TWO SEEDLING ROOTING MEDIA AND SUBSEQUENT GROWTH OF NITROGEN-FIXING PLANTS IN A NEW ZEALAND COASTAL SAND-DUNE ENVIRONMENT

RUTH L. GADGIL

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

ADRIANA M. SANDBERG

8 Waikuta Rd, Ngongotaha, New Zealand

and ALISON.T. LOWE

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Revision received for publication 9 June 1999)

ABSTRACT

Continuous vegetation cover preventing erosion of coastal sand dunes is essential for the protection and development of productive forestry, farming, and other activities in their vicinity. Use of symbiotic nitrogen fixation to enhance the nutritional status (and thus the vigour) of sand dune vegetation currently depends on the introduction of nursery-raised plants. Local sand and a standard nursery potting compost were seen as possible alternatives for seedling rooting media, but their relative effects on plant performance after transfer to exposed dune sites were unknown. Three nitrogen-fixing species representing a range of tolerance to dune conditions in the north of the North Island (*Acacia sophorae* (Labill.) C. Martius, *Chamaecytisus palmensis* (Christ) Bisby et K.Nicholls, and *Lotus uliginosus* Schk.) were used as the basis for comparison. A slight overall plant size advantage was associated with potting compost during the first year after transplanting, but this was not maintained during the second and third years. Long-term plant survival was not influenced by seedling rooting medium, although mortality of *C. palmensis* (the least tolerant species) was twice as great in compost-raised plants as in sand-raised plants during the first 6 months. There was no evidence of any consistent effect of seedling rooting medium on relative nitrogenase activity. It was concluded that choice of medium for raising seedlings in the nursery is likely to have only a minor and transitory effect on the performance of nitrogen-fixing plants in sand-dune revegetation projects and species-screening trials.

Keywords: coastal sand; nitrogen fixation; revegetation; seedling production; rooting media.

INTRODUCTION

Severe encroachment of coastal sand on to productive land was a major economic problem in New Zealand for more than a century after European settlement. By the early 1980s, steps taken by the Government and other agencies to stabilise drifting sand were considered to have been successful and had led to the reclamation of large areas for productive forestry and sheltered farmland (Gadgil & Ede 1998). Coastal sand has a low organic matter content and growth of colonising plants is known to be limited by nitrogen deficiency.

Yellow tree lupin (*Lupinus arboreus* Sims) was once widely used in the managed vegetation succession to supply biologically-fixed nitrogen to the developing ecosystem (Restall 1964; Wendelken 1974). However, the advent of a fungus disease, lupin blight or anthracnose (*Colletotrichum gloeosporioides* (Penzig) Penzig & Saccardo), in the late 1980s reduced lupin populations by up to 95% (Dick 1994) and is likely to have depleted nitrogen inputs by up to 150 kg/ha annually (Gadgil 1971). In the absence of practical control measures for lupin blight, which continues to suppress young plants developing from buried seed, the use of alternative nitrogen-fixing species is under investigation (Douglas *et al.* 1994; Ede *et al.* 1997).

In sand dune areas, which are most extensive in the North Island, a coastal strip averaging about 400 m in width continues to be vulnerable to wind erosion if the vegetation cover is not maintained. Within this strip plant growth and vigour are particularly sensitive to the loss of the lupin component, to animal browsing (especially rabbits and grazing stock), and to increased recreational pressure associated with coastal property development. Failure to maintain an adequate vegetation cover can lead to progressive erosion and the inundation of productive inland areas with sand drifts.

As a means of improving the nitrogen status of the dune ecosystem, the introduction of nitrogen-fixing plants is considered to be less expensive and more efficient than the application of fertiliser (Gadgil *et al.* 1981). For this reason a series of spaced-plant screening trials is being used to identify possible replacements for *L. arboreus*. Six trials established by different agencies on the west coast of the North Island have identified nitrogen-fixing plants that are able to survive and grow in the dune environment (Gadgil *et al.* 1999). These trials were established in different ways and consideration of the results raised important issues about the preparation of seedlings before transplanting on to the dunes. Particular discussion centred on the relative merits of local sand or a standard nursery potting compost as the medium for seedling root growth.

One school of thought suggested that costs associated with raising seedlings in local sand would be lower, plants would be hardier and therefore more likely to survive in the field, and root extension would be less likely to be inhibited when contact with field sand was eventually made. Arguments in favour of potting compost were based on the hypothesis that more vigorous seedlings would be produced and that these would be better able to withstand the harsh coastal environment. Plants would have a reserve of organic matter, nutrients, and moisture around the roots during the first months of growth on the dunes.

It was decided that the effects of the two media on growth of three nitrogen-fixing species of different habit should be compared over a number of years after transfer to the sand dune environment.

MATERIALS AND METHODS

Trial Site

The trial was located at Ninety Mile Beach (near to the northern tip of the North Island; 173°08′E, 34°59′S) in an area just behind the foredune which was colonised by spinifex (*Spinifex sericeus* R.Br.) and planted marram grass (*Ammophila arenaria* (L.) Link). Long-term average data from the nearest meteorological station indicated that mean annual rainfall was approximately 1187 mm and that mean air temperature was approximately 19.6°C in January (summer) and 12.4°C in July (Douglas *et al.* 1994). Sand pH was 6.2–7.3. The trial was fenced to exclude the rabbits, hares, and wild horses known to browse vegetation in the area.

Species

The nitrogen-fixing species selected for this trial, all able to survive and grow on New Zealand sand dunes (Ede *et al.* 1997), were the woody shrub *Acacia sophorae*, the small tree *Chamaecytisus palmensis*, and the low-growing herbaceous plant *Lotus uliginosus*. Seed sources are detailed in Table 1.

TABLE 1–Seed and *Rhizobium* spp. sources

Species	Common name	Seed source	*Rhizobium* spp. source
Acacia sophorae (Labill.) C. Martius	Coastal golden wattle	"Proseed New Zealand" ex stock.	Nodules of *A. longifolia* taken from NZFRI* nursery and macerated in a blender.
Chamaecytisus palmensis (Christ) Bisby *et* K. Nicholls	Tree lucerne; tagasaste	Margot Forde Forage Germplasm Centre Accession No.AL 3570	DSIR† Plant Protection Division Culture No.ICMP 6496
Lotus uliginosus Schk. (syn. *L. pedunculatus* Cav.) cv. "Grasslands Maku".	Maku lotus	Margot Forde Forage Germplasm Centre Accession No.ST 306	DSIR Plant Protection Division Culture No.ICMP 5942.

* New Zealand Forest Research Institute
† New Zealand Department of Scientific and Industrial Research. Plant Protection Division is now part of HortResearch.

Rooting Media

Sand was collected from a site just behind the foredune at Ninety Mile Beach, air-dried, sieved (2 mm), and stored for 1 month. Potting compost was a mixture of peat and pumice (3 : 1) with magnesium ammonium phosphate (Magamp®) added at the rate of 1.5 kg/m^3.

Seedling Preparation

Seedlings were raised at the New Zealand Forest Research Institute nursery in Rotorua. On 15 December 1992, seed was sown at the rate of three per pot in plastic pots 6.5 × 6.5 × 9 cm high, containing either sand or potting compost. Pots were covered with bird-proof netting and placed in a large tunnel house with open sides. They were watered daily for 6 weeks and on alternate days for the following 3 months. Seedlings were thinned to one per pot after emergence.

A suspension of the appropriate *Rhizobium* spp. culture (Table 1) was added to each pot on 23 December 1992. Pots containing sand were treated with an inorganic nutrient solution (Phostrogen®, 0.5 g/litre) at weekly intervals for the first 6 weeks after seedling emergence. After 2 months' growth, plants in potting compost were watered with an organic nutrient solution (Response Black Label®; 2 ml/litre) at three 2-weekly intervals to emulate standard practice at the New Zealand Forest Research Institute nursery.

Immediately before transplanting, the height and maximum spread of individual plants were recorded in a 10% random sample taken from each species/rooting medium combination. Examination of root material indicated that all plants were nodulated at the time of transfer to the field.

Trial Design

The six treatments (three species × two rooting media) were replicated in four randomised complete blocks.

Experimental units (plots) were single-species rows of 15 plants spaced at 30-cm intervals. Plots were located approximately 1.0 m apart, between rows of marram grass.

Planting-out

Plants were 4.5 months old when transferred to the field. During transplanting the intact root ball, including sand or potting compost, was carefully removed from each pot and buried in the planting hole so that it was covered with a thin layer of the surrounding sand.

Assessments

In November (late spring) of each year from 1993 to 1995, plants in each plot were counted. Where the boundaries of individuals could not be identified, cover of the area originally allocated to a plant was assumed to indicate survival. Plants in each plot were scored for vigour on a scale of 1 (weak) to 5 (robust). Height and maximum lateral spread of each plant were measured. Above-ground herbage mass was estimated by selecting the plant with height and spread closest to the plot mean, harvesting live material within the volume defined by a vertical and lateral projection of the 30-cm row segment, and determining its oven-dry weight. Relative nitrogenase activity in the roots of harvested plants was determined using an acetylene reduction technique (Hardy *et al.* 1973). Working on the assumption that acetylene reduction activity in a core sample (108 mm in diameter × 58 mm deep) centred on the severed plant root collar would be proportional to nitrogenase activity, species were ranked to show relative (rather than absolute) values at each assessment, a value of 100% being accorded to the species/medium combination that exhibited maximum activity.

Statistical Analysis

Each set of field data was subjected to a separate analysis of variance based on the factorial arrangement of treatments. A square root transformation was used for height and spread values, and the $\log_e$ transformation for herbage mass. Mean values were compared with the aid of the Least Significant Difference test.

RESULTS

At the time of transplanting, *A. sophorae* plants raised in potting compost were on average 9 cm taller than those raised in sand. Maximum spread of *L. uliginosus* was on average 20 cm greater in potting compost. No other significant differences due to rooting medium were found in terms of plant height or spread ($p = 0.05$).

Six months after planting on the dunes, survival rates of *A. sophorae* and *L. uliginosus* exceeded 85% (Table 2). There was no evidence that the nature of the rooting medium had influenced establishment, although plant vigour of *A. sophorae* appeared to have been improved by sand and that of *L. uliginosus* by potting compost. Original differences in height of *A. sophorae* and spread of *L. uliginosus* had not been maintained in the field. Mortality in *C. palmensis* was severe and surviving plants in all plots were affected by shoot dieback. Only 18% of those raised in potting compost had survived. More than twice as many (41%) were present where sand had been used and these plants were on average 5 cm shorter. At this stage all plants showed evidence of active nitrogen fixation. Nitrogenase activity rates recorded for *A. sophorae* raised in potting compost were at least three times higher than those noted for other species/medium combinations.

After 18 months in the field, the survival rate of *A. sophorae* was still high. Mortality of *L. uliginosus* had occurred and only a few *C. palmensis* plants were present. There was no evidence that survival rates, plant spread, or herbage mass were related to the nature of the seedling rooting medium. Vigour of *L. uliginosus* was higher among sand-raised survivors. Plants of *C. palmensis* raised in potting compost were now about 25 cm taller than those grown in sand. Nitrogenase activity rates were highest in *A. sophorae*, this time among plants raised in sand.

In 1995, 2.5 years after planting-out, no statistically significant differences among measured variables could be attributed to species/rooting medium combination. Nitrogenase activity was now highest in *L. uliginosus* that had been raised in potting compost.

Data for all species combined (Table 3) indicated that small increases in plant height (2 cm) and in maximum plant spread (5 cm) at the 6-month assessment could be attributed to the use of potting compost rather than sand. No other effects were discerned.

DISCUSSION

Ninety Mile Beach represents one of the harshest coastal dune environments in New Zealand. In a series of screening trials with nitrogen-fixing species on the west coast of the North Island, Gadgil *et al.* (1999) noted poorer plant performance at Ninety Mile Beach than at sites further south, and attributed this to higher temperatures at the lower latitude. In the neighbouring Aupouri Forest, productivity levels of *Pinus radiata* D. Don are lower than in more southerly sand dune forests, and this is also thought to be related to the higher mean annual temperature (Hunter & Gibson 1984). The results confirmed that the species selected for this trial represented a range of tolerance to conditions at the Ninety Mile Beach site as well as a range of growth forms. Initial rooting media effects on field performance were unlikely to have been masked by provision of insufficiently rigorous trial conditions.

TABLE 2–Effect of initial rooting medium on species performance at the dune site

Species	Assessed	Years in field	Initial rooting medium	Survival (%)	Vigour (1=weak; 5=robust)	Plant height* (cm)	Maximum plant spread* (cm)	Above-ground dry matter* (g/30 cm of row)	Relative nitrogenase activity (%)
Acacia sophorae	1993	0.5	Sand	100 a†	4	18 a	17 a	2.1 a	25
			Potting compost	100 a	3	19 a	19 a	4.6 a	100
	1994	1.5	Sand	98 p	3	28 q	38 p	156.5 p	100
			Potting compost	98 p	3	28 q	44 p	27.9 pq	72
	1995	2.5	Sand	100 w	4	64 w	99 a	277.4 w	22
			Potting compost	100 w	4	59 w	96 a	255.7 w	38
Chamaecytisus palmensis	1993	0.5	Sand	41 b	2	21 b	14	2.1 p	16
			Potting compost	18 c	2	26 a	20	2.0 p	36
	1994	1.5	Sand	1 r	2	24 qr	23 p	ND	ND
			Potting compost	1 r	2	49 p	35 p	ND	ND
	1995	2.5	Sand	1 z	3	36 wx	61 b	ND	ND
			Potting compost	7 yz	4	46 x	52 b	ND	ND
Lotus uliginosus	1993	0.5	Sand	88 a	2	7 a	28 a	0.7 a	33
			Potting compost	98 a	3	9 a	28 a	3.5 a	25
	1994	1.5	Sand	57 q	4	12 r	19 p	2.4 q	61
			Potting compost	74 q	3	14 r	50 p	6.5 q	25
	1995	2.5	Sand	22 xy	4	14 w	23 c	1.3 x	63
			Potting compost	37 x	4	13 w	23 c	0.9 x	100

* Backtransformed means.
† Within columns, values for individual years followed by the same letter do not differ significantly (LSD test; p=0.05).
ND Not determined (poor survival).

TABLE 3–Effect of initial rooting medium on overall plant performance at the dune site

Year	Initial rooting medium	Survival (%)	Vigour (1=weak; 5=robust)	Plant height* (cm)	Maximum plant spread* (cm)	Above-ground dry matter* (g/30 cm of row)
1993	Sand	76 a†	3	15 b	18 b	1.6 a
	Potting compost	72 a	3	17 a	23 a	3.4 a
1994	Sand	52 a	3	20 a	30 a	94.9 a
	Potting compost	58 a	3	25 a	41 a	17.2 a
1995	Sand	41 a	4	41 a	64 a	185.3 a
	Potting compost	48 a	4	39 a	62 a	170.8 a

* Backtransformed means.
† For each year, values within columns followed by the same letter do not differ significantly (LSD test; $p = 0.05$)

The nature of the seedling rooting medium made no difference to overall survival rates and it must be concluded that other factors in the sand dune environment were more important in determining mortality levels. There was some evidence that vulnerability of *C. palmensis* to these factors was reduced during the first year by raising seedlings in sand, but this effect did not persist. Overall survival levels of *A. sophorae* were consistently high throughout the trial period. By contrast, *C. palmensis* survival after 6 months was only 41% and most plants died during the subsequent year. Intermediate tolerance to environmental factors was apparent in *L. uliginosus* which, in spite of a decline in plant numbers, showed an overall survival rate of 30% after 2.5 years.

Environmental factors other than seedling rooting medium seem to have influenced plant vigour in the field. The relatively high vigour scores recorded throughout for *A. sophorae* are also indicators of tolerance to sand dune conditions. This type of tolerance was less well-developed in the other two species, although moderate to high vigour scores were recorded for longer-term (2.5-year) survivors of *C. palmensis* and *L. uliginosus*.

Plants grown in potting compost were slightly taller and more laterally extensive after 6 months' field growth, but differences associated with rooting medium were not maintained during the subsequent year. There was no evidence that use of either sand or potting compost had any consistent effect on relative nitrogenase activity.

Introduction of species other than *Lupinus arboreus* by direct sowing of seed in the 400-m-wide dune strip nearest the sea has so far been unsuccessful in New Zealand. For the forseeable future, transplanting of nursery-raised stock is seen as the only reliable method for restoring a continuous vegetation cover by introduction of native or exotic sand-binding grasses and nitrogen-fixing species (Bergin & Herbert 1997; Ede *et al.* 1997).

The observed transitory nature of the effects of initial rooting medium on plant growth performance means that the planning of sand dune revegetation programmes or future trials does not need to be constrained by this aspect of nursery practice. The raising of plants in either conventional potting compost or local sand is not likely to confer any lasting advantage or disadvantage in terms of the establishment of vegetation on sand dunes. Nursery facilities dedicated to specific dune revegetation projects can be set up in sheltered areas near to the planting site (Barr & Atkinson 1970), and need not rely on importation of bulk compost. If commercial nurseries are involved in the production of plant material for sand dune reclamation, costs associated with transport of potted plants are likely to be a more important consideration than the nature of the rooting medium.

ACKNOWLEDGMENTS

This study was funded by the New Zealand Foundation for Research, Science and Technology. The assistance provided by Helena Beeser and Fiona Ede with field measurements and by Mark Kimberley with statistical analysis is gratefully acknowledged.

REFERENCES

BARR, D.A.; ATKINSON, W.J. 1970: Stabilization of coastal sands after mining. *Journal of the Soil Conservation Service of New South Wales 26*: 89–107.

BERGIN, D.O.; HERBERT, J.W. 1997: Revegetation of coastal sand dunes in New Zealand using indigenous species. Pp. 425–430 *in* Vol. 1 of Proceedings of the Combined Australasian Coastal Engineering and Ports Conference, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

DICK, M.A. 1994: Blight of *Lupinus arboreus* in New Zealand. *New Zealand Journal of Forestry Science 24*: 51–68.

DOUGLAS, G.B.; GADGIL, R.L.; SKINNER, M.F.; BULLOCH, B.T.; SANDBERG, A.M.; FOOTE, A.G.; LOWE, A.T. 1994: Nitrogen-fixing replacements for tree lupin (*Lupinus arboreus* Sims) on North Island coastal dunes. Pp. 216–222 *in* Allan, B. (Ed.) Proceedings of the 1994 New Zealand Conference on Sustainable Land Management, Lincoln University, Canterbury.

EDE, F.J.; GADGIL, R.L.; DOUGLAS, G.B.; LOWE, A.T.; SMITH, C.T. 1997: Stabilising sand dunes by revegetation: the role of nitrogen-fixing plants. Pp. 437–442 *in* Vol. 1 of Proceedings of the Combined Australasian Coastal Engineering and Ports Conference, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand.

GADGIL, R.L. 1971: The nutritional role of *Lupinus arboreus* in coastal sand dune forestry. III. Nitrogen distribution in the ecosystem before tree planting. *Plant and Soil 35*: 113–126.

GADGIL, R.L.; EDE, F.J. 1998: Application of scientific principles to sand dune stabilisation in New Zealand — past progress and future needs. *Land Degradation and Development 9*: 131–142.

GADGIL, R.L.; KNIGHT, P.J.; SANDBERG, A. M.; ALLEN, P.J. 1981: Molybdenum, sulphur, and boron deficiency in lupin (*Lupinus arboreus* Sims) at Pouto Forest. *New Zealand Journal of Forestry Science 11*: 114–127.

GADGIL, R.L.; DOUGLAS, G.B.; SANDBERG, A.M.; LOWE, A.T.; FOOTE, A.G. 1999: Screening of nitrogen-fixing plants for use in sand-dune revegetation in New Zealand. *New Zealand Journal of Forestry Science 29(1)*: 64–84.

HARDY, R.W.F.; BURNS, R.C.; HOLSTEN, R.D. 1973: Applications of the acetylene-ethylene assay for measurement of nitrogen fixation. *Soil Biology and Biochemistry 5*: 47–81.

HUNTER, I.R.; GIBSON, A.R. 1984: Predicting *Pinus radiata* site index from environmental variables. *New Zealand Journal of Forestry Science 14*: 53–64.

RESTALL, A.A. 1964: Sand dune reclamation on Woodhill Forest. *New Zealand Journal of Forestry 9*: 154–161.

WENDELKEN, W.J. 1974: New Zealand experience in stabilisation and afforestation of coastal sands. *International Journal of Biometeorology 18*: 145–158.