MOLYBDENUM, SULPHUR, AND BORON DEFICIENCIES IN LUPINUS ARBOREUS AT POUTO FOREST

RUTH L. GADGIL, P. J. KNIGHT, ADRIANA M. SANDBERG, and P. J. ALLEN

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

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ABSTRACT

Past failure of yellow tree lupin (**Lupinus arboreus** Sims) at Pouto Forest can be ascribed to a combination of factors including multiple nutrient deficiencies, exposure, and pest attack. Marked growth responses to molybdenum application and to sulphur in the presence of molybdenum have been obtained. A small response to boron in the presence of molybdenum was also noted.

Deficiencies of molybdenum, sulphur, and boron have not been reported in other New Zealand sand dune forests. At Pouto it is likely that the combination of neutral sand pH, high leaching potential, and absence of fresh sand accretion from the foreshore results in losses of these elements which exceed the natural input.

Correction of nutrient deficiency is expected to increase plant vigour to a point where other factors have a negligible effect on the development of an adequate lupin cover. Radiata pine (**Pinus radiata** D. Don) trees are unlikely to be affected by molybdenum deficiency but their sulphur and boron status should be monitored during growth.

INTRODUCTION

Pouto Forest (6700 ha State Forest plus 1400 ha managed under a lease agreement) is located about 150 km north-west of Auckland. Just over half of the total area is covered by coastal scrub which can be crushed and planted directly with radiata pine. The remainder (about 3500 ha) consists of shifting sand dunes which are a constant threat to lakes and farmland on their eastern boundary. At present Pouto Forest is the only major area owned by the N.Z. Forest Service in the Auckland region which is available for afforestation.

In 1975, 4 years after the Forest Service took over responsibility for the area, it was obvious that the sand dune reclamation procedure used in other coastal forests was not succeeding. Normally sand is stabilised by planting first marram grass (*Ammophila arenaria* (L.) Link), then perennial yellow tree lupin, and finally radiata pine (Restall 1964; Wendelken 1974). At Pouto, marram grass established satisfactorily but growth of lupin seedlings between the rows of established marram grass was poor. Even several successive annual sowings failed to produce lupin cover suitable for radiata pine planting. Dune sand is notoriously nitrogen-deficient, and without the nitrogen fixed by healthy lupin plants (a possible 160 kg N/ha/year – Gadgil 1971) the future of the forest was open to question. In the absence of vigorous lupin plants, nitrogenous fertiliser (lime-coated ammonium nitrate; 60 kg/ha in spring and 60 kg/ha in autumn) had to be used to maintain the marram already planted. The high cost of the fertiliser and its application meant that the maintenance of future plantings of marram in this way would be impossible. The marram planting programme had therefore to be reduced until the cause of the lupin disorder could be determined and the problem rectified.

In 1976 several lines of investigation were initiated. The following is an account of those studies which produced positive evidence about the nature of the disorder.

THE DISORDER

Symptoms

Lupin germination was satisfactory but within 3 months of emergence, seedlings developed a reddish-purple discoloration and a silvery, hairy appearance. Cotyledons were often bright red. Leaflets of upper leaves were narrow, with a tendency to remain folded; those of the lowest leaves often became detached. Active nitrogen-fixing nodules, although few and poorly developed, were present on affected plants. Plant growth was generally stunted, and survival at the end of summer sometimes represented as little as 1% of the seed originally sown. Height growth and lateral branching in surviving plants were poor, and the leaflets were typically narrow with a pale, greyish-green appearance.

Site Factors

The drifting dune area at Pouto is separated from the foreshore by a low-lying area of swampy scrubland, and is not affected by sand accretion from the sea. The dune sand is near-neutral to slightly alkaline in reaction, with pH values ranging from 6.8 to 7.5.

Early glasshouse trials showed that lupin growth in Pouto sand was not always inferior to growth in sand from Woodhill Forest, 15–60 km south-east of Pouto, where lupins generally grow well. Colour symptoms of the Pouto disorder were, in fact, never reproduced exactly in the glasshouse. These observations suggested that site factors other than those associated with sand type might affect lupin growth.

A small trial was set up at Woodhill Forest to test this theory. (A complementary experiment was also established at Pouto, but this was washed out and had to be abandoned.) Two pits, each 2.2 × 2.2 m and 1m deep, were dug in the sand in an open but sheltered site where lupins were known to grow well. Each pit was lined with polythene with drainage holes slashed in the bottom. One pit was filled with sand from Pouto and the other was refilled with Woodhill sand. Lupin seeds from Pouto (99 seeds at 6 × 35-cm spacing) were sown in each sand type in the autumn. Observations during the following spring and summer (Table 1) showed that seedling discoloration typical of the Pouto disorder was virtually confined to plants growing in Pouto sand. Although later growth and development were much poorer in Pouto sand than in Woodhill sand, plant survival in the two plots was similar. From this it was concluded that poor colour and stunted growth were associated with some property of Pouto sand but that low survival rates at Pouto might be related to other site factors such as exposure.

TABLE 1—Trial with Pouto and Woodhill sands at Woodhill Forest

	Plant age (months)	Pouto sand	Woodhill sand
Total No. of plants/plot	3	54	46
	6	55	42
	9	54	45
No. of green plants	3	3	31
No. of red/silver plants	3	24	2
Plant height (cm) (mean and S.D.)	3	4 ± 1	4 ± 1
	6	17 ± 8	30 ± 12
Length of longest branch (cm) (mean and S.D.)	6	2 ± 4	10 ± 8
Dry weight of plant tops (g)	9	772	1078

In a larger trial at Pouto (A 705), a factorial combination of fencing, seed rate, and fertiliser treatments was tested, the fertilisers being selected on the basis of early glasshouse trial responses. All treatment combinations were replicated four times in a randomised block layout. Table 2 indicates that improvements in seedling survival, colour, and height growth could be attributed to the erection of fences (1.5 m high, coarse Sarlon cloth) around experimental plots. A fourfold increase in seeding rate produced a negative effect on survival and early growth, presumably due to increased between-plant competition. Broadcast application of phosphorus or potassium fertiliser reduced the survival rate 6 months after sowing. No positive effects on lupin growth were attributable to phosphorus, sulphur, or potassium additions, but an increase in height growth was associated with the two treatments which included the micronutrient mixture.

Nutrient Deficiency

Having established that exposure and sand nutrient status affected lupin growth at Pouto, interest centred on the examination of the effects of plant nutrients. The results of glasshouse trials in which one element at a time was omitted from a full nutrient solution supplement (Table 3), indicated that Pouto sand might be deficient in sulphur, molybdenum, and boron, although supplies of iron and zinc might be more than adequate for lupin growth. When these five nutrients were added singly to Pouto sand at the same rate as in the full nutrient solution, only molybdenum had a positive effect on plant growth (Table 3).

In 1978 Mr K. Middleton and Dr G. Smith of the Ruakura Agricultural Research Centre, undertook some semi-routine diagnostic tests (after Middleton & Toxopeus 1973) on the nutritional status of Pouto sand. The results (unpubl. data) of their subtractive trials with ryegrass or lucerne as indicator plants were similar to those of

TABLE 2—Trial A 705, Pouto. Assessments of lupin growth

Treatment	6 months after sowing				12 months after sowing	
	Survival (% of seed sown)	Plants (% of seed sown) Red/silver	Plants (% of seed sown) Green	Mean height of green plants (cm)	Survival (% of seed sown)	Mean height of all plants (cm)
Unfenced	8.3	1.8	7.0	10.5	1.1	27.0
Fenced	19.0*(+)	2.1	16.6*(+)	14.4	6.0*(+)	41.9*(+)
4 kg seed/ha (normal rate)	15.4	2.3	13.2	14.0	4.1	32.5
20 kg seed/ha	11.9*(—)	1.6*(—)	10.4*(—)	10.9*(—)	3.0*(—)	36.4
No fertiliser	16.3	1.8	13.8	10.0	3.5	23.8
P, 100 kg/ha as monocalcium phosphate	10.8*(—)	1.1	10.2	10.2	2.3	29.9
S, 50 kg/ha elemental	15.6	2.9*(—)	12.4	10.6	2.7	24.5
K, 100 kg/ha as muriate of potash	12.9*(—)	2.4	10.8	10.9	3.5	24.6
Micronutrient mixture (kg/ha: Cu 4.0; B 1.7; Zn 3.6; Mo 0.06; Fe 2.9)	15.6	2.6	13.4	14.9*(+)	4.9	47.8*(+)
Combination (P + S + K + micronutrients)	10.9*(—)	0.8	10.2	13.3*(+)	4.3	56.3*(+)

* Effect significant at p = < 0.05: (+) = positive effect; (—) = negative effect.

our subtractive trials with lupins (RG 31, RG 36; *see* Table 3) in that they suggested deficiencies of sulphur and molybdenum. On the other hand, phosphate and potassium deficiencies indicated by ryegrass responses were not observed with lupins. Lucerne growth was not affected by omission of magnesium, boron, manganese, or zinc from the nutrient solution. Results for copper and iron were inconclusive.

In spring 1978 the first field evidence of molybdenum deficiency was obtained at Pouto (Fig. 1). Two rows of 6-month-old lupin plants, which had been heavily side-dressed with molybdenum trioxide 3 months after sowing, had mean heights of 9.3

TABLE 3—Subtractive and additive nutrient trials

Pouto sand treatment	Mean dry weight of lupin plants/pot (g)
Trial RG 31	
Long Ashton nutrient solution, N-free (LA)*	3.6_a†
LA minus K	3.5_a
LA minus S	2.9_{bc}
LA minus Mg	3.8_a
LA minus Cu	3.4_{ab}
LA minus B	3.0_{bc}
LA minus Mo	2.9_c
Trial RG 36	
LA	3.0_a
LA minus P	3.4_a
LA minus Fe	6.3_b
LA minus Mn	3.6_a
LA minus Zn	4.5_a
Trial RG 28	
Nil	4.7_a
$CaCO_3$, 20 g/pot	2.1_a
Trial RG 39	
Nil	2.2_a
Zn (Solution H)*	1.8_a
Fe (Solution E)	1.4_a
Trial RG 40	
Nil	2.7_a
S (Solution B)	0.7_b
B (Solution I)	1.0_b
Mo (Solution J)	5.1_a
Trial RG 48	
Nil	2.7_a
PO_4 (Solution A)	1.3_a
Mo (Solution J)	3.9_b

* Compounds and concentrations used in these trials were based on a nitrogen-free version of the Long Ashton nutrient solution (Hewitt 1966) - see Table following.

† In this and subsequent tables, values within a trial which are followed by the same letter do not differ significantly at $p = < 0.05$ (Least Significant Difference Test).

	Stock solutions g/100 ml		g/100 ml
A $NaH_2PO_4.2H_2O$	10.06	H $ZnSO_4.7H_20$	0.012
B K_2SO_4	7.26	I H_3BO_3	0.150
C $MgSO_4.7H_2O$	10.30	J $Na_2MoO_4.2H_2O$	0.006
D $CaCl_2$	5.90	K KCl	6.23
E Fe EDTA	1.93	L Na_2SO_4	5.95
F $CuSO_4.5H_2O$	0.012	M $MgCl_2.6H_2O$	8.46
G $MnSO_4.4H_2O$	0.111		

Treatment	Solutions added (5 ml per pot at beginning of trial)												
	A	B	C	D	E	F	G	H	I	J	K	L	M
LA	x	x	x	x	x	x	x	x	x	x			
LA minus K	x		x	x	x	x	x	x	x	x		x	
LA minus S	x			x	x	x	x	x	x	x	x		x
LA minus Mg	x	x		x	x	x	x	x	x	x		x	
LA minus Cu	x	x	x	x	x		x	x	x	x			
LA minus B	x	x	x	x	x	x	x	x		x			
LA minus Mo	x	x	x	x	x	x	x	x	x				
LA minus P		x	x	x	x	x	x	x	x	x		x	
LA minus Fe	x	x	x	x		x	x	x	x	x			
LA minus Mn	x	x	x	x	x	x		x	x	x			
LA minus Zn	x	x	x	x	x	x	x		x	x			

Each pot contained 4000 g sand and two lupin plants

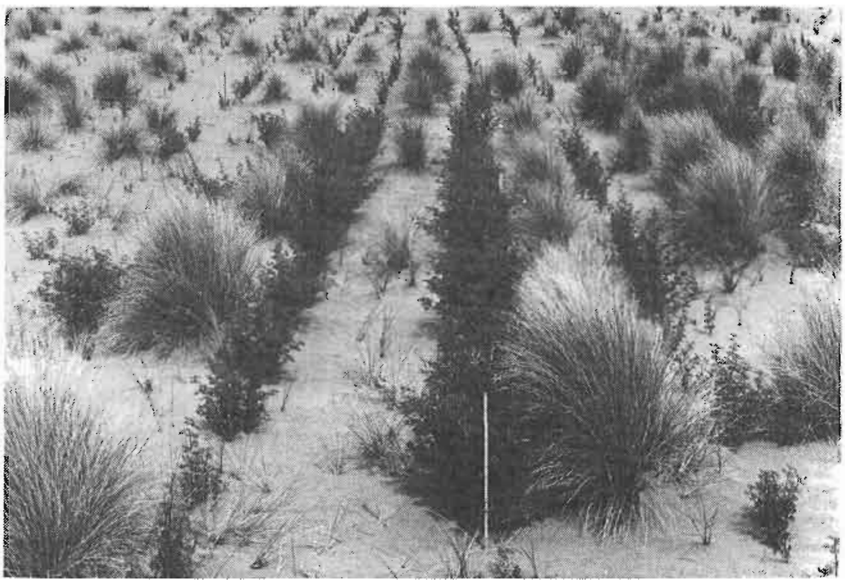

FIG. 1—Lupin response to molybdenum addition at Pouto. Plants in the marked row were side-dressed with molybdenum trioxide when 3 months old. The effect has spread to the two adjacent untreated rows.

and 16.8 cm respectively compared with 5.3 and 6.5 cm in untreated rows. Molybdenum-treated plants were a healthier green colour and their leaves were larger with broad, fully expanded leaflets.

Sherrell & Smith (1978) found that the concentrations of nutrient elements in seeds of a number of pasture plants usually fall within a narrow range regardless of management and fertiliser practice. Molybdenum, however, was shown to be an exception since its concentration in seed can be increased by raising the molybdenum status of the soil in which the plants are growing. Analysis of random samples of lupin seed from Pouto and from Woodhill Forest showed that Woodhill seed contained three times as much molybdenum as Pouto seed (0.077 and 0.025 ppm, or 0.323 and 0.096 μg per 100 seeds, respectively). A glasshouse trial showed that plant growth from Woodhill seed in Pouto sand was superior to growth from Pouto seed and that total molybdenum content of plant tops was also greater (Table 4). These findings underlined the advisability of using Pouto seed for investigations involved in this study. Only Pouto seed is used for routine lupin establishment at Pouto.

TABLE 4—Influence of seed source on lupin growth and molybdenum status (all plants grown in Pouto sand)

Seed source	Mean dry weight/pot (g)	Mean Mo content of plant tops/pot (μg)
Woodhill	7.0_a	0.18
Pouto	3.5_b	0.05

During the 1979 growing season a lupin growth response to molybdenum application was shown in several different areas of the Pouto dunes. In trial A 812/5, factorial combinations of molybdenum, boron, copper, sulphate-sulphur, and ammonum-nitrogen were applied as side dressings to rows of lupins at the time of sowing. Table 5 shows that although ammonium-nitrogen treatment was associated with a small increase in survival and vigour 6 months after sowing, only molybdenum treatment had a persisent effect on lupin growth. No positive first-order interaction effects were observed. The ammonium-nitrogen treatment might have been expected to improve early seedling growth before nodulation and symbiotic nitrogen-fixation were fully developed. There was, however, no evidence of a lasting "nitrogen-starter" effect.

In a concurrent glasshouse trial no "nitrogen-starter" effect was observed with either ammonium sulphate or sodium nitrate, but ammonium sulphate improved lupin growth when molybdenum was present (Table 6, Trial RG 54). Subsequent glasshouse trials suggested a positive interactive effect between molybdenum and sulphate-sulphur on lupin growth and also provided evidence of molybdenum × boron interaction (Trials RG 59 and RG 60 in Table 6 and Fig. 2).

Neither of these effects had been demonstrated in the A 812/5 field trial where fertilisers had been applied at time of seed sowing. In August 1979 it was decided that the effects of sulphate-sulphur and boron should be tested on established seedlings.

TABLE 5—Trial A 812/5, Pouto. Treatments producing a positive effect on lupin growth (lupin seed sown and fertiliser applied in April 1979)

Months from sowing	Treatment	Mean No. of plants/plot (= 3 × 3-m rows)	Mean plant height (cm)	Plants > 20 cm (6 months) or > 60 cm (8 months) (%)	Unhealthy plants (%)
6	Mo (0.3 g MoO_3/m row)	37*	8*	8*	11*
	Mo nil	32	5	2	24
	NH_4-N (16.7 g NH_4Cl/m row)	37*	7	6	15*
	N nil	32	6	4	21
8	Mo (0.3 g MoO_3/m row)	28*	41*	25*	—
	Mo nil	20	22	6	—
12	Mo (0.3 g MoO_3/m row)	—	67*	—	—
	Mo nil	—	26	—	—

* Effect significant at $p = < 0.05$

— No data recorded

TABLE 6—Glasshouse trials with nitrogen, sulphur, molybdenum, and boron

Pouto sand treatment	Mean dry weight of lupin plants/pot (g)
Trial RG 54	
Nil	7.9_{ab}
$NaNO_3$ (816)*	11.4_{bc}
$(NH_4)_2SO_4$ (636)	6.2_{a}
$NaNO_3 + Na_2MoO_4.2H_2O$ (816 + 0.3)	11.1_{bc}
$(NH_4)_2SO_4 + Na_2MoO_4.2H_2O$ (636 + 0.3)	13.1_{c}
Trial RG 59	
Nil	4.1_{ab}
NH_4Cl (516)	4.4_{b}
$NH_4Cl + Na_2MoO_4.2H_2O$ (516 + 0.3)	4.8_{bc}
$(NH_4)_2SO_4$ (277)	4.3_{b}
$(NH_4)_2SO_4 + Na_2MoO_4.2H_2O$ (277 + 0.3)	6.1_{c}
Trial RG 60	
Nil	2.5_{a}
$Na_2MoO_4.2H_2O$ (2.1)	5.2_{c}
H_3BO_3 (7.5)	3.5_{abc}
Na_2SO_4 (298)	2.4_{a}
$Na_2MoO_4.2H_2O + H_3BO_3$ (2.1 + 7.5)	5.1_{bc}
$Na_2MoO_4.2H_2O + Na_2SO_4$ (2.1 + 298)	9.6_{de}
$H_3BO_3 + Na_2SO_4$ (7.5 + 298)	1.8_{a}
$Na_2MoO_4.2H_2O + H_3BO_3 + Na_2SO_4$ (2.1 + 7.5 + 298)	10.2_{de}

* Figures in brackets indicate amount of compound (mg) added per pot (4000 g sand)

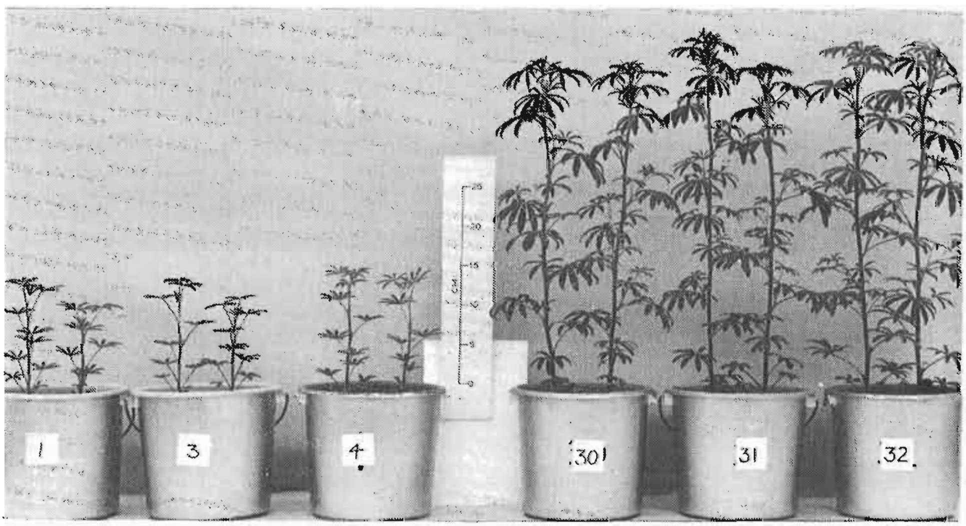

FIG. 2—Glasshouse trial RG 60. Three-month-old lupin plants grown in untreated Pouto sand (pots 1, 3, 4) and sand treated with molybdenum, boron, and sulphur (pots 30, 31, 32).

An area was selected which had been sown 4 months previously with molybdenum-treated lupin seed, and duplicate 10-m rows of plants were side-dressed with sodium borate and sodium sulphate. During the following 6 months a molybdenum × sulphate-sulphur (Fig. 3) and a later less-pronounced molybdenum × boron interaction effect were observed. There was no additional response when all three nutrients were present (Table 7).

FIG. 3—Response of molybdenum-treated lupins to sulphur addition. All lupins were grown from seed dusted with MoO_3 (10 g/kg seed). Plants in the marked row were side-dressed with sodium sulphate (222 g/10 m row) when 4 months old.

TABLE 7—Trial A 812/14, Pouto

Treatment		Mean plant height (cm)	
At time of sowing	4 months after sowing	6 months old	12 months old
MoO_3 (10 g/kg seed)	Nil	6_a	70_c
MoO_3	$Na_2B_4O_7.10H_2O$ (1.76 g/m row)	9_a	85_d
MoO_3	Na_2SO_4 (22.2 g/m row)	18_b	105_e
MoO_3	$Na_2B_4O_7.10H_2O$ + Na_2SO_4 (as above)	20_b	116_e

Confirmation of the molybdenum/sulphur responses was obtained in 1980 from a trial in which heavy dressings of elemental sulphur had been applied in 1978 in an attempt to reduce sand pH. The 1978–79 growing season had shown little effect of sulphur treatment on pH values and no effect on growth of lupins sown in June 1978. (A concurrent glasshouse trial had also failed to show a positive effect of elemental sulphur addition on lupin growth even though sand pH was lowered by 0.6 units at high rates of application – Table 8.) In April 1979 the area in which the trial was located was sown with molybdenum-treated lupin seed (10 g MoO_3/kg seed). During the following year the two sulphur-treated plots were clearly defined by taller lupin growth and improved ground cover (Table 9). No large pH differences were found between sand samples taken from inside and outside the plots (Table 10).

TABLE 8—The effect of elemental sulphur on lupin growth in Pouto sand (glasshouse trial PK 1)

Treatment	Mean dry weight of lupin plants per pot (g)	Mean sand pH after 3 months
Nil	3.9_a	6.6_a
Elemental S (50 kg/ha)	3.5_{ab}	6.3_b
Elemental S (100 kg/ha)	2.6_{ab}	6.0_c
Elemental S (500 kg/ha)	3.0_{ab}	6.0_c
Elemental S (1000 kg/ha)	2.4_b	6.0_c

TABLE 9—Lupin growth in the resown sulphur trial, Pouto. Values are derived from lupin measurements recorded at 1-m intervals along eight 10-m transects, each laid at right angles to one boundary of the relevant plot. Lupins were grown from molybdenum-treated seed (0.04 kg Mo/ha)

Location	Transect no.	Mean canopy height* (cm)	95% confidence intervals for means
Plot A, 500 kg S/ha	1	102	± 44
(S + Mo)	2	100	± 20
Plot B, 100 kg S/ha	3	102	± 34
(S + Mo)	4	118	± 16
10-20 m from Plot A	5	37	± 34
boundary (Mo only)	6	31	± 32
10-20 m from Plot B	7	30	± 28
boundary (Mo only)	8	37	± 23

* Analysis of variance showed that the overall mean for transects in sulphur-treated plots was significantly different from that for transects outside the plot boundaries ($p = < 0.001$)

TABLE 10—Sand reaction in the resown sulphur trial, Pouto

Location	Sulphur treatment June 1978	Mean pH value July 1980
Plot A	500 kg S/ha	6.5_a
Plot B	100 kg S/ha	7.0_b
Outside experimental plots	Nil	6.8_c

Pest Damage

Browsing damage, often seen along rows of young lupin seedlings at Pouto, is thought to be caused by rabbits. Often the cotyledons and first leaves are completely removed and seedling survival is impossible.

In 1979 it was noticed that germinating lupins were being attacked by a burrowing sand weevil. The insect, which also feeds on marram grass, was identified as *Cecyropa modesta F.* Mr M. Kay (Forest Research Institute, Rotorua) estimated that in some areas 76–89% of germinating and developing lupin seedlings had been damaged (pers. comm.). Older plants appeared to be less vulnerable. In 1980 Mr Kay estimated that only 12% of germinating seedlings had been damaged.

Defoliation of lupin plants by moth larvae (*Uresiphita* and *Helicoverpa* spp.) is common in all sand dune forests during January and February. Vigorous plants are able to survive one or more attacks in a season, but losses among poorly developed plants at Pouto are severe. In trial A 705 (described earlier), overall survival of untreated plants (expressed as a percentage of seed sown) was 16.3 in November 1977 and only 3.5 in July 1978. Defoliation by moth larvae certainly contributed to mortality during this period.

DISCUSSION

The results show that lupin growth on the Pouto sand dunes is restricted by

(1) exposure,

(2) molybdenum deficiency,

(3) sulphur deficiency when molybdenum is supplied,

(4) boron deficiency when molybdenum is supplied,

(5) insect and (?) rabbit damage.

This list may not be exhaustive, but there is reason to believe that application of molybdenum and sulphur will increase plant vigour to the point where the total effect of other factors is insufficient to prevent the development of an adequate lupin cover. In crop plants the correction of molybdenum deficiency has been known to increase resistance to disease (Blomfield 1954) and frost damage (Bortels 1941). At Pouto the molybdenum + sulphur treatments produced 1-year-old plants with a mean height exceeding 1 m, and in Trial A 812/14 plant cover was continuous along molybdenum + sulphur-treated rows. In the resown sulphur trial only three points without lupins were recorded among measurements taken at 1-m intervals along four 10-m transects. Survival rates were not measured in either of these trials, but it was obvious that lateral branch development in molybdenum + sulphur-treated plants had been sufficient to compensate for any losses in plant numbers.

Neither molybdenum deficiency nor the interacting deficiencies of molybdenum, sulphur, and boron have been encountered previously in New Zealand sand dune forests. In agriculture, molybdenum deficiency is most commonly associated with acid soils and is caused by increased molybdenum-adsorption by soil minerals and colloids at low pH (Mengel & Kirkby 1978). However, molybdenum deficiency has been observed in freely draining soils with neutral or high pH. Jones & Belling (1967) reported low molybdenum retention in two deep sands in Australia with a pH of 7.2

and, from a survey carried out in the United States, Rubins (1956) concluded that soils responding to molybdenum at neutral or alkaline reactions could be considered truly deficient in this element.

In most soils, organically bound sulphur provides the major sulphur reservoir. This is, of course, almost completely absent in Pouto dune sands. The relationship between sulphate adsorption and pH is very similar to that of molybdate, and the sulphate ion is very susceptible to leaching (Mengel & Kirkby 1978).

Adsorption of borate increases with pH and maximum retention can be expected at pH 7–9. Boron retention is also determined by clay minerals and sesquioxides with the result that boron mobility, and therefore susceptibility to leaching, are greatest in coarse-textured soils. Mengel & Kirkby (1978) point out that the boron content of sea water is appreciable and that soils affected by sea spray may be high in boron.

At Pouto the amounts of molybdenum, sulphur, and boron deposited from sea spray are apparently insufficient to compensate for their unavailability to plants growing in the sand, although the boron content of the sea spray may reduce the potential severity of boron deficiency. It is probable that raw Pouto sand is inherently low in these elements also. The absence of fresh sand accretion from the foreshore almost guarantees that, under conditions favouring low molybdenum and sulphur retention (neutral pH, absence of organic matter), the fairly high rainfall (at Dargaville, 50 km north-west of Pouto, mean annual rainfall is 1166 mm with 188 rain days) will cause losses of molybdenum and sulphur through leaching which will exceed natural inputs.

Leguminous plants require a great deal of molybdenum, sulphur, and boron (Murphy & Walsh 1972; Spencer 1975) whereas grasses usually have a lower boron requirement than other crop species (Shive 1941). Providing that adequate ntrogen is supplied, marram grass is evidently able to obtain sufficient molybdenum, sulphur, and boron from Pouto sand; it may even compete with lupin plants for natural supplies of these elements. Radiata pine, which will be planted when good lupin cover is achieved, is unlikely to be affected by molybdenum deficiency (Stone 1968). Although field occurrences of sulphur and boron deficiency have been recorded in this species (Humphreys *et al.* 1975; Stone & Will 1965), problems are not likely to occur at Pouto in areas where the lupin has been treated. Once a continuous plant cover has developed, the building up and recycling of nutrient reserves in organic matter should help to prevent recurring deficiency.

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