Phytophthora cinnamomi* has killed 2-year-old beech seedlings under high moisture conditions (Rawlings 1962).

Mountain beech plants surplus to the trial were planted on a mudstone surface (arising from beneath gravel overburden) near the trial site at Giles Creek, and these showed good (83%) survival after 3 years, and appear vigorous. In common with the overburden gravel, the mudstone contains no forest soil, suggesting that the presence of forest soil may have contributed to the high mortality of the beech species in both the mixed and layered soil treatments. The soil may provide a source of root-rot fungi, and/or a suitable environment for their survival, growth, and infection of beech plants. The failure of the beeches in soil is consistent with better natural establishment of beeches on raised surfaces such as rotting logs, stumps, and root mounds (Wardle 1984; Allen 1987). Logs and stumps are clearly soil-free environments, while root mounds, which are caused by windthrow, are characterised by exposure of subsoil, which may provide a less favourable environment for root-rot fungi than organic and topsoil material.

Effect of Soil Covering on Natural Regeneration

Natural regeneration in overburden gravel was negligible. By the end of the second growing season after planting the soil plots had assumed a markedly different appearance, with adventive rush species dominating physiognomically in mixed soil, and the mat-forming native herb *Nertera depressa* dominating in layered soil. Although other species established over the following years, tall-statured rushes continued to dominate in mixed soil, while shorter vegetation dominated in layered soil. Ground cover developed more rapidly in layered than in mixed soil, but cover never exceeded 50%, and in the final assessment year declined to be similar to that in mixed soil. The decline in cover may be associated with reduced summer rainfall over the 1996–97 summer; rainfall for the December to March period in the neighbouring Maimai catchment was 72% of normal for the years 1990–97 (J.Payne, pers. comm.). The relatively slow rate of cover development in both soil treatments indicates that there may be a substantial period of time after soil spreading, in the largely gorse-free environment at Giles Creek, when native forest species may be introduced, either by planting or seeding.

Apart from seedlings arising from planted stock, 11 (48%) of the species recorded in the regeneration plots in layered soil at the final assessment, and seven (30%) of those in mixed soil, were recorded in an inventory of forest immediately adjoining the mine site, but only four and one of these respectively were native species. These results suggest that soil replacement has only a limited capacity to introduce native species from the original forest; however, the timing of the earthmoving operations in the present study (February) in relation to seedfall needs to be considered. Most seed of beech species, for example, is shed between the months of March and May (Wardle 1984, p.259), while most seed germinates in spring in the first year after seedfall, with little seed remaining viable after 18 months (Wardle 1984, p.265). The best time for carrying out soil stripping and replacement operations to obtain optimum numbers of viable seed, therefore, may be between June and September, after most seedfall has occurred, and prior to the period of peak germination, though this may only be useful after a good seed year. This may also apply to other woody forest species as seedlings of only one species, mountain toatoa, established in significant numbers in layered soil. Plants of this species may have arisen from seed spread by birds after the plots were constructed, as seedlings have been noted away from the trial site on disturbed areas adjoining forest.

CONCLUSIONS

Soil replacement over gravel overburden material after mining of alluvial terrace land in Westland may provide little benefit to plant survival, at least in the short term, but will greatly improve growth of planted native tree and shrub species. Growth of species in layered soil is substantially better than in mixed soil because of better drainage and improved nitrogen nutrition. Salvage and replacement of O and A horizon material on the surface of rehabilitation sites appears to be of much greater benefit for native tree and shrub species in the high rainfall Westland environment than has been demonstrated for pasture species in lower rainfall zones in New Zealand. Ripping of underlying gravels provided no benefit. Soil replacement appears to have only a limited capacity to introduce native species from the original forest, but studies are required to determine the optimum timing of earthmoving operations in relation to natural seedfall.

Poor survival of nursery-raised beech species in forest soil has some parallels to establishment of the species under natural conditions, and appears to be due to the presence of root-rot pathogens. Further studies are required to determine appropriate methods for raising beech species in nurseries for establishment in situations where forest soil is replaced.

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