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NOTE

ESTABLISHMENT OF NITROGEN-FIXING PLANTS FROM SEED ON PARTIALLY STABILISED COASTAL SAND

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ABSTRACT

Seeds of eight nitrogen-fixing species (*Acacia saligna* H.Wendl., *Acacia sophorae* (Labill.) C.Martius, *Astragalus cicer* L., *Chamaecytisus palmensis* (Christ) Bisby et K.Nicholls, *Dorycnium hirsutum* (L.) Ser., *Lathyrus latifolius* L., *Lotus pedunculatus* Schk., *Teline stenopetala* Webb et Berth.) which tolerate the coastal sand dune environment when introduced as healthy plants, were broadcast-sown in 1995 at two sites on sand dunes which had been partially stabilised by planting marram grass (*Ammophila arenaria* L.). Establishment rates of 0–1% of viable seed sown after 6 months and 0–9% after 10 months, were considered to be unsatisfactory for sand revegetation purposes.

Other trials at the two sites commenced in 1996 and compared the effects of three sowing methods on establishment rates of *Lathyrus latifolius* and *Lotus pedunculatus*. *Lupinus arboreus* Sims, once successful in this habitat but now attacked by a fungal disease before reaching full maturity, was included as a benchmark species. Sand accretion resulted in establishment failure at one site but at the other site *L. arboreus* provided satisfactory vegetation cover within 6 months (84–99% where seed had been partially or completely buried; 31% where seed had been broadcast-sown). Plot coverage by the other two species did not exceed 4%.

Results of these trials do not explain why establishment rates were low in species other than *Lupinus arboreus*, but indicate that direct seeding is unlikely to be a satisfactory technique for establishing most nitrogen-fixing species on sand partially stabilised by the planting of a sand-binding grass. Enhancement of the chronically low nitrogen status of coastal sand in order to promote effective vegetation cover continues to depend on either frequent fertiliser application or the introduction of nursery-raised, nitrogen-fixing plants.

Keywords: coastal sand; New Zealand; nitrogen; legumes; establishment; species performance; revegetation.

INTRODUCTION

Approximately 1090 km of the New Zealand coastline are bordered by sand dunes which are vulnerable to wind erosion if there is no vegetation cover. During the twentieth century, 115 000 ha of sand drifting inland from these dunes were stabilised (van Kraayenoord 1986) by means of a successional planting procedure recommended by Cockayne (1911). A sand-binding grass, *Ammophila arenaria* (marram grass), was planted first to achieve partial stabilisation; a nitrogen-fixing shrub, *Lupinus arboreus* (tree lupin), was then introduced to increase vegetation cover and to enhance the nitrogen and organic matter status of the ecosystem; finally, trees (*Pinus radiata* D.Don) were planted to complete the stabilisation process. The nutritional importance of the nitrogen-fixing component of the planting succession has been described (Gadgil 1979; Gadgil *et al.* 1984). Forests developed to protect land adjacent to coastal dunes have become a valuable source of timber (Wendelken 1974).

During the late 1980s, lupin blight caused by the fungus *Colletotrichum gloeosporioides* (Penzig) Penzig & Saccardo spread rapidly throughout the country, reducing lupin populations by 60–95% (Dick 1994). The danger of reliance on a single species for addition of the nitrogen necessary for the development of a continuous, protective, vegetation cover on sand dunes immediately became apparent. A search for alternative nitrogen-fixing species was undertaken, and spaced-plant trials were used to screen potential candidates for tolerance to the partially stabilised sand environment (Gadgil *et al.* 1999). The spaced-plant technique allowed comparison of a larger number of species by ensuring that germination and early development had been successfully completed under nursery conditions. Once tolerance of mature plants to sand dune conditions had been demonstrated, it was important to determine whether an effective population could be established from seed.

Although seed sowing is the most cost-effective method of introducing live plant material to a new environment, it is not always possible or appropriate. It is not an option for marram grass, which produces little viable seed in New Zealand, or for *P. radiata* which must be planted with accurate spacing and zero mortality to ensure efficient forest management and consistent sand stabilisation. *Lupinus arboreus* establishes readily from seed, and continuous vegetation cover was achieved within 2–3 years if 3–4 kg seed/ha were distributed from aircraft (Restall 1964) or drilled into the sand (Berg & Smithies 1973) among planted marram grass tussocks.

As a further step in the identification of alternatives to *L. arboreus*, seed sowing trials were carried out in stands of planted marram grass on open dunes on the west coast of the North Island. The objective was to determine relative establishment rates for species that had performed well as mature plants in the spaced-plant trials.

MATERIALS AND METHODS

Sites

Trials were conducted in 1995 and 1996 at Kawhia Beach and at Santoft Beach (Table 1). Sites were located in flat areas behind the current foredune where bare sand had been planted with marram grass at least 1 year previously. The distance between grass tussocks, originally spaced at 1.5-m intervals in rows 1.5 m apart, was approximately 1 m. Colonisation of sand by other plant species was negligible.

Treatments and Experimental Design

Seed for all trials was subjected to light mechanical abrasion of the testas and then coated with a mixture of lime, sulphur, potassium monophosphate, sodium molybdate, and the appropriate *Rhizobium* species/strain. It was sown at a rate of 200 viable seeds/m^2 in single-species plots (1 × 1 m) arranged in four randomised complete blocks. Plots were positioned so that one side was immediately adjacent to, and therefore sheltered by, a marram grass tussock with a diameter greater than 10 cm. Experimental areas were fenced to exclude rabbits and, at Kawhia, wandering cattle. They were treated with urea (25 kg/ha) and superphosphate (250 kg/ha) broadcast at time of sowing.

The 1995 trials compared the establishment performance of eight leguminous species (Table 2) broadcast-sown in June at Kawhia Beach and at Santoft Beach. Species were selected on the basis of observed nitrogen-fixing potential after 3 years' growth in screening trials (Gadgil *et al.* 1999). Plant establishment was assessed in December 1995 and in April 1996.

In the 1996 trials, three methods were used to sow each of three leguminous species at Kawhia Beach and at Santoft Beach :

(a) Broadcast — seed was scattered evenly over the sand surface by hand.

(b) Partial burial — seed was scattered evenly and raked lightly into the sand surface (2–3 cm deep). The plot was then rolled with a garden roller.

(c) Complete burial — seed was distributed evenly along furrows (100 cm long × 2 cm deep, orientated parallel to marram rows at 30 cm spacing) and covered with sand which was then tamped flat.

Species used in the comparison were *Lathyrus latifolius* and *Lotus pedunculatus*, both selected on the basis of relatively high establishment rates in the Santoft Beach trial in December 1995*, and *Lupinus arboreus*, included as a benchmark. According to Dick

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* During 1995 it was decided that acacias would not be included in future Forest Research trials on sand dunes. The decision was a response to concern expressed by land managers about the spread and potential weediness of *Acacia* species, especially *A. sophorae*, in sand dune forests.

TABLE 1–Trial site details.

Location	Region	Approximate co-ordinates	Annual rainfall* (mm)	Mean air temperature (°C)*		Sand pH
				January	July	
Kawhia Beach	Waikato	174°48′E 38°25′S	1187	19.6	12.4	6.3
Santoft Beach	Manawatu-Wanganui	175°11′E 40°09′S	874	17.1	8.0	8.1

* Long-term average from nearest meteorological station (NZ Met. Service 1980).

TABLE 2–Number of plants present at each site in the 1995 trials.

Species	Accession No.†	Kawhia Beach				Santoft Beach			
		December 1995		April 1996		December 1995		April 1996	
		Inside 1×1-m plots	Outside 1×1-m plots	Inside 1×1-m plots	Outside 1×1-m plots	Inside 1×1-m plots	Outside 1×1-m plots	Inside 1×1-m plots	Outside 1×1-m plots
Acacia saligna H. Wendl. (Orange wattle)	AL 4573	0	0	0	0	0	0	0	0
Acacia sophorae (Labill.) C. Martius (Coast wattle)	AL 4572	0	0	0	0	9	0	66	7
Astragalus cicer L. (Cicer milkvetch)	AL 4325	0	0	0	0	4	0	40	9
Chamaecytisus palmensis (Christ) Bisby et K. Nicholls (Tagasaste; tree lucerne)	AL 3548	0	0	0	0	0	1	0	0
Dorycnium hirsutum (L.) Ser. (Hairy dorycnium)	AL 4278	0	7	0	1	5	0	1	0
Lathyrus latifolius L. (Everlasting pea)	AL 3533	0	0	0	0	15	0	7	1
Lotus pedunculatus Schk. cv. Grasslands Maku (Lotus)	ST 1009	4	0	6	1	11	1	6	4
Teline stenopetala Webb et Berth. (Madeira broom)	AL 3371	0	0	0	0	0	0	3	29

† Seed obtained from the Margot Forde Forage Germplasm Centre, Palmerston North, New Zealand

(1994), fewer than 25% of lupin plants grown from seed collected before 1990 are likely to be affected by blight during the first spring season (i.e., before December). Seed from a 1988 collection (Accession Number AL 4654; current viability 79%) was selected for these trials. Mesurol pellets (a.i. methiocarb, 20 g/kg) were scattered in and around the experimental plots at time of sowing (June 1996) to control snails. Results were assessed in December 1996.

Data Collection and Analysis

Very few plants developed in the 1995 trials and it was clear that wind had moved some seeds beyond the boundaries of the sown plots. Establishment rates were determined by counting all plants of each species present at each trial site, and expressing this number as a percentage of viable seeds sown. In the 1996 trials, relative establishment rates were determined as the proportion of plot area covered by the sown species. Mean height of *Lupinus arboreus* was derived from measurements of 10 randomly selected plants per plot. The 1996 data were subjected to analysis of variance and a Least Significant Difference test was used to compare treatment means.

RESULTS AND DISCUSSION

1995 Trials

Establishment rates for all eight species at both sites were low (Table 2). Only isolated plants of *Dorycnium hirsutum* and *Lotus pedunculatus* were found at Kawhia Beach. At Santoft Beach the most successful species were *Lathyrus latifolius* and *Lotus pedunculatus* after 6 months (2% establishment in each case); *Acacia sophorae* (9%), *Astragalus cicer* (6%), and *Teline stenopetala* (4%) after 10 months. There was little evidence of seedling mortality at either site, but many ungerminated seeds or empty testas were present on the sand surface. Total plant numbers after 10 months (all species combined) represented 0.1% (Kawhia Beach) and 2.7% (Santoft Beach) of the 6400 viable seeds sown.

Possible reasons for low establishment rates were:

(i) Removal of seeds by birds;

(ii) Removal of seeds beyond trial boundaries by wind action;

(iii) Unfavourable conditions for germination and/or growth at the sand surface;

(iv) Destruction of plants by snails, which were abundant at the Kawhia Beach site.

1996 Trials

The Santoft Beach site was badly affected by sand accretion. By December 1996 many plots and their marker pegs had been inundated by drifting sand and no plants of sown species were found. At Kawhia Beach, where no mass sand erosion or accretion had occurred, plant cover had been significantly ($p < 0.005$) influenced by species, sowing methods, and their interaction. Only occasional *Lotus pedunculatus* and *Lathyrus latifolius* plants were present (ground cover 1.3–4.0%; Table 3). Several dead *Lathyrus* seedlings were found and ungerminated/unimbibed seeds or empty testas were observed in the broadcast-sown plots. By contrast, *Lupinus arboreus* plants were too numerous to count without damage. They covered the greatest proportion of ground area (98.8%) in plots where seed had been buried completely (Table 3). Partial burial was associated with more ground cover (83.8%) than broadcast sowing (31.3%). Plants grown from buried seed were more than twice as tall as those in broadcast-sown plots (Table 3), but no height difference could be attributed to method of burial. Plants in all plots had early symptoms of lupin blight.

TABLE 3–Mean establishment after 6 months in the 1996 Kawhia Beach trial. Means followed by the same letter do not differ at the 5% probability level (Least Significant Difference test). Comparisons involved nine means (3 spp. × 3 sowing methods) for percentage cover; three means (sowing methods) for height of *Lupinus arboreus*.

	Seed broadcast	Seed partially buried	Seed completely buried
Ground cover (%)			
Lathyrus latifolius	1.3 d	4.0 d	3.8 d
Lotus pedunculatus	1.3 d	1.3 d	2.5 d
Lupinus arboreus	31.3 c	83.8 b	98.8 a
Plant height (cm)			
Lupinus arboreus	35.4 y	72.0 x	84.2 x

Results of these trials, in combination with previous experience of sand revegetation, suggest that *Lupinus arboreus* possesses some eco-physiological adaptation which confers an advantage during the period of seed germination and early growth in partially stabilised coastal sand. Specific reasons for the superior performance of *L. arboreus* are not immediately apparent. Seeds were scarified and it is therefore unlikely that physiological mechanisms controlling moisture imbibition (Hyde 1954; Quinlivan 1968) were involved. All three species tested are pioneer colonisers of disturbed soil under a range of moisture conditions (van Kraayenoord & Hathaway 1986), but only *L. arboreus* has ever developed a naturally abundant distribution in coastal sand dune areas where it was not specifically sown. Seed size of *L. arboreus* is similar to that of *Lathyrus latifolius* and therefore unlikely to account for the observed differences. Some of the *Rhizobium* strains used may have been unable to tolerate sand dune conditions. It is probable that *Lupinus arboreus* plants, developing more rapidly after germination than those of the other species (especially when protected by burial), were able to complete vulnerable growth phases during short periods of favourable weather conditions. The positive effect of seed burial on height growth of *L. arboreus* plants supports this theory. Dependence on mycotrophy, which is less apparent in *Lupinus* than in some other genera of the Fabaceae (Trinick 1977; Harley & Smith 1983; O'Dell & Trappe 1992), may have contributed to establishment differences, but no comparative work on the vesicular-arbuscular mycorrhizal status of these three species has been reported.

Low establishment rates demonstrated for most species tested in these trials indicate that seed sowing is unlikely to be a successful method for introducing nitrogen-fixing species other than *L. arboreus* into the partially stabilised sand dune environment, even if the seed is buried. Bergin & Kimberley (1999), working with sand-binding grasses native to New Zealand, have also reported unsatisfactory results from direct seeding. A glasshouse comparison of relative establishment rates of a wide range of leguminous species has commenced. This will determine the effects of seed size and sowing depth on seedling emergence and growth in sand under favourable moisture and temperature conditions, and may help to explain poor performance in the field. At present the use of nursery-raised plants is recommended for all sand dune revegetation work. If nitrogen-fixing species are not included in the artificial vegetation succession, large quantities of fertiliser will be needed to raise and maintain the nitrogen status of the ecosystem at levels required for vigorous plant growth and effective ground cover.

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