COPPER DEFICIENCY IN *PINUS RADIATA* IN A PEAT SOIL NURSERY

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ABSTRACT

A disorder which hitherto had affected radiata pine (**Pinus radiata** D. Don) seedlings sporadically in Sweetwater Forest Service Nursery became more widespread in the summer-sown crop of 1973. Visual symptoms in 6-month-old seedlings were:

(i) Needle-tip necrosis, generally affecting all but the youngest needles in the apical tuft of primary foliage;

(ii) Depressed and wilted appearance of the seedling tops, resulting from abnormal downward curving of the outer apical tuft needles;

(iii) Apical tuft needles slightly darker than in normal plants; and

(iv) Stunted growth.

Chemical analyses of shoots and foliage from normal and affected seedlings growing in this peat-based nursery showed that the affected seedlings were abnormally low in copper content, containing less than 2 ppm. Peat from an area with a high incidence of the disorder contained only 0.7 ppm total copper. Copper extractable by dilute hydrochloric acid was also low, amounting to 0.1 ppm. Foliage sprays and soil applications of copper oxychloride and cuprous oxide restored affected seedlings to normal appearance and vigour within 6 weeks.

INTRODUCTION

Sweetwater Nursery (31 ha), about 10 km north-west of Kaitaia in the far north of New Zealand, is established on a deep, strongly acid, sandy peat soil in which drainage has been improved by open drains.

Localised patches of seedlings of radiata pine *(Pinus radiata* D. Don) with a distinctive unhealthy appearance have occurred sporadically in the nursery during past years. In the 1973 growing season, when affected areas were more extensive than hitherto, it became important to establish the cause of the disorder and to find an effective means of treatment.

Approach to the Problem

Seedling disorders may be the outcome of pathological, physical or nutritional disturbances. Although none of these could be immediately discounted at Sweetwater, the first two possibilities seemed unlikely. Roots and mycorrhizal development in the affected plants were apparently normal, so that root pathogens and nematode damage were not suspected. Nor was there any evidence that the common nursery pathogen

Botrytis sp., which was isolated from affected seedling shoots (P. D. Gadgil, pers. comm.) was responsible for their condition; indeed, normally effective control measures for this fungus were of little avail in affected areas. The physical condition of affected beds was no different from that of beds supporting normal vigorous stock. Both had been subjected to the same cultural procedures and had received identical fertiliser, weedicide and fungicide treatments.

On the other hand, the remaining possibility seemed likely since peat soils, with their strongly acid reaction and organic nature, are notoriously prone to nutritional disorders, particularly copper deficiency (Gilbert, 1952; Reuther and Labanauskas, 1966). A deficiency of this micronutrient was therefore immediately suspected, especially as the nursery had escaped routine copper spraying for needle blight (*Dothistroma pini*) control, being in a blight-free area.

To test the copper deficiency hypothesis four avenues of investigation were followed, more or less concurrently:

(1) Visual diagnosis;
(2) Plant tissue analysis;
(3) Soil analysis; and
(4) Experimental applications of copper compounds in nursery and glasshouse trials.

ANALYTICAL METHODS

Tissue Analyses

All cations were determined in a dilute hydrochloric acid extract by atomic absorption spectrophotometry. Phosphorus was determined in the same extract using the vanado-molybdophosphoric yellow colorimetric procedure described by Jackson (1958). Nitrogen was determined by an automated colorimetric method based on the phenol-hypochlorite reaction (Tetlow and Wilson, 1964) after digestion of the tissue by micro-Kjeldahl method described by Bremner (1965). Chloride was determined in an 0.01 N nitric acid extract of the ground tissue by titration against standard silver nitrate solution, using a chloride specific electrode and potentiograph to detect the end point.

Soil Analyses

Total nitrogen and soil chloride were determined by the same methods used for plant tissues. The Bray 2 procedure described by Jackson (1958) was used to determine available soil phosphorus. The methods used for determining exchangeable sodium, loss-on-ignition, conductivity of a 1 : 5 soil : water extract, and pH were as described by Metson (1956).

The peat was extracted with 0.1 N hydrochloric acid (Fiskell, 1965) to provide a chemical index of copper availability. The copper in the extract was determined by atomic absorption spectrophotometry. The total copper of the peat was determined by the same means following perchloric acid extraction of the ashed soil.

RESULTS OF INVESTIGATION

Description and Visual Diagnosis of the Disorder

The seedlings under study had been sown on 24 February 1973. About 14 weeks later, a browning of the needle tips was noted in some parts of the nursery. During the following 2-3 weeks this became more pronounced.

Visual examination of affected 6-month-old seedlings on 3 September 1973 showed the following features to be characteristic of the disorder:

(i) *Necrotic needle tips:* The most severely affected seedlings had a singed appearance, with almost every needle having a brown necrotic tip (Fig. 1). Generally, only the youngest primary needles in the centre of the apical tuft were unaffected. The necrosis appeared to be preceded by yellowing of the needle tips. Colour of the needles lower down on the shoot was normal.

(ii) *Abnormal conformation of the apical tufts:* The needles of the apical tuft were shorter than in normal plants and were abaxially reflexed to an abnormal extent (Fig. 2), almost as though they lacked turgidity. This gave the apical tuft a distinctive flattened appearance. When viewed *en masse* in the nursery beds, seedlings had an unthrifty, wilted appearance.

(iii) *Colour of foliage:* The apical tuft needles were generally slightly darker in colour (Munsell colour 10GY 5/4) than normal shoots (Munsell colour 7.5GY 5/6).

(iv) *Stunted growth:* Height growth of affected seedlings was poor compared with that of normal seedlings in the same nursery (Fig. 1).

FIG. 1—Eight-month-old radiata pine seedlings from Sweetwater Nursery. Left—three unhealthy seedlings from untreated control bed; right—three vigorous seedlings restored to health by treatment with copper oxychloride (10 kg/ha applied to ground as powder). The rule is 20 cm.

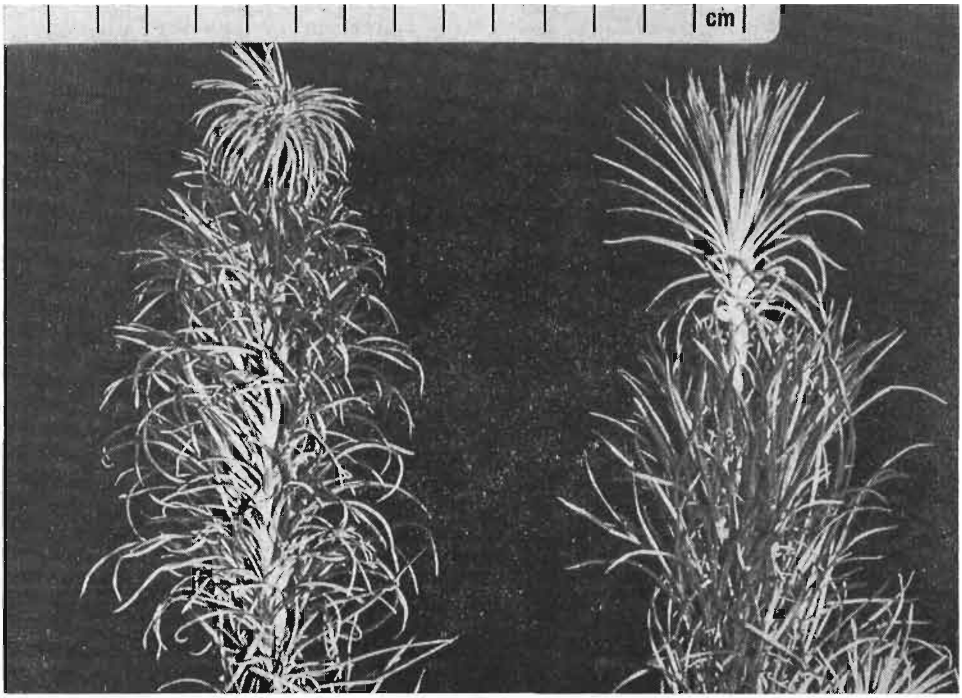

FIG. 2—Close-up of tops of 8-month-old seedlings taken from Sweetwater Nursery (15.10.73). Left—top of an unhealthy seedling typical of control bed; right—top from a healthy vigorous seedling which recovered following soil treatment with copper oxychloride (10 kg/ha). Note downward curving needles and retarded shoot growth in unhealthy specimen.

These symptoms correspond closely to those described by Smith (1943) for seedlings grown in culture solution minus copper for 4½ months. He observed that the tips of the secondary needles and the primary needles on the upper part of the plant were brown and dead, that the needles near the plant apex were curved downward, and that growth of the younger needles was very limited. Stem and branch twisting, which has been reported as associated with copper deficiency in older radiata pine plants (Hall, 1961; Ruiter, 1969; Will, 1971), was not evident in either the Sweetwater Nursery stock or the seedlings described by Smith (1943).

The symptoms characteristic of other nutrient deficiencies have been described for radiata pine seedlings: e.g., Ludbrook, 1940 (B); Smith and Bayliss, 1942 (Zn); Purnell, 1958 (P,K,Ca,Mg); Will, 1961a (N,P,K,Ca,Mg) and 1961b (Mg); Marcos de Lanuza, 1966 (B,Mn,Mo); and Truman, 1972 (N,P,K,Ca,Mg,Fe). Sulphur deficiency symptoms are known from unpublished work at the Institute to closely resemble those of nitrogen deficiency. None of these deficiencies, viz., N,P,K,Ca,Mg,S,B,Fe,Mn,Mo,Zn, results in symptoms which match those displayed by the Sweetwater seedlings.

Tissue Analyses

Analyses of composite samples of shoots from normal and affected plants are compared in Table 1, section A. Each sample consisted of the above-ground portions of

TABLE 1—Chemical analyses of composite samples of radiata pine seedling shoots collected on two different dates from Sweetwater Nursery.

Date collected	Sample description	% dry weight								ppm (dry wt)		
		Total ash	N	P	K	Mg	Ca	Na	Cl	Mn	Zn	Cu
	A.											
20. 7.73	25 seedlings											
	1. normal 1-year-old plants	4.85	2.30	0.38	1.30	0.14	0.13	0.07	--	288	19	2.3
	2. 1-year-old plants with extensive needle tip necrosis	5.37	3.59	0.53	1.52	0.18	0.13	0.18	--	382	22	1.5
	3. normal 2-year-old plants	3.36	0.92	0.23	0.59	0.21	0.31	0.05	--	169	19	2.0
	4. 2-year-old plants with extensive needle tip necrosis	5.10	1.68	0.32	0.82	0.21	0.26	0.11	--	156	15	1.3
	B.											
15.10.73	10 seedlings											
	5. recuperated plants from spray-treated plot A2*	4.85	1.68	0.35	1.15	0.15	0.18	0.20	0.47	248	--	107‡
	6. affected plants from control bed alongside plot A2	5.37	2.93	0.49	1.84	0.25	0.18	0.28	0.68	354	--	1.2
	7. recuperated plants representative of side-dressed plot B†	3.36	1.44	0.31	1.04	0.14	0.18	0.15	0.36	235	--	4.5
	8. affected plants from control bed alongside plot B	5.10	2.83	0.44	1.63	0.19	0.20	0.24	0.68	322	--	1.2

* Plot A2 treated with 11.2 kg cuprous oxide/ha on 3 September 1973

† Plot B treated with 10.0 kg copper oxychloride/ha on 3 September 1973

‡ High level of copper is probably the result of copper spray persisting on foliage

25 representative seedlings. The concentrations of all nutrients determined, with the exception of copper, were consistent with adequate supply.

Whereas the shoots of the normal plants contained at least 2 ppm copper, affected plants contained 1.5 ppm or less.. A composite sample of stem needles taken from 10 representative affected seedlings contained only 1.7 ppm copper, whereas the usual range in foliage of healthy radiata pine trees is 3-5 ppm (Will, 1971). Stone (1968), in reviewing published data for copper nutrition in forest tree species, concluded that foliar concentrations of 2-3 ppm are probably marginal for pine and various other conifers. Will (1971) noted that the critical level of copper in radiata pine foliage is *ca.* 3 ppm but that this may vary with the level of other nutrients, particularly N and P. Section B of Table 1 compares analyses of composite samples of shoots taken (a) from affected (control) seedlings and (b) from seedlings which had resumed normal growth following treatment with copper compounds (see later under "Nursery Trial" section). Whereas the shoots of affected control plants contained 1.2 ppm copper, those of plants which had recuperated following an application of copper oxychloride to the soil contained 4.5 ppm. Extrinsic copper persisting from the foliar spray application probably accounts for a large part of the high concentration of this element found in the shoots of spray-treated seedlings.

The levels of both sodium and chloride are high in both normal and affected seedlings, and more particularly the latter, but there is no evidence that they are injurious.

Will (1971) suggested that the needle tip "burn" associated with the copper deficiency in the coastal forest at Mangawhai could be due to an increased susceptibility to salt burn. Needle tip "burn", however, has been recorded as a symptom of copper deficiency in several coniferous species in situations other than exposed coastal sites (Benzian and Warren, 1956; Benzian, 1965; Lyle, 1969).

The shoot N and P concentrations in the unhealthy seedlings sampled on two separate occasions were higher than those in normal plants (see Table 1). This probably reflects accumulation of these elements in the affected plants when growth was restricted by inadequate copper supply. Gilbert (1952) has pointed out that the term "deficiency" is generally used in a relative sense. In this particular instance, the seedling condition could perhaps be described as either a deficiency of copper as compared with nitrogen and phosphorus, or an excess of nitrogen and phosphorus as compared to copper. The former view is more practical as it is quite simple to supply a "deficient" element but difficult to remove an excess.

Soil Analyses

Table 2 gives results of analyses of a composite soil sample taken on 3 September 1973 from 1-10 cm depth at about 25 points along a badly affected nursery bed.

The concentration of acid-extractable (0.1 N HCl) copper in the peat on a dry weight basis was only 0.1 ppm. This is well below the range of results quoted by Reuther and Labanauskas (1966). The total copper content of the peat was only 0.7 ppm on a dry weight basis. Assuming that this value closely approximates the total soil copper, the content is extremely low. Wells (1957), in a survey of copper in New Zealand soil sequences, reported total contents ranging from 2 to 150 ppm with a mean of 17.5 ppm. The mean value which he obtained for eight representative organic soils was 9.6 (SD $\pm$ 5.2) ppm. According to Lucas and Knezek (1972), sufficiency of copper

TABLE 2—Sweetwater Nursery peat soil: Summary of results of selected soil tests

Test	Result	
Loss on ignition	88.5	%
pH in water (1 : 2.5; 20°C)	4.2	pH
Conductivity (EC) 1 : 5 soil : water extract (25°C)	0.32	mmho/cm
Total soluble salts (EC × 0.350)	0.11	%
Acid-extractable chloride (0.01N HNO_3)	0.2	me%
Exchangeable sodium	0.4	me%
Total nitrogen	1.00	%
Bray 2 phosphorus	24	ppm (w/w)
"Total" copper	0.7	ppm (w/w)
Acid-extractable copper (0.1NHCl)	0.1	ppm (w/w)
Bulk density	0.37	g/cc

is fairly easy to predict. From the literature they concluded that the total copper in organic soils should exceed 20-30 ppm for copper-responsive crops.

The values of exchangeable sodium, acid-extractable chloride, and total soluble salts in the nursery peat soil are not abnormally high. It seems likely therefore that the high shoot concentrations of sodium and chloride in the nursery stock (see Table 1) are caused by foliar absorption of windborne salt reaching the nursery in aerosol form from the nearby coast, rather than by soil salinity.

The results of the total nitrogen and Bray 2 tests indicate that the N and P status of the nursery soil is reasonably high. Both Reuther and Labanauskas (1966), and Lucas and Knezek (1972), in reviewing soil conditions which may promote micronutrient deficiencies in plants, conclude that high levels of N and P in the soil are likely to induce or accentuate copper deficiency.

EXPERIMENTAL APPLICATIONS OF COPPER COMPOUNDS

Nursery Trial

To see whether affected 6-month-old seedlings would respond to copper compounds, the following five treatments were applied to 10 m lengths of nursery bed separated by 2 m buffer zones:

Spray application (0.4% weight/volume suspensions of compound in water)

(1) Copper oxychloride at 11.2 kg/ha
(2) Copper oxychloride at 22.4 kg/ha
(3) Cuprous oxide at 11.2 kg/ha
(4) Cuprous oxide at 22.4 kg/ha

Soil application

(5) Copper oxychloride at 10 kg/ha

Each treatment had three replications. Untreated beds adjacent to those with treatment plots served as controls. The two commercial wettable powder copper compounds used each contained approximately 50% copper.

Relatively insoluble copper compounds were used in this preliminary trial to minimise the risk of any toxic effects on the young seedlings and to provide a slow-release source of copper for the plants.

An improvement in the appearance of the treated seedlings was first noted 5 weeks after treatment. By 6 weeks, the difference between treated and control seedlings was marked (Fig. 3). The former were now healthy in appearance and had established a clear height lead over the control seedlings, which showed no signs of recovery. Average height increment over the 6-week period following treatment was 14 cm in treated plots and 7 cm in adjacent control plots. There was little variation in response to different treatments and no phytotoxicity was recorded.

FIG. 3—View of part of nursery trial. The section of the seedling bed in the centre foreground marked by four white pegs is an untreated buffer strip between two treated sections. Note the stunted, wilted appearance of the seedlings compared with the healthy, vigorous seedlings in the treated sections. The copper treatments were cuprous oxide (22.4 kg/ha) nearest camera and copper oxychloride (22.4 kg/ha) at far side of untreated strip.

Glasshouse Pot Trial

Affected 6-month-old seedlings were lifted intact from the nursery and brought to a Forest Research Institute glasshouse. These were transplanted, one per pot, into 4.25-litre plastic buckets filled with soil collected from affected nursery beds. After one month, four pots were each treated with 0.04 g cuprous oxide wettable powder (50% active ingredient) applied as a suspension in water. Four untreated seedlings were retained as controls. All pots were subsequently watered regularly to weight. Within 2 months, three of the four copper-treated seedlings had resumed normal healthy growth. By contrast, three of the four control seedlings remained stunted and continued to exhibit the symptoms described previously. Fig. 4 shows representative control and copper-treated seedlings 2 months after treatment.

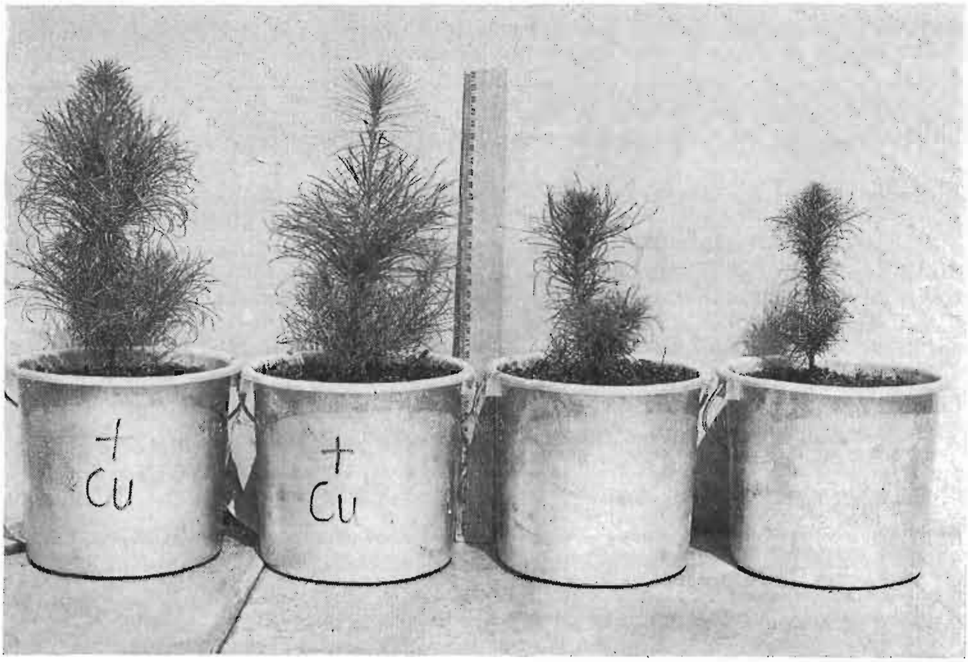

FIG. 4—Ten-month-old seedlings taken from Sweetwater Nursery when 6 months old and transplanted into pots containing nursery peat from a bed with a high incidence of disordered seedlings. The two pots on the left were treated with cuprous oxide at a rate equivalent to 5 kg/ha copper. The pots on the right are untreated controls. When transplanted, the seedlings were of almost identical height. Height increments recorded for the 15-week period following treatment were: controls 6 cm (SD ± 2 cm); treated seedlings 20 cm (SD ± 6 cm).

CONCLUSIONS

1. A disorder of radiata pine seedlings which developed in parts of a peat-based nursery at Sweetwater, with symptoms including stunting, abnormal apical tufts, and extensive needle-tip necrosis, is caused by copper deficiency.
2. The disorder can be readily corrected by a single application of copper oxychloride or cuprous oxide wettable powder, either as a side dressing (solid) or foliar spray (suspension). The lowest dosage rate tested, i.e., 10 kg/ha of copper oxychloride (equivalent to 5 kg/ha copper) applied as a side dressing, was as effective as similar or heavier rates applied as sprays.*

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* 0.4% weight/volume suspensions of wettable powder in water.

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