

CHLOROSIS OF DOUGLAS FIR

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Summary

Chlorosis followed by stagnation of up to 80% of the newly established Douglas fir at Akatore, Berwick, and Herbert State Forests is described. Field investigations indicated that this condition was caused by the poor development of a particular type of mycorrhiza in the heavy clay soils occurring in these forests and in Milton nursery. Only stands established with Milton raised seedlings have been severely affected. Interim results from planting trials showed that Tapanui seedlings and Milton seedlings treated with duff in the field, were far superior to untreated Milton seedlings in transplantability and survival. Lack of mycorrhizal development in Milton nursery appeared to be due to the absence of proper inoculation, certain unfavourable nursery practices and possibly periodic anaerobic soil conditions.

INTRODUCTION

The development of a chlorotic moribund condition in young Douglas fir (*Pseudotsuga taxifolia* (Poiret) Britton) has been alarmingly evident in the establishment of a number of plantations in the South Island of New Zealand.

In 1939, at Golden Downs State Forest, early chlorosis was reported by Forest Ranger R. E. Lawrence. He believed that this condition was caused by the absence of all the appropriate mycorrhizal fungi in certain nurseries. He also saw similar symptoms in newly established Douglas fir grown at Ashley State Forest in 1940. Here it was supposed to have been corrected by the addition of duff collected from under established stands of Douglas fir at Hanmer. Unfortunately his ideas and observations were not adequately recorded or investigated at the time.

In 1954 a similar chlorotic condition of Douglas fir was reported from Berwick, Herbert and Akatore State Forests, near Dunedin in the South Island.

All areas of this species established since 1949 in these forests, using seedlings raised in Milton nursery, showed many sickly yellow, stagnating trees scattered at random among apparently healthy fast growing trees. The purpose of this paper is to describe this early chlorotic moribund condition of Douglas fir in newly established areas, to discuss its probable cause and remedy, and to present interim results of two field trials.

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SYMPTOMS

A. *Foliage and stem growth.* The first sign of an abnormal condition is shown by the transplants within the first growing season in the plantations. The light green new growth instead of darkening in colour as it matures, becomes progressively more yellow, and the mature seedling foliage, which at the beginning of the season was dark green, also becomes yellow. Initial growth is often quite good but is arrested after the first flush of spring. In subsequent years many of these transplants slowly starve and finally die while others change from sickly yellow trees into green healthy ones which thereafter grow vigorously.

It was observed on two occasions that trees which have existed for six years in this moribund condition suddenly recovered completely during one growing season and from thereon grew normally.

Usually about 50 per cent. of the established trees are severely affected. However, on poor exposed sites the effect appears more pronounced, with fewer trees surviving the first year. Of these only 30 - 50 per cent. are green and even their growth is retarded and malformed. In both cases the resulting young stand is made up of chlorotic moribund trees scattered among a few healthy ones. If this stagnation persists for 5 or 6 years, many of the moribund trees die. During this time on favourable sites the healthy may grow 12 - 15 ft. and, since these are open grown, a very undesirable type of tree is formed. (Plate 1).

B. *Root systems.* The root systems of the green thriving trees are extensive, fibrous and possess an abundant complement of mycorrhizal short roots, predominantly of one particular type. These mycorrhizae which are white, plump, compact, pinnately branched structures, are readily observed and identified. In contrast the chlorotic plants either possess a poor complement of brown, open monopodially branched mycorrhizal roots or lack mycorrhizae altogether. That part of the rooting system formed in the nursery usually possesses the brown type of mycorrhiza whereas the part formed after transplanting is devoid of mycorrhizae. Within the first year after transplanting, the long roots grow about six inches. These long roots produce many short roots which usually remain unbranched, retain their root hairs and remain uninfected by mycorrhizal fungi. (Plate 2.)

The intermediate yellow-green plants usually have a few mycorrhizal clusters of the white pinnate type. These clusters first appear on the upper parts of the older roots. In fully recovered trees the whole feeding system becomes mycorrhizal with the formation of mycorrhizae predominantly of the white pinnate type.

C. *Nursery Stock.* All the seedlings planted in the forests under investigation were raised in Milton nursery which is situated on heavy clay agricultural land within 15 miles of Berwick State Forest. The chlorotic moribund symptoms did not develop in the nursery. The Milton seedlings appeared particularly healthy and vigorous, being



Plate 1.—Douglas fir, Compt. 31, Berwick Forest, nine years old. Note variation in tree height (3-20 ft) and open habit of large trees. The smaller trees had been chlorotic and in check for seven years but recovered their green colour during the winter, 1956, and as can be seen are now growing vigorously.

uniformly green, sturdy plants, averaging about 1 foot 3 inches in height in two years, with very extensive fibrous rooting systems.

About half the rooting system is usually mycorrhizal, predominantly of the brown monopodially branched type. Occasionally, in seedlings 2 or more years old, the white pinnate branched type is also present.

Certain local nursery practices together with a heavy clay soil are considered to have been unfavourable for the build-up of the Douglas fir mycorrhizal fungus complement for the following reasons:

1. No inoculation with duff from under established Douglas fir in this part of the country had been made. The nearest source from which natural inoculation could take place is about 25 miles away.
2. While the nursery was not in full production it was the practice to rest the ground for two years between lifting one crop and sowing another.

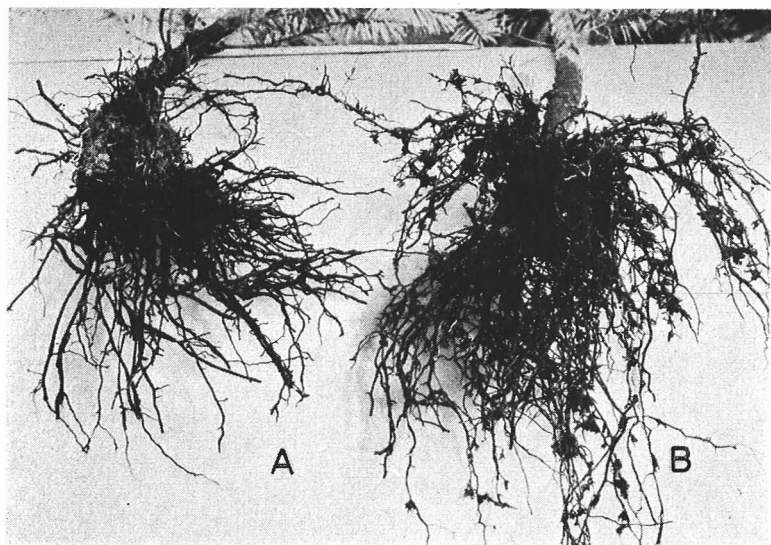


Plate 2—Typical root systems of two types of Douglas fir after one growing season, from Herbert Forest.

- A. A chlorotic tree showing only simple, unbranched, non-mycorrhizal short roots.
- B. A green tree showing abundant, pinnately branched, mycorrhizal short roots which are white in colour.

3. Intensive cultivation was carried out during this resting period and large quantities of straw (20 tons per acre) and green crops (wheat) were turned in to improve the tilth.
4. Since 1946, when the nursery was established, Douglas fir has not been raised in ground that had previously grown this species.
5. Due to slow natural drainage and the high water holding capacity of this heavy clay soil this nursery becomes saturated for most of the winter and early spring. Although a great deal has been done to alleviate this water-logging of the soil, many depressed parts of this nursery do still become saturated for some time, following periods of heavy rain.

Presuming that some natural inoculation of one crop did occur, the mycorrhizal fungi would have very little chance of becoming abundantly established and benefiting any later crop.

Douglas fir seedlings from Tapanui nursery, which is bounded by healthy 50-year old Douglas fir, have a quite different type of rooting system and their foliage is a darker green than that of those produced

in Milton nursery. All short roots on the Tapanui seedlings were found to be mycorrhizal and were predominantly of the white pinnate type.

STUDY OF THE POSSIBLE CAUSES

It was first thought that some factor of the planting sites was responsible for the malnutrition of the trees since the nursery stock appeared vigorous and healthy. Usually a mycorrhizal deficiency shows up in the nursery (as Lawrence found at Golden Downs and Ashley). Various factors, including topography, degree of exposure, weed competition, age and size of planting stock and molybdenum deficiency, were considered and discounted.

A general analysis of the soils made by the Agriculture Department showed that the general fertility was marginal by agricultural standards but the content of major soil nutrients was sufficiently high to promote good tree growth. This, of course, was demonstrated by the fact that up to 50 per cent. of the trees were healthy and vigorous and by the random distribution of chlorotic trees which was not consistent with the low fertility theory.

However, analyses of the soils in Compts 34 and 35, Berwick Forest, and in one block of Milton nursery where experiments were later carried out, were made and the results are summarised in Table 1.

TABLE 1.

Chemical soil analysis. Summary of samples from the top six inches.

Location	pH	P ₂ O ₅		%C	%N	C/N	TEB	CEC	%BS	Ca	Mg	K
		av.	p.p.m.									
Milton Nursery	5.0	340	1.73	.20	9	4.4	11.5	38	4.95	0.54	0.26	
Berwick Forest	5.7	180	1.7	.14	12	5.6	11.5	50	3.6	1.8	0.31	

These figures indicate that chemically both soils contain adequate amounts of the major nutrients for satisfactory growth of Douglas fir. Also, except for the moderately high available phosphate level in the nursery, there is no factor shown here to explain why non-mycorrhizal plants should do well in the nursery but fail in the forest.

An anaerobic condition which may develop in these heavy clay soils is a factor which has only recently been considered. Following the very wet winter and spring of 1957 and summer 1958, chlorosis developed in previously healthy green mycorrhizal trees in the field, and it is felt that this factor deserves further investigation.

After consideration of the above facts and symptoms, it was thought probable that, for normal growth of Douglas fir on these forest soils, a high percentage of the seedlings lacked a particular type of mycorrhiza. This lack was further thought to be caused by inadequate inoculation of Milton nursery by one or more mycorrhizal fungus, or some soil factor which prevented the growth of the mycorrhizal fungi in the nursery and/or the field. To test this theory, four trials were planned and they consisted broadly of:

- A. Inoculating ordinary Milton nursery seedlings at time of planting at Berwick with mycorrhizal material using several methods.
- B. Planting untreated Milton nursery seedlings alongside untreated Tapanui nursery seedlings at Berwick State Forest.
- C. Treating Milton nursery beds with mycorrhizal material and planting out at Berwick Forest the 2/0 seedlings raised in them.
- D. Pure culture synthesis of the mycorrhiza.

Trials A and B will be reported on here, but C and D will be the subject of later publications.

EXPERIMENTAL

A. *Inoculation of Milton seedlings—Berwick Forest.*

In this trial 2/0 Douglas fir, grown by normal nursery practice at Milton nursery, was treated by two methods with forest duff and by one method with mycorrhizal fungus fruiting bodies. The duff-treated seedlings were planted at Berwick State Forest immediately after treatment in August 1955 and at the same time the seedlings for the fruiting body treatment were planted at Berwick Forest, but were not treated until June 1956, eleven months later. The forest duff was collected from under healthy 23-year old Douglas fir in the Ross Creek Reservoir Plantation belonging to the Dunedin City Corporation. The duff consisted of the litter layer together with the upper half inch of mineral soil.

All trees were planted by one local planter using a grubber, which is the usual practice in this area.

The soil was so saturated that the planting hole quickly filled with water as the tree was planted. From December to April there was only about 6.0 inches of rain, about half the mean. Under these dry conditions the heavy clay soil caked and the cracks made by the grubber opened up, exposing a considerable portion of the roots.

Treatments.

1. *Control*: This consisted of untreated 2/0 Milton nursery seedlings.
2. *Duff inoculation during planting*: This consisted of 2/0 Milton seedlings inoculated when planting out by adding a handful of duff to the planting hole before the tree was inserted.
3. *Duff inoculation during puddling operations*: This consisted of 2/0 Milton seedlings inoculated with duff by adding two shovels full of duff to 5 gallons of clay puddle. The tree roots were then dipped in this mixed puddle until thoroughly coated and allowed to drain.
4. *Fungus fruiting body inoculation*: This consisted of 2/0 Milton seedlings planted out as were the controls and treated eleven months later with a water suspension of macerated fruiting bodies of fungi suspected of forming Douglas fir mycorrhizae in this part of the country. Each tree was watered with a pint of this thick suspension made up from the following species:

Boletus sp. (This species, as yet unidentified, which was very plen-

tiful under Douglas fir at Tapanui and Dunedin, made up the main bulk of the inoculation material.)

Amanita muscaria (a few).

Paxillus involutus (a few).

Lycoperdon perlatum (a few).

B. Trial of Seedlings from two nurseries.

1. Untreated 2/0 Milton Nursery seedlings.

2. Untreated 2/1 Tapanui Nursery seedlings.

Unfortunately 2/0 Tapanui seedlings could not be obtained.

Plot Design.

The two trials were incorporated in a sample plot which was planted in Compartments 34 and 35 at Berwick State Forest. The area was considered to be a good site for Douglas fir.

Ten $\frac{1}{10}$ th acre subplots, each half a chain by two chains, were marked out in two adjacent blocks with five subplots in each block. Each subplot was separated from the next by an unplanted area of equal size. The subplots were arranged side by side in such a way that no plot drained into another. 132 trees were planted per plot at 6' x 6' spacing. The number of subplots allowed two replications to be made.

Results.

An inspection of the plot trials was made in the autumn of 1956 and in the following spring. A mortality count was made and the colour of the foliage of each tree was classified into one of three classes, viz., green, yellow-green, yellow. It was found that it was difficult to carry out this classification when the spring growth was

TABLE 2.

Tree colour and mortality of Douglas fir in trials at Berwick Forest as at 6/11/56

Treatment	Plot	Number of Trees				Total	
		Foliage Colour					
		Green	Yellow-Green	Yellow	Dead		
Control untreated 2/0	1	32	15	42	43	132	
Milton seedlings	2	15	18	58	41	132	
Totals		47	33	100	84	264	
Untreated 2/1 Tapanui	1	106	5	5	16	132	
seedlings	2	129	2	1	0	132	
Totals		235	7	6	16	264	
2/0 Milton seedlings	1	90	3	0	39	132	
with duff in planting	2	116	2	0	14	132	
hole	Totals		206	2	0	53	264
2/0 Milton seedlings	1	94	3	2	33	132	
puddled in clay + duff	2	118	7	0	7	132	
Totals		212	10	2	40	264	
2/0 Milton seedlings	1	25	21	29	57	132	
treated with fungus	2	36	22	32	42	132	
Sporophores	Totals		61	43	61	99	264

still soft, for at this stage the new season's needles are a lighter shade of green, even on the "green" trees, and the yellow colour of the needles on the moribund trees tends to become more pronounced as the season progresses. Mortality and foliage colour classification figures are presented for each plot in Table 2 and these figures are summarised for each treatment in Table 3. The histogram presented in Figure 1 illustrates this data.

TABLE 3.

Summary of data for tree colour and mortality of Douglas fir in trials at Berwick Forest as at 6/11/56.

Treatment	As a % of the living trees			% of Total	
	Foliage Colour			trees planted	
Control untreated 2/0 Milton seedlings	26	18	56	32	68
Untreated 2/1 Tapanui seedlings	95	3	2	6	94
2/0 Milton seedlings with duff in planting hole	98	2	0	20	80
2/0 Milton seedlings puddled in clay + duff	95	4.5	0.5	15	85
2/0 Milton seedlings treated with fungus sporophores	37	26	37	38	62

Comparison between Field Trials of Tapanui stock and Milton stock.

The untreated Tapanui seedlings were far superior to the untreated Milton seedlings in both colour and survival when planted at Berwick State Forest. (Plate 3 and 4.)

Response of Milton Stock to treatments. (Plate 5 and 6.)

The response of the Milton seedlings treated with duff by both methods was quite spectacular within the first year after planting out. In both instances the treatment produced more than a 60 per cent. improvement in the number of green trees. Also the total number of green trees produced by these treatments was closely comparable to that obtained from the Tapanui seedlings.

In the control, less than a quarter of the living seedlings were green, while about 95 per cent. of the duff treated Milton seedlings and the untreated Tapanui stock were green.

Mortality in the duff treatments was also lower than that in the control but was greater than that in the plots of untreated Tapanui seedlings.

Only a small response was shown by the trees which were treated with mycorrhizal fungus fruiting bodies. At the time of treatment nearly 80 per cent. of the living seedlings in this plot had developed chlorotic symptoms and in half of these the yellowing was very pronounced. It might be expected that such trees would take longer to respond to treatment than the transplants which were vigorous when treated. The figures for this treatment were obtained in the

spring of 1956, only seven months after treatment. A more conclusive result is expected after a later inspection.

Future observations on these experiments will be restricted to the second block only, the first block of subplots being accidentally destroyed in the summer of 1957.

SUMMARY OF OBSERVATIONS

1. Up to 80 per cent. of the Douglas fir, some 470 acres, planted at Akatore, Berwick and Herbert State Forests has shown chlorotic moribund symptoms for periods from one to six years.

2. Milton nursery seedlings developed these symptoms when planted out in trials at Berwick while Tapanui nursery seedlings did not.

3. In their first growing season, the development of this condition in Milton nursery seedlings was prevented in about 90 per cent. of the trees planted in the 1955 trials, by treating them by either of two methods with forest duff:

(a) By puddling the roots of the seedlings in a mixture of clay and forest duff (7 : 3) when preparing the seedlings for planting out.

(b) By the inclusion of a handful of forest duff in the planting hole as the trees were planted in the forest.

Note: It could be argued that the improvement given by treatment (b) (duff in the planting hole) could be attributed to a compost effect. Such an argument could not be used to explain the improvement obtained by treatment (a) (duff in the puddle), for in this case very little duff would be retained by the roots of each plant.

4. When established trees which had developed the stagnating symptoms over a one year period were inoculated with fruiting bodies of suspected mycorrhizal fungi, little response was evident seven months after treatment.

5. The root systems of the green trees possessed an abundance of mycorrhizal roots and the mycorrhizae were predominantly of the white pinnate type. (Plate 2).

6. The root systems of the chlorotic trees were predominantly non-mycorrhizal, the few mycorrhizae which were sometimes present being of the brown monopodial type (Plate 2).

7. The brown monopodial type of mycorrhiza was common on the Milton nursery seedlings. The white pinnate type was abundant on the Tapanui seedlings but seldom occurred on the Milton seedlings.

CONCLUSIONS

These observations strongly indicate that the chlorotic condition developed in Douglas fir planted at Akatore, Berwick and Herbert State Forests, using seedlings raised in Milton Nursery, was due to an inadequate mycorrhizal development on the seedlings.

The mycorrhizal deficiency could be attributed to the absence of artificial inoculation in the nursery and inadequate natural inoculation in the nursery and in the field, with Douglas fir mycorrhizal fungi.

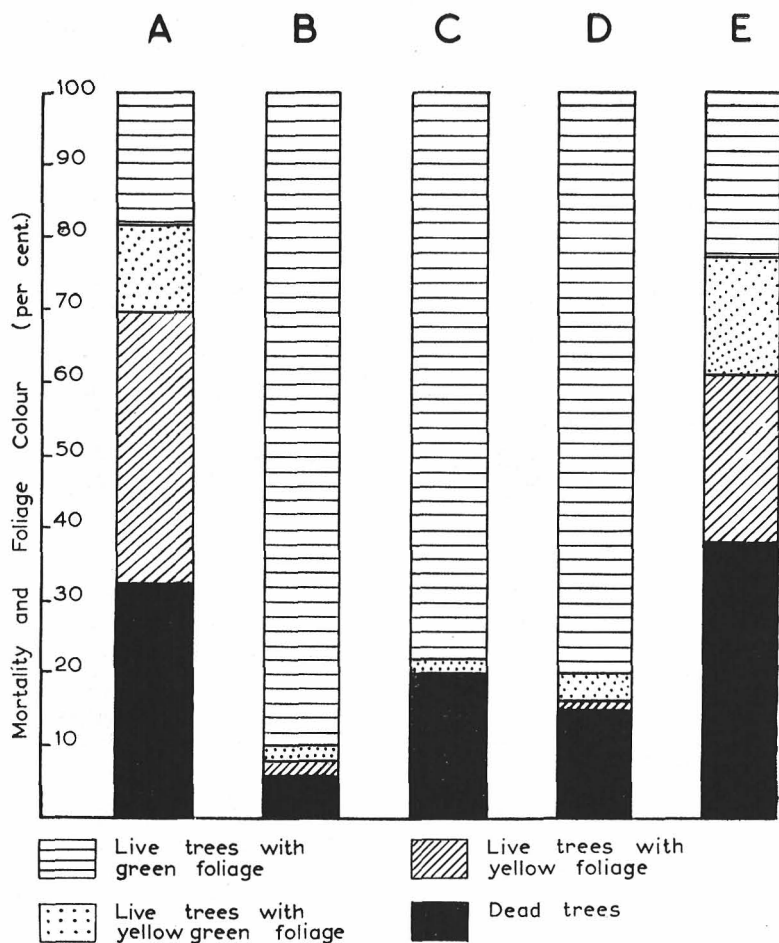


Figure 1. Mortality and foliage colour of Douglas fir established at Berwick Forest using Milton Nursery stock (four different treatments) and Tapanui Nursery stock (one treatment), fifteen months after planting.

- Milton seedlings untreated.
- Tapanui seedlings untreated.
- Milton seedlings treated with duff in the planting hole.
- Milton seedlings treated with duff in the puddle.
- Milton seedlings treated with fungus sporophores.



Plate 3.—Berwick trials, subplot 2A., Control, untreated 2/0 Milton Douglas fir photographed 3 years after establishment. Note variation in height growth and numerous blanks. The small trees are chlorotic. Mean height 2.0 ft., more than $\frac{3}{4}$ are under 2 ft. 6 inch. Survival 68%.



Plate 4.—Berwick trials, subplot 2B., Untreated 2/1 Tapanui Douglas fir photographed 3 years after establishment. Mean height 3 ft. 10 inches, nearly $\frac{2}{3}$ are between 3 ft. 7 inch and 6 ft. 6 inches. Survival 98%.



Plate 5.—Berwick trials, subplot 2C., 2/0 Milton Douglas fir treated with a handful of duff in the planting hole, photographed 3 years after establishment. Mean height 2 ft. 10 inches; over half the trees are between 2 ft. 7 inches and 5 ft. 6 inches. Survival 98%.



Plate 6.—Berwick trials, subplot 2D., 2/0 Milton Douglas fir treated by puddling in a clay and duff puddle. Mean height 2 ft. 11 inches. About $\frac{2}{3}$ are between 2 ft. 7 inches and 5 ft. 6 inches. Survival 95%.

Also it is suggested that local nursery practices and possibly seasonal anaerobic soil conditions were not always favourable for the development of established mycorrhizae.

A white pinnate type of mycorrhiza appeared to be the most efficient for the growth of Douglas fir in Akatore, Berwick and Herbert State Forests.

Acknowledgement is made of the work of Dr K. Strzemienski, of the Soil Bureau, D.S.I.R. He confirmed the opinion that the trouble was probably due to lack of mycorrhiza and made suggestions, some of which were incorporated in the present investigations.