CONTROL OF *DOTHISTROMA* NEEDLE BLIGHT BY LOW VOLUME AERIAL APPLICATION OF COPPER FUNGICIDES

J. W. GILMOUR and A. NOORDERHAVEN*
Forest Research Institute, New Zealand Forest Service, Rotorua

(Received for publication 22 June 1972)

ABSTRACT

Two-year aerial spray trials of copper-based fungicides were undertaken to control **Dothistroma** needle blight in heavily infected, young **Pinus radiata** D. Don. Two applications, 3 months apart, of cuprous oxide at 2.24 kg copper metallic equivalent in 56 litres water per ha (2 lb/5 gal/ac), provided adequate control for 2 years. Over 1 year a single application in December was almost as effective as the double application, but the single application in February was only half as effective as the December application. Evidence suggests that the effect of the copper fungicides was independent of the initial disease intensity.

Fungicide formulation in water or oil made no difference to its effectiveness, nor did diluent dosage rates of 56 and 112 litres per ha (5 and 10 gal per ac). A summer spraying oil had no effect; cuprous oxide at 1.12 kg copper metallic equivalent per ha (1 lb/ac) was effective, but less so than 2.24 kg (2 lb).

There were appreciable residues of copper on pine needles after 2 months and 254 mm (10 in.) of rain, but not after 3 months and 432 mm (17 in.) of rain.

INTRODUCTION

Defoliation of pines by the needle blight caused by *Dothistroma pini* Hulbary is new in New Zealand. The disease was probably present in localised areas in the late 1950s but was not identified until June 1964 (Gilmour, 1967a). By the end of 1965 it was established in 4040 ha (10 000 ac) of young *Pinus radiata* in the central North Island. It was estimated (Gilmour, 1967b) that by the end of 1966 at least 48 480 ha (120 000 ac) of the three main pine species, *P. radiata, P. ponderosa* Laws. and *P. nigra* Arnold were infected, of which 8080 ha (20 000 ac) were moderately to heavily infected. This epidemic build-up of a potentially crippling disease was a major threat to the exotic pine industry, and some form of economic control became imperative.

Thomas and Lindberg (1954) showed in limited screening trials that three to five applications of Bordeaux mixture gave the best control of this disease. The effectiveness of copper fungicides was confirmed by Gibson (1965 and 1967), Peterson (1965), Gibson *et al.* (1966), Schischkina and Tzanava (1966). In Tanzania, Hocking (1967) showed that if spraying was started when the disease intensity was very light (10%), then two light dosages of a colloidal copper oxychloride formulation (40 mg active Cu/m^2 of leaf surface), applied by mistblower, provided adequate protection for

* Present address: Department of Primary Industries, Brisbane, Australia.

N.Z. Jl For. Sci. 3 (1): 120-136

2 years. In Nebraska, U.S.A., Peterson (1967) demonstrated in small scale handspray trials with individual branches of adult *P. ponderosa* that any of five copper fungicides provided nearly 100% protection for one growing season, when applied twice, 3 to 6 weeks apart.

To test the efficacy of copper fungicides in controlling the disease in severely infected *P. radiata* in New Zealand, low volume aerial application trials using low dosage rates of three copper fungicides were established in 1965. This paper reports on the preliminary analysis of the effect of spraying on defoliation over the first 2-year period of these trials.

One trial series was begun in December 1965. A second was superimposed on the first in December 1966.

SERIES 1: COMPARISON OF COPPER FORMULATIONS, DOSAGE RATE, AND TYPE OF DILUENT

METHODS

Nine 402 × 40.2 m (20 × 2 chain) plots were marked out in one block (Fig. 1) in a 5-year-old *P. radiata* plantation, in which the disease intensity had reached a high level (mean defoliation level 50% to 60%). Eight treatments were compared using the following material:

Perenox (aerial) — Cuprous oxide (Cu_2O) WP* 50% w/w† copper, manufactured by Plant Protection Ltd for Imperial Chemicals Ltd, England, marketed by ICI (NZ) Ltd.

Stantox Ultra — Copper oxychloride (COC) WP, 52% w/w copper, formulated by Ivon Watkins-Dow Ltd (NZ), 0.4% Stantac — a non-ionic spreader-sticker was added to the spray mixture.

Brunokop — 57% copper oxychloride (COC) suspension in oil, manufactured by S.D.C. Pesticide Ltd, England, and supplied by Ivon Watkins-Dow Ltd, NZ.

Mobiloil M1103 — (oil alone). A non-phytotoxic summer spraying oil. This oil was used as the diluent for the Brunokop. It was also used on its own because a similar copper-in-oil diluent had been shown to be effective against Sigatoka leaf spot of bananas, when it was applied without the copper fungicide (Pearson, 1958).

The treatments consisted of the following nominal dosage rates of metallic equivalent (m.e.) copper per ha:

T1. No spray — (two plots, 1a and 1b)
T2. Cu_2O (Perenox) at 2.24 kg Cu m.e. in 56 litres water
T3. Su_2O (Perenox) at 2.24 kg Cu m.e. in 112 litres water
T4. COC (Stantox) at 2.24 kg Cu m.e. in 56 litres water
T5. COC (Stantox) at 2.24 kg Cu m.e. in 112 litres water
T6. COC (Stantox) at 1.12 kg Cu m.e. in 56 litres water
T7. COC (Brunokop) at 2.24 kg Cu m.e. in 56 litres oil (M1103)
T8. Oil (M1103) alone at 56 litres

* WP = wettable powder
† w/w = weight for weight

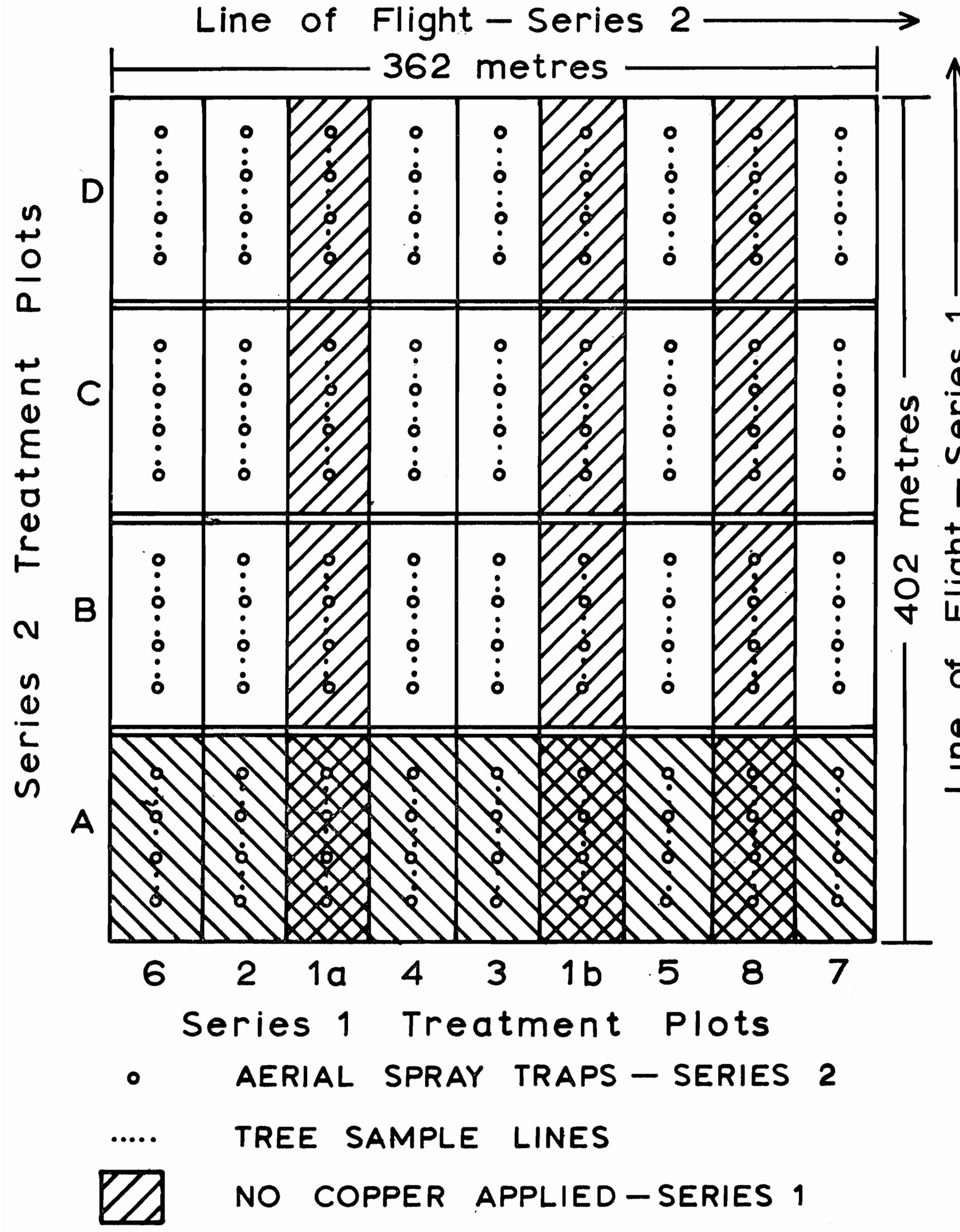


FIG. 1—Treatment plot layout.

Series I—The 1965-66 spray treatments T1-T8 were applied to the 402 × 40.2 m (20 × 2 chain) plots.

Series II—The 1966-67 spray treatments A, B, C and D were applied to the 362 × 101 m (18 × 5 chain) plots at 90° to those in Series I.

(2.24 kg/ha = 2 lb/ac; 1.12 kg/ha = 1 lb/ac; 56 l/ha = 5 gal/ac; 112 l/ha = 10 gal/ac).

The first application was made on 5 December 1965, and the second 3 months later on 4 March 1966.

Spraying was done in the early morning at wind speeds of less than 3.22 km/h and with relative humidities greater than 90%. A Cessna 185 aircraft fitted with a conventional boom and nozzle rig was used. The 9.1 m (30 ft) boom hung below the wing was fitted with Monarch 99 fan-type nozzles at 23 cm (9 in.) centres. A flying height of 3-6 m (10-20 ft) above tree-top height, at 180-190 km/h (*ca.* 110-120 mph) and a pump pressure of 5.6 kg/cm^2 (80 psi) gave a swath width of 18.3 m (60 ft) at 56 litres per ha (5 gal per ac). Dosage rates of 112 litres per ha (10 gal per ac) were produced by substituting T-Jet 807 nozzles and working at a pressure of 3.5 kg/cm^2 (50 psi). A wide spectrum of medium to fine droplets was produced by pointing the nozzles directly backwards (Fig. 2). Deposition of the spray, in both sprayed and

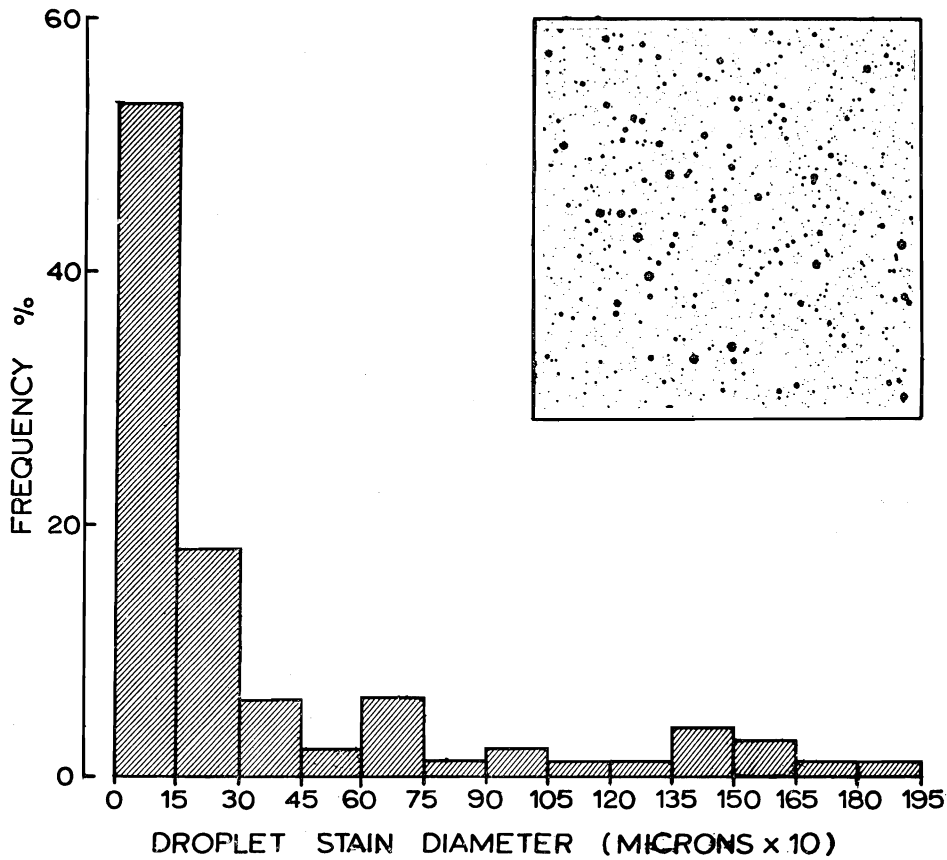


FIG. 2—Average spray deposit pattern in the open on horizontal paper traps at ground level:

Mean copper dosage	=	1.12 kg/hectare (1.0 lb/ac)
Mean droplet stain diameter	=	0.28 mm
Mean number of droplets	=	27 ± 3/cm^2
Coverage	=	7.25%

unsprayed plots, was checked by laying paper traps on the ground across the line of flight.

Copper deposits on the foliage were assessed immediately after spraying and on 1 March 1966, which was about 3 months and 445 mm (17.5 in.) of rain after the December application. A further assessment was made on 11 May 1966, which was 2 months and 244 mm (9.59 in.) of rain after the March application. Branches were marked for foliage sampling in the exposed crowns of 10 trees selected at random along the centre line of each treatment plot. A composite (10 g oven-dry) sample was made up by combining a small sample of the 1-year-old needles from one marked branch at 2.1 m (7 ft) above ground level, in each quadrant of each tree. The subsequent samples to assess the erosion of copper deposits were taken from the remaining 1-year-old needles from the same marked branches. Copper analysis was made by X-ray emission spectrography.

Disease development was assessed at about 6-week intervals on a marked 100-tree sample located systematically along the central axis of each plot. A scoring method was used based on photographs of trees showing the following mean grades of defoliation and needle infection:

Grade	Percentage of normal crown depth defoliated or severely infected by **D. pini** Mean	Range
1	2.5	Trace to 5
2	15.0	6 to 25
3	37.5	26 to 50
4	62.5	51 to 75
5	84.5	76 to 95
6	97.5	96 to 100
7	100.0 and dead	

The range of each grade was based on a $1\frac{1}{2}$ logarithmic scale after Horsfall (1945). All assessments of each tree were made independently by three trained observers. In the few cases of disagreement, the majority or mean grade was accepted.

This visual scoring method cannot provide an estimate of the real change in disease intensity since the score is based on the interaction of the loss of foliage caused by disease, and the gain of foliage resulting from growth. However, in areas where growth rates are similar it will provide a readily obtained estimate of disease development.

RESULTS

Copper Recoveries

Table 1 shows that deposition of the spray was reasonably accurate, with little drift onto unsprayed plots.

These figures show a wide variation within the treatments. The variation in spray deposition along the line of flight and within the swath width was unexpected, and so the sample size proved to be inadequate for comparing small differences. However, the sample means and their standard errors indicate that:

1. Higher dosages were deposited during the second application than during the first, particularly in treatment 6.

TABLE 1—Copper deposits on ***P. radiata*** foliage. Mean values for 10 trees per treatment (each foliage sub-sample = 3 g O.D.)

Treatment: Fungicide and diluent	Nominal dose per ha: Cu kg	Nominal dose per ha: Diluent litres	Mean 5 Dec 1965	SEM 5 Dec 1965	Mean 1 Mar 1966	Mean 4 Mar 1966	SEM 4 Mar 1966	Mean 11 May 1966
			Copper in ppm of oven dry wt of foliage					
T1 Nil	Nil	Nil	Tr	—	O	Tr	—	O
T2 Cu_2O/water	2.24	56	117	23.9 abcde	Tr	118	26.9 abcd	59
T3 Cu_2O/water	2.24	112	54	15.9 cde	Tr	239	40.5 a	69
T4 COC/water	2.24	56	107	15.6 bcde	Tr	302	64.4 a	26
T5 COC/water	2.24	112	91	18.8 bcde	Tr	189	36.2 ab	53
T6 COC/water	1.12	56	28	15.7 e	O	131	20.0 abc	Tr
T7 COC/oil	2.24	56	84	30.9 bcde	O	250	39.4 a	25
T8 Oil alone	Nil	56	O	O	O	41	18.4 de	O

Tr = trace — less than 10 ppm (1.12 kg/ha = 1 lb/ac, 56 l/ha = 5 gal/ac)

Spray application dates 5/12/65 and 4/3/66

The small letters abcde indicate Duncan's multiple range groupings of mean deposits which do not differ signficantly at the 5% level.

2. There was no statistically significant difference between the amounts of copper recovered in the comparable 56 and 112 litre (5 and 10 gal) application rates.
3. Similar recoveries of copper were obtained whether the diluent was water or oil.
4. The erosion of the copper deposit was almost complete 3 months and 445 mm (17.5 in.) of rain after the December application, while 2 months and 224 mm (9.59 in.) of rain after the March application there was still an appreciable residue of copper on the needles.

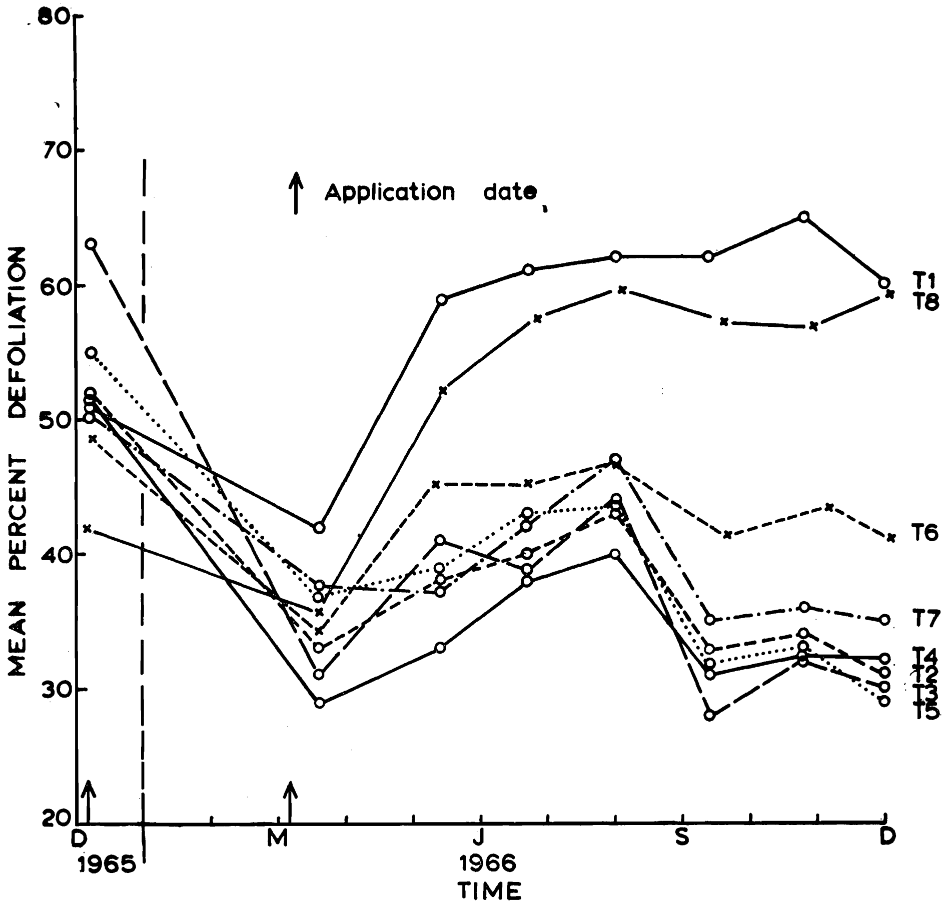


FIG. 3—Comparative effects of different copper fungicide formulations, dosages and dilution rates on percentage defoliation of **Pinus radiata** by **Dothistroma.**

T1 = Unsprayed control
T2 = Cuprous oxide WP, at 2.24 kg Cu/56 l/ha
T3 = Cuprous oxide WP, at 2.24 kg Cu/112 l/ha
T4 = Copper oxychloride WP, at 2.24 kg Cu/56 l/ha
T5 = Copper oxychloride WP, at 2.24 kg Cu/112 l/ha
T6 = Copper oxychloride WP, at 1.12 kg Cu/56 l/ha
T7 = Copper oxychloride OS, at 2.24 kg Cu/56 l/ha
T8 = Oil only at 56 l/ha
(2.24 kg/56 l/ha = 2 lb/5 gal/ac)
(1.12 kg/56 l/ha = 1 lb/5 gal/ac)

Effect of Treatment on Defoliation Levels

The progress of mean defoliation levels in treated trees and in the control plots over a 12-month period is illustrated in Fig 3.

Fig 3 indicates that:

1. The five 2.24 kg (2 lb) copper dosage rates (T2-T5, T7) had a similar effect which was to reduce the defoliation level by about half compared to the unsprayed control.
2. Irrespective of treatment there was a sharp reduction in the mean percentage defoliation between December 1965 and March 1966, although the decline was slightly greater in the copper treatments than in the unsprayed control.
3. The 1.12 kg (1 lb) copper dosage (T6) reduced defoliation levels by about one-third, as compared with the unsprayed control.
4. The oil alone treatment (T8) had no effect.

Statistical analysis of these data was not attempted because the frequency distribution of the defoliation grades was not comparable in all treatments at the beginning of the trial. However, to overcome this difficulty some of the data were grouped into the individual defoliation grades (1-7) as at the start of the trial, and the mean change in these with treatment and time was compared by analysis of variance. This analysis was completed for the 2.24 kg (2 lb) copper treatments (T2-T5, T7) which were combined as they had a similar effect, and the unsprayed control (T1). It showed that:

1. There was no interaction between treatment and the initial defoliation grade.
2. All treatment effects were very highly significant ($p < 0.001$) at 3, 7, 9 and 12 months after the first spray application in December 1965.

This suggests that the effect of treatment was the same irrespective of the initial defoliation grade, which is illustrated in Fig. 4.

This figure shows that:

1. In the lower initial defoliation grades (2 and 3) there was a greater increase in defoliation levels without spraying than in the higher initial grades.
2. In the higher initial defoliation grades (4 and 5) there was a greater reduction in defoliation levels with spraying than in the lower initial grades.
3. In all initial defoliation grades, the overall effect of spraying was to reduce defoliation levels to about 50% of what they would have been without spraying.
4. Besides confirming the effect of the 2.24 kg (2 lb) copper treatments (combined), the analysis has shown that, although the total effect was similar for different disease intensities, the way in which it was brought about varies.

SERIES II: COMPARISON OF TIME OF APPLICATION

METHODS

The 1966-67 treatment series was superimposed on the 1965-66 series in the same trial block (Fig. 1).

The 1965-66 trial block was demarcated into plots 101 m (5 chain) wide at right angles to the long axis of the original plots, producing four 101 × 362 m (5 × 18 chain) plots superimposed across part of each of the original treatments. Because of their similar effect, the five 2.24 kg copper per ha (2 lb/ac) treatments were considered as one treatment in the second series. The ineffective oil alone treatment was considered as a nil copper spray control.

This gave 20 subplots 101 × 40.2 m (5 × 2 chain) which had received 2.24 kg

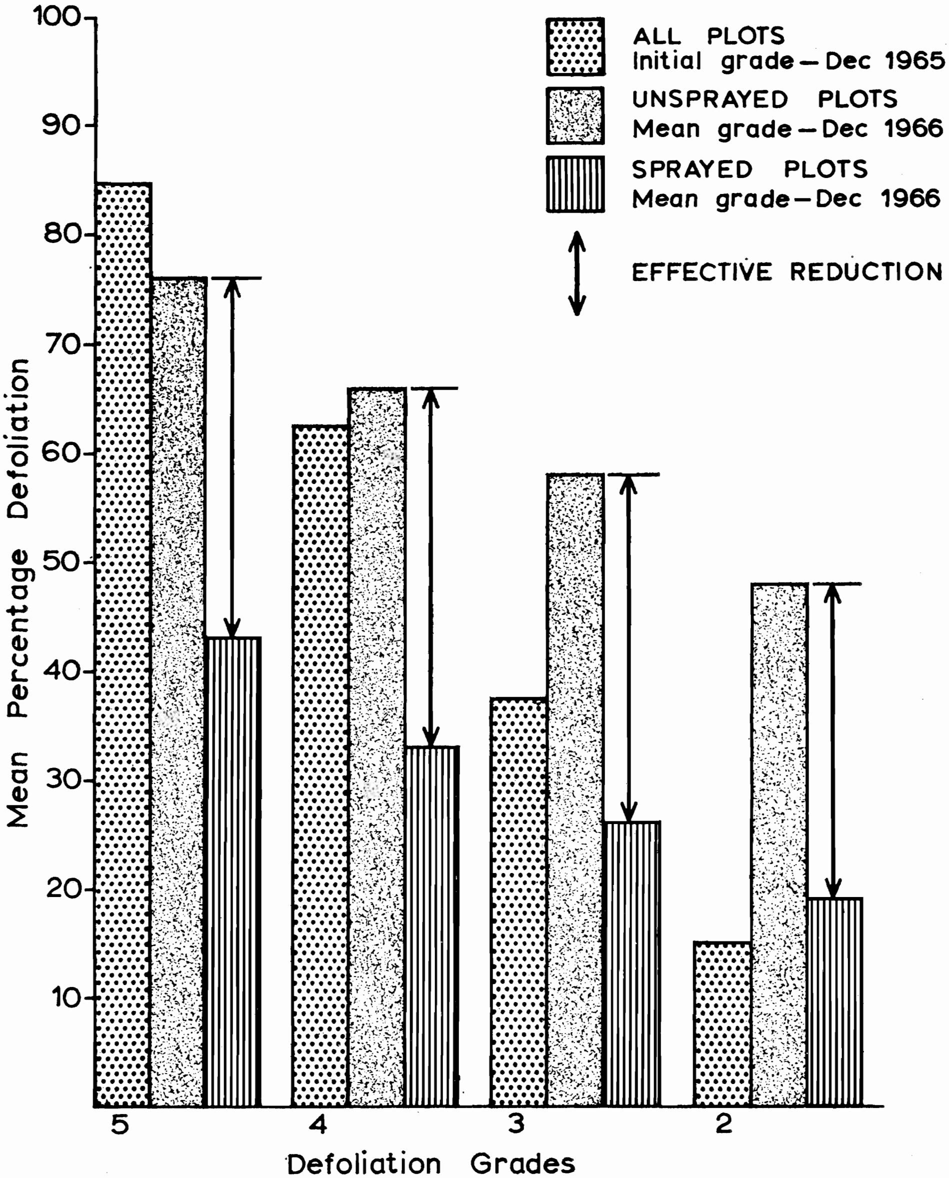


FIG. 4—The effect of the 1965-66 cuprous oxide or copper oxychloride fungicide treatments as expressed by the change within each initial defoliation grade, 12 months after the December 1965 spray application. (Dosage rate per application = 2.24 kg Cu/56 l water/ha = 2 lb Cu/5 gal/ac).

copper m.e./ha (2 lb/ac) in December 1965 and in March 1966, and 12 subplots which had received no copper spray in the first series.

Cuproxide* (Cu_2O) at a dosage rate of 2.24 kg copper m.e. in 56 litres water/ha (2 lb copper in 5 gal water/ac) plus 0.125% v/v Surfac† was applied to the plots as follows:

A. No application
B. One application on 5 December 1966 and another on 22 February 1967
C. One application on 5 December 1966
D. One application on 22 February 1967

Combining the 2.24 kg (2 lb) copper treatments and the nil treatment in the first series with these treatments in the second series, provided eight 2-year treatments as shown in Table 2, which are referred to by a new series of treatment numbers.

TABLE 2—Experimental treatment schedules

Treatment No.	Times of application§ First Series (1965-66 growth season)	Second Series (1966-67 growth season)
T 9	No application	No application
T10	One in Dec + one in Mar	+ No application
T11	One in Dec + one in Mar	+ One in Dec + one in Feb
T12	One in Dec + one in Mar	+ One in Dec
T13	One in Dec + one in Mar	+ One in Feb
T14	No application	+ One in Dec + one in Feb
T15	No application	+ One in Dec
T16	No application	+ One in Feb

§ Nominal dosage rate = 2.24 kg Cu/ha/application = 2 lb Cu/ac/application as a cuprous oxide or copper oxychloride fungicide formulation

Treatments were applied as in the first series, except that the spray plane used was a long wing Cessna 188 Agwagon fitted with a "Transland Swath King" boom and nozzle spray rig‡, and the swath width was *ca.* 20 m (66 ft) because of the extra wing and boom span.

Before spraying, paper spray traps 12.7 × 20.3 cm (5 × 8 in.) were placed horizontally on poles, which were positioned so that they sampled the deposition of the spray in the open between the upper tree crowns. Lines of four traps, with a 20.1 m (1 chain) space between each trap, were placed at 40.2 m (2 chain) intervals along the line of flight (Fig. 1). This provided a 36-trap sample for each 101 m (5 chain) wide treatment. As soon as the deposits had dried, a copper analysis of them was made on an atomic absorption spectrophotometer. Progress in defoliation levels was estimated as in Series 1.

---

* A cuprous oxide wettable powder, 50% w/w copper m.e., formulated by Ivon Watkins-Dow (NZ) Ltd.

† Surfac—a non-ionic surfactant based on ethylene oxide and a resinous bonding agent, manufactured by Ivon Watkins-Dow NZ Ltd.

‡ Manufactured by Transland Ltd, San Francisco, California, U.S.A.

RESULTS

Copper Deposition

As shown in Table 3 the mean copper deposits recovered were between 33% and 66% of the nominal dosage of 2.24 kg per ha, (2 lb/ac). There was little difference in the mean deposits between treatments. Variation within treatments was large, particularly in treatments B and C in December 1966, and B in February 1967. Drift onto unsprayed plots was minimal.

TABLE 3—Copper deposits in kg/ha (lb/acre) on horizontal paper traps between the upper crowns
(Means of 36 traps per treatment)

Treatment Schedules	Dec 1966 appl. Mean	Dec 1966 appl. SEM	Feb 1967 appl. Mean	Feb 1967 appl. SEM
A. Nil	Nil	—	T	—
B. 5/12/66 & 22/2/67	1.23 (1.10)	0.17 (0.15)	1.15 (1.03)	0.15 (0.13)
C. 5/12/66	1.24 (1.11)	0.15 (0.13)	T	—
D. 22/2/67	Nil	—	0.88 (0.79)	0.10 (0.09)

T = < 0.001 kg/ha
Nominal dose = 2.24 kg Cu/ha (2 lb Cu/ac)

Effect of Treatment on the Progress of Defoliation

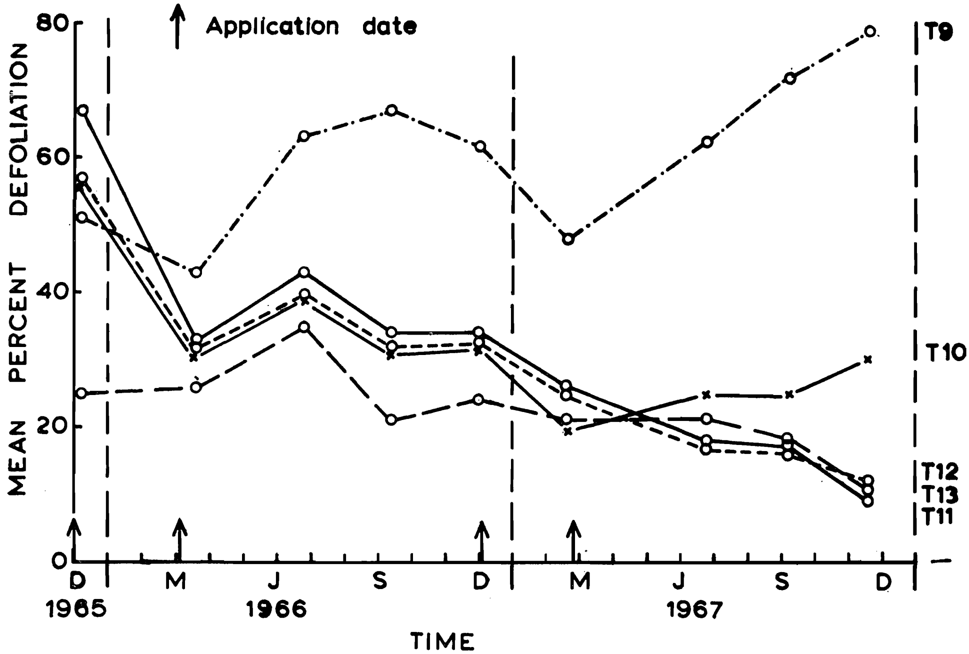
The effect of treatment and timing on mean percent defoliation is presented in Table 4 (12-month assessments) and is illustrated in Figs. 5 and 6 (3-month assessments).

TABLE 4—The effect of the timing and the number of copper fungicide applications on percent defoliation (1965-67)

Treatment No.	MEAN % DEFOLIATION Annual progressions 12/65	12/66	12/67	DEFOLIATION INCREMENT OR DECREMENT Within treatments 1965-66	1966-67
T 9	51	62	79	+ 11	+ 17
T10	56	34	33	— 22	— 1
T11	67	34	9	— 33	— 25
T12	57	34	12	— 23	— 22
T13	25	24	10	— 1	— 14
T14	61	66	28	+ 5	— 38
T15	46	65	34	+ 19	— 31
T16	14	45	44	+ 31	— 1

Fig. 5 indicates that:

1. The double application each year for 2 years (T11) reduced the mean defoliation from 67% to 8% in the second year.
2. The double application in 1965-66 followed by a single application in December 1966 (T12) or a single application in February 1967 (T13) also reduced defoliation to about 10% at the end of 1967.
3. The double application (T10) in 1965-66 followed by no treatment in 1966-67 reduced the mean defoliation level from about 55% to 30% in the first year, and maintained it a little below 30% for a further year.



Spraying combinations		T9	T10	T11	T12	T13
December	1965 :	nil	+	+	+	+
March	1966 :	nil	+	+	+	+
December	1966 :	nil	nil	+	+	nil
February	1967 :	nil	nil	+	nil	+

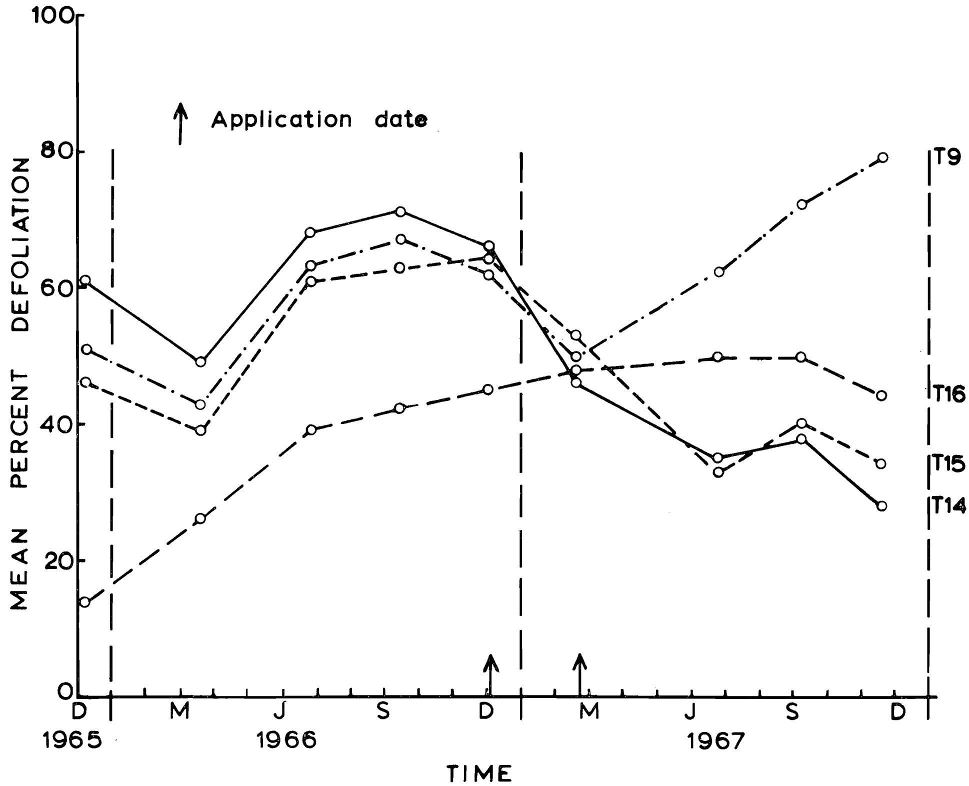
FIG. 5—The effect of different sequences of spraying on **Dothistroma** defoliation of **P. radiata**. (Nominal dosage = 2.24 kg Cu/ha (2 lb/ac), as cuprous oxide or copper oxychloride fungicide, at each application.)

Fig. 6 indicates that without any previous copper applications:

1. Both the double (T14) and the December alone (T15) applications reduced the mean defoliation level from 65% to 30% over 1967.
2. The February alone (T16) treatment reduced defoliation levels but was about 10% less effective than the double (T14) or December alone (T15) application.

The approach to statistical analysis of the effects of Series II treatments was the same as for Series I. The data from those plots which received the same treatment in 1966-67 were combined and grouped into initial defoliation grades as at December 1966. This provided four treatments between which the effects of the second series treatments could be compared:

T9 + T10	unsprayed 1966-67
T11 + T14	sprayed December 1966 and February 1967
T12 + T15	sprayed December 1966
T13 + T16	sprayed February 1967



Spraying combinations		T9	T14	T15	T16
December	1965 :	nil	nil	nil	nil
March	1966 :	nil	nil	nil	nil
December	1966 :	nil	+	+	nil
February	1967 :	nil	+	nil	+

FIG. 6—The effect of a double application of a cuprous oxide or a copper oxychloride fungicide, compared with a single application in December or February, against **Dothistroma** defoliation of **P. radiata.** (Nominal dosage = 2.24 kg Cu/ha/application = 2 lb/ac.)

The effect of the different times of application was compared by an analysis of variance which showed that:

1. There was no interaction between treatment and the initial defoliation grade.
2. The effect of all treatments was highly significant ($p < 0.01$) 9 and 12 months after the December treatment.

Two other results of this statistical treatment of the data are illustrated in Fig. 7.

1. The effect of the single application in December was equal to the double application (December and February), which was an average reduction in defoliation grades of about 50%.

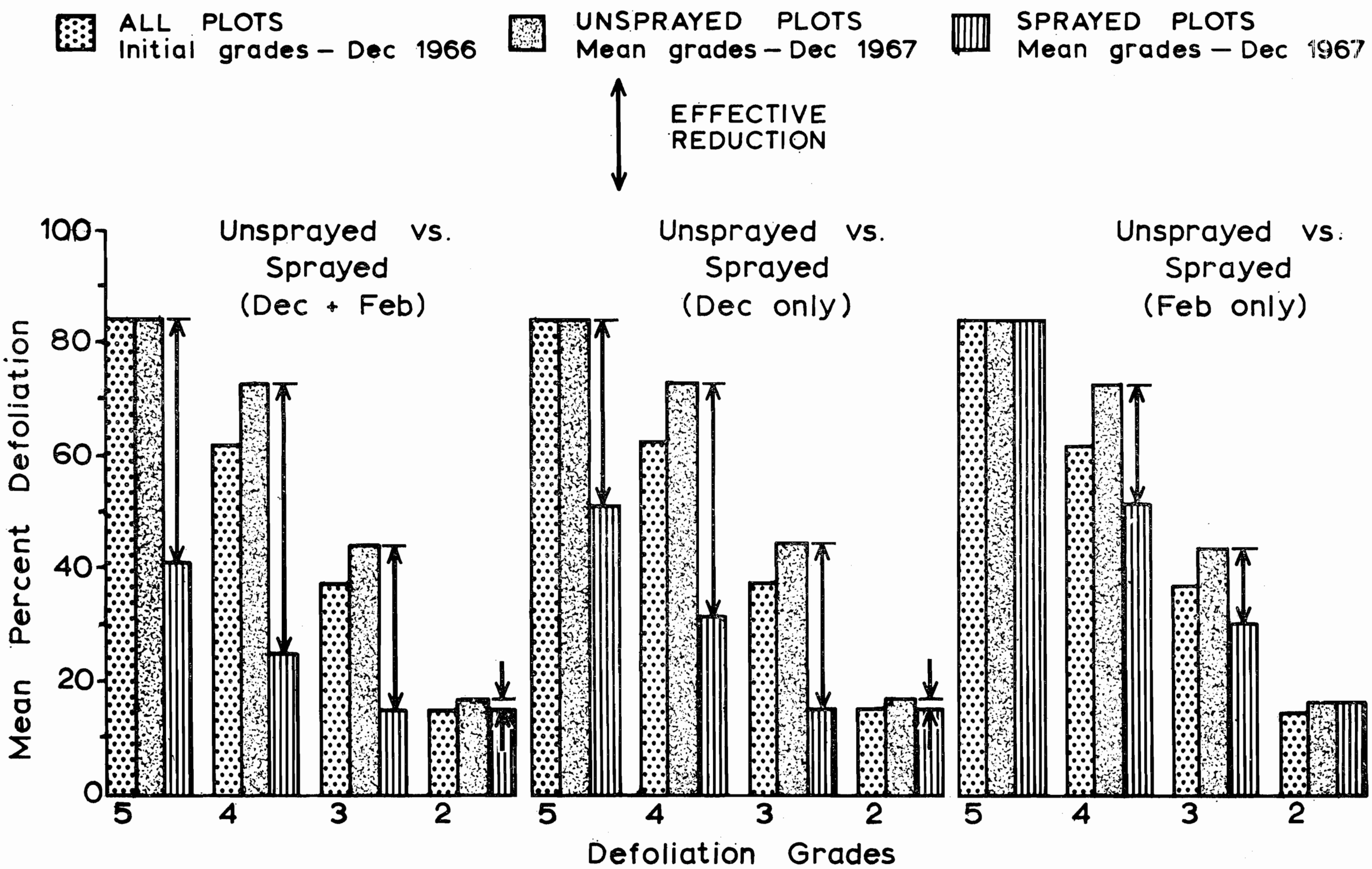


FIG. 7—Comparison of the 1966-67 time of application treatments as expressed by the change within each initial defoliation grade 12 months after the December 1966 spray application. (Nominal dosage rate of a cuprous oxide fungicide = 2.24 kg Cu/ha/application = 2 lb/ac.)

2. The single February application was only half as effective as the single (December) or the double (December and February) application. This difference was not apparent from a simple comparison of the mean percentage defoliation changes as presented in Fig. 5 (T13) and Fig. 6 (T16). (The apparent effect of this treatment on initial defoliation grade 5 is not valid because of the small amount of data in this grade.)

Contrary to the results of the first series, the effect of treatments was not the same on each initial defoliation grade. In particular, the effect of all treatments on grade 2 is minimal compared to the effects on other grades. The apparent anomaly may be because most of the data in this grade were derived from the plots which were sprayed twice in the first treatment series. The effect of this first year treatment was probably carried over into the 1966-67 growth season, with the result that there was little increase in defoliation levels in the unsprayed control plots in the second series in 1966-67.

DISCUSSION

The control over a two-year period obtained by the double application of copper fungicides did not result from persistence of the copper deposits over this whole period. The copper deposits were greatly reduced after 2 months and *ca.* 254 mm (10 in.) of rain, and were almost completely eroded after 3 months and *ca.* 432 mm (17 in.) of rain. The initial persistence of copper undoubtedly provided a long period of protection (*ca.* 4 months) at a critical stage in the development of the new season's foliage. However, it is thought that the slow initial development of this disease, and the rapid height and foliage growth of *P. radiata* in New Zealand are major factors in minimising reinfection of the current year's foliage, following the initial protection provided by the copper fungicide.

A reduction in defoliation from about 60% to about 30% in the first year, followed by a reduction to 20% and then a return to about 30% at the end of the second year after the double spray application (Fig. 7, T10 double spray 1965-66 only), may not appear to indicate a very effective degree of control. However, this 30% defoliation occurs in the lower crown and consists mainly of foliage which is older than 1 year, so that at this level most of the rising 1-year-old needles are unaffected, and the crown appears reasonably normal. D. A. Rook (pers. comm.) found that the fully developed current year's foliage is the most efficient foliage photosynthetically and accounts for about 70% of the crown of a young *P. radiata* at the end of the growing season. Therefore, in order to minimise growth loss it is probably only necessary to protect the upper 70% of the crown. This has been achieved in these trials.

Further evidence to support this hypothesis was provided by Whyte (1968), who used a stem analysis technique to study volume increment in relation to green crown depth in one sprayed and one unsprayed plot in this trial. He found that the gain in volume increment obtained by the double spray in 1965-66 and 1966-67 using 2.24 kg Cu m.e./ha/application (2 lb copper m.e./acre/application) was 10% in 1965-66 and 30% in 1966-67. He also stated "the recovery was so complete that the current annual volume increment of the sprayed trees in this once heavily infected stand is only slightly less than that of comparable uninfected trees".

It may be inferred that a similar gain in growth can be expected from the single

December application since it gave a similar degree of control to that given by the double application. However, further evidence is necessary to confirm this.

Whyte (1968) also stated that "subsequent loss of increment per acre is hardly affected until defoliation becomes greater than 25% of the rising 1-year-old foliage on half the total number of trees in a stand". It is considered that this level of defoliation is comparable to defoliation grade 2 as defined in this paper.

The degree of control obtained was not related to the initial disease intensity; this was apparently due to the difference in the normal development of the disease at the "high" compared with the "low" disease levels, and to the high efficacy of the copper sprays. At the high disease level there was little increase in disease intensity without spraying, and a big decrease after spraying. At the low disease level, the disease intensity increased rapidly wihout spraying, but was almost static with spraying.

The preliminary results of the first treatment series of these trials provided the basis for an operational aerial spray programme which was commenced in December 1966.

The present schedule is to apply an aerial spray of a copper-based fungicide at the rate of 2.24 kg copper m.e. in 56 litres of water per ha (2 lb/5 gal/ac) in November or December, if the mean defoliation level in a stand has reached 25% to 30% of the unsuppressed crown in that year. This schedule has so far been successful, but the frequency of applications required to control the disease within economic limits over one rotaton is still unknown. It will depend largely on the long-term results of operational spraying.

In operational spraying, where unsprayed controls are rarely available, it is easy to conclude that spraying has been ineffective when the defoliation level in lightly infected stands is almost static after spraying. This conclusion may be erroneous as the effect of spraying lightly infected stands was not to reduce the defoliation level at the time of spraying but to prevent the rapid increase in defoliation that may have occurred in the absence of spraying.

CONCLUSIONS

1. Low volume 56 litres per ha (5 gal/ac) aerial application of copper-based fungicides at low dosage rates (2.24 kg copper m.e. per ha or 2 lb/ac) provided effective control of *Dothistroma* needle blight in severely infected young *P. radiata* stands.
2. One application in December followed by a second application 3 months later gave adequate control for 2 years.
3. There was little difference in effect between the four copper-based fungicide formulations, namely, an English cuprous oxide wettable powder (Perenox); a New Zealand manufactured and formulated cuprous oxide wettable powder (Cuproxide); an English copper oxychloride suspension in oil (Brunokop), and a New Zealand-formulated copper oxychloride wettable powder (Stantox Ultra).
4. Although the deposition of the fungicide by aerial application appeared to be inefficient and variable, it was adequate. Residues of copper fungicides on pine foliage were appreciable after 2 months and *ca.* 254 mm (10 in.) of rain, but were almost completely eroded after 3 months and *ca.* 432 mm (17 in.) of rain.
5. Over a 1-year period, a single application in December was as effective as a double

application (December and February) when applied to heavily infected stands, while the single application in February was less effective.

6. The 1.12 kg copper m.e./ha (1 lb/ac) treatment was less effective than the 2.24 kg copper m.e./ha (2 lb/ac) treatments. A spraying-oil alone had no effect.
7. The degree of control obtained was independent of the initial disease intensity.
8. These trials suggest that chemical control of this disease in New Zealand can be readily achieved over substantial areas, even with heavily diseased crops.

ACKNOWLEDGMENTS

The authors wish to thank the FRI Forest Biology Survey team for carrying out the laborious defoliation assessments; Mr P. Knight for his assistance with the copper analysis; the chemical companies for the supply of materials; Adastra Aviation Ltd for expert aerial application; Tuck and Watkins Ltd, and Ellis & Burnand Ltd for allowing these trials to be conducted in their plantations, and the FRI Biometrics Section for the preparation and running of computer programmes to sort out data by initial grades.

REFERENCES

GIBSON, I. A. S. 1965: Recent research into **Dothistroma** blight in Kenya. **Agricultural and Veterinary Chemicals 6:** 39-42.

GIBSON, I. A. S. 1967: The distribution, impact and control of a foliage disease of pines in Africa caused by **Dothistroma pini** Hulbary. **Proceedings of the 14th Congress of the International Union of Forest Research Organisations, Munich, 1967, 5:** 209-20.

GIBSON, I. A. S., KENNEDY, P., and DEDAN, J. K. 1966: Further observations in Kenya on a foliage disease of pines caused by **Dothistroma pini** Hulbary. II. Investigations into fungicidal control of the disease. **Commonwealth Forestry Review 45:** 67-76.

GILMOUR, J. W. 1967a: Distribution and significance of the needle blight of pines caused by **Dothistroma pini** in New Zealand. **Plant Disease Reporter 51: 727-30.** (N.Z. Forest Service Reprint No. 340).

GILMOUR, J. W. 1967b: Distribution, impact and control of **Dothistroma pini** in New Zealand. **Proceedings of the 14th Congress of the International Union of Forest Research Organisations, Munich, 1967, 5:** 221-48.

HOCKING, D. 1967: **Dothistroma** needle blight of pines. II. Chemical Control. **Annals of Applied Biology 59:** 363-73.

HORSFALL, J. G. 1945: "Fungicides and their Action". Chronica Botanical Co., Waltham, Mass. 239 pp.

PEARSON, A. J. A. 1958: Banana spraying with mineral oil—a new control for leaf spot. **Span 3:** 2-4.

PETERSON, G. W. 1965: **Dothistroma** needle blight of Austrian pine: infection and control. **Plant Disease Reporter 49:** 124-6.

PETERSON, G. W. 1967: **Dothistroma** needle blight of Austrian and ponderosa pines: epidemiology and control. **Phytopathology 57:** 437-41.

SCHISCHKINA, A. K., and TZANAVA, N. I. 1966: Study of red needle spot of pine in Georgia. **Trudy Instytuta zashchity rastenii. Tbilisii 18:** 285-95.

THOMAS, J. E., and LINDBERG, G. D. 1954: A needle disease of pines caused by **Dothistroma pini. Phytopathology 44:** 333 (Abstr.).

WHYTE, A. G. D. 1968: **In N.Z. Forest Service, Report of Forest Research Institute for 1968,** p. 52.