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WORK PLAN NO.: **EXPERIMENT NO.:**

TITLE: REVIEW OF DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII*) NUTRITION IN NEW ZEALAND

AUTHOR(S): T.W. PAYN AND J.A.C. HUNTER-SMITH

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KEYWORDS: DOUGLAS FIR, PSEUDOTSUGA MENZIESII, NUTRITION

ABSTRACT*

This report for the Douglas-fir Cooperative summarises the state of nutritional knowledge on this species in New Zealand. It covers foliar nutrition, forest health surveys, past fertiliser trials and other nutrition related research. A bibliography is included. Recommendations for future research needs are made.

* **Note: This material is unpublished and must not be cited as a literature reference.**

Review of Douglas-fir (*Pseudotsuga menziesii*) nutrition in New Zealand.

T.W. Payn and J.A.C. Hunter-Smith
Soils and Site Productivity Group,
N.Z. Forest Research Institute
Private Bag 3020
Rotorua.

INTRODUCTION.

A review of the state of knowledge of the nutritional characteristics of Douglas-fir in New Zealand was requested by the newly established Industry/NZ FRI Research Cooperative in 1993. This report contains that summary. Douglas-fir makes up approximately 5% of New Zealand's plantation resource (NZFOA, 1993), but has received little research emphasis compared to that of radiata pine in recent years. Given the increasing interest in the species, and value of the timber, a shift in emphasis has been seen. This review covers nutritional information available in New Zealand, a summary of past research carried out and a synthesis and recommendations for Douglas-fir nutritional research in the future.

EXISTING FOLIAGE DATA

The foliage database kept at the NZ FRI Forest Nutrition laboratory was searched for all data on Douglas-fir. There were only 157 records on the database, and the majority of these were associated with three fertiliser trials, the remainder were diagnostic samples submitted for fertiliser prescription. Although the analytical results are likely to have been affected by fertiliser treatments, summary statistics for each element are shown in Table 1.

Table 1. Summarised foliage data for Douglas-fir samples available on the NZ FRI Forest Nutrition Database.

	N	P	K	Ca	Mg	B	Fe	Mn	Zn	Cu	S	Al	Na	Cl
	g.kg^{-1}					mg.kg^{-1}					g.kg^{-1}			
Mean	15.6	1.7	9.3	3.1	1.1	23	55	294	25.2	3.7	1.5	0.17	0.16	0.52
S. dev	2.91	0.54	2.81	1.73	0.23	13	8.9	227	12.2	0.85	0.18	0.06	0.04	0.11
Min	5.1	0.5	2.1	1.4	0.6	7	4	90	9.0	1.4	1.1	0.11	0.10	0.36
Max	23.8	3.2	15.1	9.4	1.8	63	68	1095	51.0	5.1	1.7	0.27	0.24	0.69

NB. Concentration of all elements except B, Fe, Mn, Zn and Cu are expressed as g.kg^{-1}, this is different to the %dm commonly used in NZ and can be converted to %dm by division by 10. In future reporting these new units will be used in line with international practice.

Published 'critical levels'

A series of critical levels for Douglas-fir were obtained by the NZ FRI from Canada (reference unknown), and others were extracted from published literature, these are summarised in Table 2. These critical levels refer to the foliar nutrient concentration below which growth is likely to be reduced due to a deficiency of that particular element. Compared to *P. radiata* critical levels for New Zealand the levels seem relatively high, especially the Canadian values and those of Turner *et al.* (1988). Generally P, K and Ca levels are high compared to radiata while published Mg levels are very variable. Given that Douglas-fir is slower growing than radiata this may indicate that the critical levels in New Zealand may be lower than those from overseas.

Table 2. Critical levels for Douglas-fir from literature.

Element	Walker & Gessel (1991)	Binns *et al.* 1980	Powers (1983)	Turner *et al.* 1988	Canada	*P. radiata* Will 1985)
Nitrogen ($g.kg^{-1}$)	12.5	12.0	12.0	17.0[1]	18.0	12.0
Phosphorus ($g.kg^{-1}$)	1.6	1.8	1.5	-	2.0	1.1
Potassium ($g.kg^{-1}$)	6.0	6.0	6.0	-	10.0	3.5
Calcium ($g.kg^{-1}$)	2.5	-	1.2	-	5.0	1.0
Magnesium ($g.kg^{-1}$)	1.7	0.4	0.6	-	2.0	0.7
Sulphur ($g.kg^{-1}$)	3.5	-	-	-	-	-
Boron ($mg.kg^{-1}$)	20	-	-	-	-	8

Fertiliser experiments in New Zealand.

Two fertiliser trials are on record in the Nelson region. In the first trial (NN468) nitrogen was applied to a 15 year old stand at 100, 200 and 300 $kg.ha^{-1}$. Three years after fertilisation there had been no improvement in either foliar nutrient concentrations or tree growth in the treated plots. Foliage concentrations are shown in Table 3.

Table 3. Foliar nutrient concentrations in NN468 three years after trial establishment.

Treatment $kg.ha^{-1}$	N	P	K	Ca	Mg	B
	$g.kg^{-1}$					$mg.kg^{-1}$
0 N	14.0	1.3	7.0	5.2	1.5	31
100 N	13.9	1.6	8.6	5.7	1.4	30
200 N	14.6	1.3	8.0	4.5	1.5	30
300 N	15.0	1.1	7.4	5.7	1.4	30

The second trial in Nelson (NN412) was in a 45 year old stand of Douglas-fir that had recently been thinned. Nitrogen was applied at the rate of 200 $kg.ha^{-1}$ but did not improve either tree growth or foliar concentrations of N, P or B (Table 4).

Table 4. Foliar nutrient concentrations in NN412 following fertilisation with nitrogen

Treatment $kg.ha^{-1}$	N	P	B
	$g.kg^{-1}$		$mg.kg^{-1}$
0 N	13.5	2.1	22
200 N	13.4	2.2	18

A trial in Southland (SD622/1) where foliar P concentrations were 0.6 $g.kg^{-1}$ showed a strong response to a mixture of N and P fertiliser. Treatment consisted of 500 $kg.ha^{-1}$ DAP in 1980, followed by 400 $kg.ha^{-1}$ Urea in 1981 and a follow up of 500 $kg.ha^{-1}$ in 1984. Foliar P concentration was raised from 0.6 $g.kg^{-1}$ to 1.6 $g.kg^{-1}$ two years after fertiliser application and diameter increment doubled. Belton and Davis (1986) reported successful treatment of a phosphorus deficiency in 18 year old Douglas-fir growing on a yellow brown earth in the Canterbury high country. Foliar P concentrations were 0.8 $g.kg^{-1}$ in the area showing poor health, while adjacent healthy looking stands had foliar P concentrations of 1.0 $g.kg^{-1}$. An application of 100 $kg.ha^{-1}$ P more than doubled basal area growth and shoot growth increased by 38% two growing seasons after trial establishment. No response to N, (foliar concentration 9.0 $g.kg^{-1}$), was recorded.

A fourth trial, RO2015/2, was established in 1985 plantings in Whakarewarewa forest. Foliage analysis was conducted on this trial, and it appeared that the fertiliser treatment had had no effect on foliar nutrient concentrations. The trial has not yet been written up and no growth response data is readily available.

Three studies into the biomass production of Douglas-fir have been done, two are published (Kay 1978, Madgwick 1982) and the third is presently being undertaken by Nordmeyer and co-workers at three South Island high country sites. This third study will yield considerable nutritional information relating to the growth patterns and nutrient uptake rates of the species. The other two studies did not investigate nutrient contents in NZ Douglas-fir stands.

The results presented here suggest that critical foliar concentrations for N and P are likely to be lower than some of the published overseas figures. Growth responses to N were not recorded where foliar concentrations were of the order of 13 to 14 $g.kg^{-1}$, so critical levels are likely to be below this. For phosphorus, a growth response at 0.8 $g.kg^{-1}$ was reported by Belton and Davis (1986) where healthy stands had a concentration of 1.0 $g.kg^{-1}$. A response was obtained at 0.6 $g.kg^{-1}$ in the trial in Southland. This would suggest that critical levels may be around 1.0 $g.kg^{-1}$.

NZ FRI Forest Health Database.

This database contains summaries of forest health surveys carried out in New Zealand since the 1960s. A search for record associated with Douglas-fir produced the listing shown in Appendix 1. Records are based on visual observations and comments are included. Of interest is the common reference to early problems with poor myccorhizal infections. This species does very poorly in the absence of mycorrhizae, or the presence of an unsuitable type. This problem was eliminated once all nurseries were infected with suitable mycorrrhizal species which ensured a good crop of mycorrhizae of planted seedlings. Given the interest in increased D. fir planting and the establishment of new nurseries to serve the forestry industry this aspect should not be overlooked. General chlorosis has been reported from a number of forests around the country, but this has rarely been followed up with foliage analysis except in the Nelson region where a number of diagnostic foliage tests have been performed confirming low N and P concentrations in some instances.

Nutritional experience internationally.

Nutrient deficiencies in Douglas-fir reported internationally have included nitrogen, phosphorus, potassium, magnesium, boron, copper, iron and manganese. The majority of research has been on nitrogen nutrition. Growth responses to fertiliser have been reported for most elements. A good general summary is the booklet produced by Walker and Gessel (1991). The importance of foliar and soil N:P ratios and soil C:N ratios in predicting responses to N and P was indicated in a number of references (Radwan *et al.* 1991, Gessel *et al.* 1990, Mohren *et al.* 1986, Edmonds and Hsiang 1987, Peterson *et al.* 1984)

Future direction of Douglas-fir Nutritional Research in New Zealand.

In summary the information related to the nutrition of Douglas-fir in New Zealand is extremely limited. We have no tested foliar critical levels to allow us to evaluate nutrient limitations to growth in plantation stands. There is little information on fertiliser responses with only four documented fertiliser trials. The foliage database for the species is very limited. The requirements for developing tools to manage Douglas-fir nutrition are therefore extensive as it is a case of almost starting from scratch. The sort of questions that will need to be answered when managing Douglas-fir stands will include: is stand productivity limited by a shortage of one or more nutrients; how would growth be improved in a nutrient deficient

stand by the addition of fertiliser; what types and rates of fertiliser are appropriate; and how do the pervious three points relate to the genetics of the species?

Areas that will need to be addressed are:

- Determination of foliage critical levels
- Development of detailed picture of foliar nutrition of the species within NZ
- Identification of limiting nutrients and appropriate treatments

Determination of foliage critical levels

These can be developed in two ways. As part of a field trial programme where the effects of various application rates of an element upon foliar nutrient concentration can be measured. This is then related to tree growth and the critical level determined. This is generally defined as the foliar nutrient concentration at which the tree is growing at 10% below its maximum expected productivity. The vehicle for this approach is therefore a number of field trials with varied rates on applied nutrients. The critical levels can also be developed in a glasshouse environment where seedlings are used to quickly determine optimum concentrations for growth in the foliage. This is how Will (1961) first set critical levels for *P. radiata*. It has the advantage of speed and economy, all nutrients can be evaluated in pot experiments in a short time and in combination with other elements. This is difficult with field experiments as only certain combinations of nutrient treatments can be used at certain sites. We would suggest that this approach has a high priority. Critical levels would be refined as field experiments were installed and began to yield results.

Development of a detailed picture of foliar nutrition of the species within NZ

A limited picture of foliar nutrition of Douglas-fir exists for New Zealand, this should be augmented by a systematic foliage sampling strategy for the species. Foliage samples should be taken as a routine stand management operation similarly to the *P. radiata* foliage sampling programs. Possibly when stands reach the age of 4 in the case of recent plantings. Sampling methodology is the same as for *P. radiata*. Take samples from the current year's mature needles on secondary branches in the top third of the crown. Sample 15 to 20 separate trees per sample unit and bulk into one composite sample. Samples should be taken in February to March. Samples should be stored in plastic bags and dispatched to the NZ FRI laboratory immediately. If this is not possible samples should be refrigerated until sent. This sampling strategy is not based on as extensive research as went into setting the methods for *P. radiata* but the same processes should apply for this species and it is probably best to keep foliage sampling to one period of the year for all species. Foresters can take these samples, and if all details of the stands are recorded and NZ map grid co-ordinates are included, the results will contribute to the national database. As an incentive to Co-operative members to increase their knowledge of Douglas-fir the NZ FRI Forest Nutrition Laboratory will offer a two for the price of one special offer for the 1995 sampling season on this species. Send in two samples for the basic plant test of N, P, K, Ca, Mg, B, Mn, Zn, Fe and Cu and pay for one[1].

Identification of limiting nutrients and appropriate treatments

At the NZ FRI we are aware of Douglas Fr plantings where foliar concentrations of N, P, Mg and B are likely to be low. Given our knowledge of New Zealand soils and the distribution of Douglas-fir plantings these are the elements most likely to need further investigation. Field experiments will be necessary to investigate field response to fertilisers over a range of sites representative of Douglas-fir plantings. Initially one trial is planned for the 1994/95 year to investigate N, P, Mg and B responses on a site where

[1] To a maximum number of samples per company, please contact the Laboratory Manager Jean Prince on 07 3475 899.

it is already exhibiting visual deficiency symptoms of these elements. Further work will need to be planned as the picture of nutritional status is built up around the country by the foliage sampling program. As there will be a strong genetic component within the Cooperative programme for the next few years it is suggested that there is strong collaboration between the genetics work and the nutritional work planned to ensure that nutritional management is linked to future breeding populations as well as current genotypes.

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DOUGLAS FIR BIBLIOGRAPHY (NZ FRI PUBLICATIONS AND PUBLISHED PAPERS)

Allen, P.J. 1982. Effect of different exotic species on soil properties within Kaingaroa Forest. Production Forestry Project Record No. 206 (unpublished).

Balneaves, J.M. 1975. Initial Weed Control in Douglas-fir nursery beds at Rangiora. *N.Z. Journal of Forestry* 20(1).

Belton, M.C., Davis, M.R. 1986. Growth decline and phosphorus response by Douglas-fir on a degraded high-country yellow-brown earth. *New Zealand Journal of Forestry Science* 16(10: 55-68

Bunn, E.H., James, R.N. 1974. Factors to be considered in formulating silvicultural regimes for Douglas-fir. FRI Symposium No 15 " A Review of Douglas-fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Chu-Chou, M., Grace, L.J. 1987. Mycorrhizal fungi of *Psuedotsuga menziesii* in the South Island of New Zealand. In *Soil Biol. Biochem* Vol. 19, No. 3, pp 243-246.

Chu-Chou, M., Grace, L.J. 1979. Mycorrhizal study of Douglas-fir (4) *Tuber* sp. as a mycorrhizal symbiont in New Zealand. Soils and Site Productivity Internal Report No 61 (unpublished).

Chu-Chou, M., Grace, L.J. 1981. Characterisation and identification of Mycorrhizas of Douglas-fir in New Zealand. Soils and Site Productivity Internal Report No 99 (unpublished).

Cole, E.C., Newton, M. 1986. Nutrient, moisture, and light relations in 5-year-old Douglas-fir plantations under variable competition. *Canadian Journal of Forest Research*, 1986., 16:4, 727-732.

DeBell, D.S., Silen, R.R., Radwan, M.A., Mandel, N.L. 1986. Effect of family and nitrogen fertiliser on growth and foliar nutrients of Douglas-fir saplings. *Forest Science* 1986., 32:3, 643-652.

Decourt, N., le Tacon, F., Nys, C. 1979. The influence of environmental factors on production of Douglas-fir in the north-east of the Massif Central. *Revue Forestiere Francaise.* 1979., 31:1, 20-27.

Dosskey, M.G., Linderman, R.G., Boersma, L. 1990. Carbon-sink stimulation of photosynthesis in Douglas-fir seedlings by some ectomycorrhizas. *New Phytologist* 1990. 1115:2, 269-274.

Edmonds, R.L., Hsiang, T. 1987. Forest floor and soil influence in response of Douglas-fir to urea. *Soil Science Society of America Journal.* 1987., 51:5, 1332-1337.

Forest Research Institute 1974. A Hard Look at Douglas-fir. What's New in Forest Research No 19.

Gessel, S.P., Walker, R.B., Haddock, P.G. 1951. Preliminary report on mineral deficiencies in Douglas-fir and Western Red Ceder. *Proceedings of Soil Science Society of America.* 1950, 1951: 15, 364-9

Gessel, S.P., Miller, R.E., Cole, D.W. 1990. Relative importance of water and nutrients on the growth of Douglas-fir in the Pacific Northwest. *Forest Management and Ecology* 1990., 30: 1-4, 327-340.

Glass, B. 1983. Douglas-fir growth models. Production Forestry Project Record No. 532 (unpublished).

James, R.N. 1975. A review of Douglas-fir in New Zealand. *N.Z. Journal of Forestry* 20(1).

Kay, M. 1978. Foliage Biomass of Douglas-fir in a 53-year-old plantation. *New Zealand Journal of Forestry Science* 8(3): 315-26.

Kershaw, D.J. 1969. Douglas-fir terminal loss in Otago. Forest Pathology Internal Report No. 28 (unpublished)

Madgwick, H.A.I. 1982. Biomass and nitrogen uptake in exotic forests. In "Nitrogen Balances in New Zealand Ecosystems", DSIR, New Zealand, p.117-121.

Menzies, M.I., Holden, D.G. 1981. Seasonal frost-tolerance of *Pinus radiata, Pinus muricata* , and *Pseudotsuga menziesii* .*New Zealand Journal of Forestry Science* 11(2): 92-9.

Mohren, G.M.J., Burg J. van den, Burger F.W., 1986. Phosphorus deficiency induced by nitrogen input in Douglas-fir in the Netherlands. *Plant and Soil.* 95(2) 191-200.

Mountford, C.J. 1974. Growth of Douglas-fir. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

New Zealand Forest Owners' Association Inc. 1993. Forestry Facts and Figures 1993.

Oldenkamp, L. Smilde, K.W. 1966. Copper deficiency in Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco). *Plant and Soil* 1966 25(1)., 150-2 + 2 photos.

Olsen, P.F. 1974. Current status of Douglas-fir. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Peterson, C.E., Ryan, P.J., Gessel, S.P. 1984. Response of northwest Douglas-fir stands to urea: correlations with forest soil properties. *Soil Science Society of America Journal.* 1984., 48:1, 162-169.

Preest, D.S. 1977. Long-term growth response of Douglas-fir to weed control. *New Zealand Journal of Forestry Science* 7(3): 329-32.

Prince, J.M. 1990. The nutrient status of Douglas-fir in New Zealand forestry.
Forest Research Institute Project Record No. 2391 (unpublished).

Radwan, M.A., Shumway, J.S. , DeBell, D.S., Kraft, J.M. 1991. Variance in response of pole-size trees and seedlings of Douglas-fir and western hemlock to nitrogen and phosphorus fertilisers. *Canadian Journal of Forest Research,* 1991., 21:10, 1431-1438.

Rawcliffe, D.J. 1973. Decline of Douglas-fir - Kaingaroa. Forest Pathology Internal Report No. 10 (unpublished).

Revell, D.H. 1974. The site limitations of Douglas-fir. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Rook, D.A. 1974. A note on the physiology of Douglas-fir. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Schone, D. 1987. A manganese- induced iron chlorosis in Douglas-fir. *Allgemeine Forstzeitschrift.* 1987 No. 45, 1154-1157.

Sutton, W.R.J. 1974. A selective review of Douglas-fir in North America. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Touzet, G. 1975. The mineral composition of Douglas-fir needles. *Rapport Annuel, Association Foret Cellulose (AFOCEL)* 1975., 57-91.

Turner, J. 1980. Nitrogen and phosphorus distributions in naturally regenerated *Eucalyptus* spp. and planted Douglas-fir. *Australian Forest Research.* 1980. 10:3., 289-294.

Turner, J., Lambert, M.J., Gessel, S.P. 1988. Nitrogen requirements in young Douglas-fir of the Pacific North-west. *Fertilizer Research.* 1988., 15:2, 173-179.

van den Driessche, R. 1969. Relationships between Douglas-fir seedling growth and levels of some soil and tissue nutrients. *The Forestry Chronicles* 1969. 45(4), 273-7.

Velazquez-Martinez, A., Perry, D.A., Bell, T.E. 1992. Response of above-ground biomass increment, growth efficiency, and foliar nutrients to thinning, fertilization, and pruning of young Douglas-fir plantations in the central Oregon Cascades. *Canadian Journal of Forest Research,* 1992., 22:9, 1278-1289.

West, G.G. 1991. Douglas-fir, Japanese larch and European larch in pure and mixed stands. *New Zealand Journal of Forestry Science* 21(1): 3-9.

Will, G.M. 1961. The mineral nutrient requirements of radiata pine seedlings. *NZ Journal of Agricultural Research.* 4:309-327.

Will, G.M. 1974. Nutrition of Douglas-fir. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Wooff, W.G. 1974. Douglas-fir decline in growth. FRI Symposium No 15 " A Review of Douglas Fir in New Zealand" 16-19 September 1974. Eds. R.N. James and E.H. Bunn

Youngberg, C.T., Austin, R.C. 1954. Fertility standards for raising Douglas-fir in forest nurseries. *Journal of Forestry* 1954, 52(1), 4-6.

Appendix 1. Output of search of NZ FRI Forest Health Database: Occurrence of health problems in Douglas-fir in New Zealand.

Site_Description	Disorder_Comments
ASHLEY	POSSIBLE BORON DEFICIENCY BEGINNING TO APPEAR. SCATTERED YELLOWING DUE TO MYCORRIZAL IMBALANCES.
ASHLEY	HEAVY PHAEOCRYPTOPUS INFECTIONS. LITTLE NEEDLE RETENTION AFTER 2 YEARS. POSSIBLE NUTRIENT DEFICIENCIES.
BALMORAL	STAND VARIABLE IN COLOUR DUE TO MYCORRIZAL DEFICIENCY.
BEAUMONT	MOD - HEAVY PHAEOCRYPTOPUS- UP TO 4YR NEEDLE RETENTION. LOCALISED CHLOROSIS ON RIDGE CREST.
BERWICK	RIDGE TOPS SEVERE WIND DAMAGE-CHLOROSIS, NEEDLE STRIPPING.
BERWICK	15% MATURE TREES SHOWING CHLOROSIS WITH ABOUT 2% WITH VERY SPARSE FOLIAGE. _
BERWICK	NEEDLE DISCOLOURATION AND EVENTUAL LOSS.
BLACKMOUNT	CHLOROTIC MINERAL DEFICIENCY. ROOTS VIGOROUS - PLENTY OF FIBROUS MATTER - MYCORRHIZAE OR OTHER FUNGI
BLACKMOUNT	A FEW PROBLEMS RELATED TO SITE - HAIL DAMAGE, WIND. CHLOROSIS NOTED BY AHK SEEMS TO HAVE CEASED.
CATHERWOODS NURSERY.	SEEDLINGS BIT PALISH DUE TO MYCORRIZAL LACK.
CHNY BLOCK 3	ROOT DEVELOPMENT IS GOOD. MAY BE A MYCORRHIZA PROBLEM.
DUNEDIN COUNTY COUNCIL PLANTATION	CHLOROSIS AND DEATH OF NEEDLES
EAST EYRETON RGNY	MAY BE MYCHORRIZAL DEFICIENCIES.
EDENDALE	GOOD ROOT DEVELOPMENT AND MYCORRHIZAL GROWTH LOCALLY SEVERE YELLOWING/DRAINAGE 82/288 16 BEDS
EDENDALE NURSERY	7/2/86/06. 3 BEDS OUT OF 44 CHLOROTIC- CAUSE? WRENCHING/PRUNING PROBLEMS? OR LOCALISED MYCORRHIZAL DEFICIENCY. OVERALL GOOD ROOT DEVT AND FOLIAGE COLOUR.
EDENDALE NURSERY	VERY LITTLE CHLOROSIS OF PREVIOUS YEARS. 7/2/82/04.
EDENDALE NURSERY	CHLOROTIC-MYCORRHIZAL DEFICIENCY.
EDENDALE NURSERY	CHLOROTIC MULTILEADERING. SMALL AREA INNOCULATED WITH RHIZOPOGON MYCORRHIZA FROM WOODLAW.
FISH HATCHERY, NGONGOTAHA	CHLOROSIS
FORDS HIGHWAY BLK	600,000 TREES. 7/2/85/13 + 4/2/84/02 AREAS OF YELLOWING- DAMP CONDITIONS,NEVER FERTILISED. GOOD MYCORRHIZAL/ROOT GROWTH.
FORDS SOUTH BLK	FLOOD DAMAGED MARCH 1986. WIDESPREAD CHLOROSIS. MINIMAL MYCORRHIZAE.
GERALDINE	MODERATE PHAEOCRYPTOPUS - MAX. 4 YR FDL. RETENTION - SOME YELLOWING/CHLOROSIS.
GLEN DHU	VERY CHLOROTIC. OCCASIONAL TREE HAS PROLIFIC MYCORRHIZA. SOME HAVE LARGE QUANTITIES OF MYCELIUM AROUND ROOT SURVIVAL ABOUT 85%. NEW FOLIAGE DISTINCTLY YELLOW.
GOLDEN DOWNS	CHLOROSIS
GOLDEN DOWNS	SEVERE CHLOROSIS
GOLDEN DOWNS	CHLOROSIS
GOLDEN DOWNS GDNS	SOME CHLOROSIS, THINNED 1 YEAR AGO.
GWAVAS	VARYING DEGREES OF CROWN CHLOROSIS OF 1-2YR NEEDLES
GWAVAS	PHAEOCRYPTOPUS WELL ESTABLISHED ON 1-2, 2-3, 3-4 YR OLD NEEDLES. VARYING DEGREES OF CHLOROSIS OVER WHOLE CROW
GWAVAS	PROVENANCE 644 WORST AFFECTED WITH 1-2 AND 2-3YR NEEDLES SHOWING SEVERE CHLOROSIS.
HENNEBRYS F/F	POSSIBLE LACK OF MYCHORIZA IN SOIL CAUSING YELLOWING OF ISOLATED SEEDLINGS
HIGHLANDS RD BLOCK WHAKAWERAWERA	CHLOROSIS
HIRA PT SF002	SCATTERED SINGLE TREE CHLOROSIS PRESENT.
HOCHSTETTER	HEALTHY. SOME CHLOROSIS OF FOLIAGE IN WET AREAS.
HOCHSTETTER	RECENTLY THINNED. NUTRIENT DEFICIENCY YELLOWING ON RIDGES.

HOCHSTETTER	PALE PATCHES THROUGHOUT DUE TO NUTRIENT DEFICIENCIES ESPECIALLY ON RIDGES.
HOKONUI	PHAEOCRYPTOPUS ON NEARLY EVERY LEAF. SOME SLIGHT CHLOROSIS.
KAINGAROA	CHLOROSIS.
KAINGAROA	DIEBACK, CHLOROSIS, NEEDLE-CAST.
KAINGAROA	1920, 1975. GENERAL YELLOWISH IN YOUNGER PLANTING - PROBABLY DUE TO STEM DENSITY & POSSIBLE MYCORRHIZAL DEFICIENCY. MORE DISTINCT YELLOWING ON MARGINS ESPECIALLY ON REGEN.
KAINGAROA	1980 CPT 674 APPEARS MORE CONSISTANTLY GREENER THAN IN PREVIOUS YEARS. A BALANCE OF MYCORRHIZA MAY BE A FACTOR IN THIS.
KAINGAROA	ON BARER SITES OLD RABBIT AND HARE DAMAGE IS EVIDENT ALONG WITH POSSIBLE MARGINAL NUTRIENT DEFICIENCIES.
KAINGAROA	IT'S HARD TO FIND THE TREES AMONGST THE WEEDS. MOST SEEDLINGS APPEAR HEALTHY THOUGH VARIABLE SIZE. IN THE DRY SPELL THE WEEDS WOULD HAVE COMPETED FOR NUTRIENTS & WATER
KAINGAROA	WEEDS ARE EQUAL HEIGHT WITH D. FIR. STANDS APPEAR THRIFTY POSSIBLY BECAUSE THE WEEDS PROVIDE SHELTER. THEY COULD BE REDUCING VOLUME BY NUTRIENT & MOISTURE COMPETITION.
KAINGAROA	THERE IS THE USUAL SLIGHT VARIATION IN COLOUR IN 1982-83 DOUGLAS FIR PROBABLY DUE TO COMPETITION FOR NUTRITION AN MYCORRHIZA.
KAINGAROA	VARIATION IN COLOUR CAUSED BY ESTABLISHMENT SHOCK AND MYCORRHIZAL IMBALANCES. FROST DAMAGE IN GULLIES SW END OF CPT 1065.
KAINGAROA	CHLOROSIS OCCURING IN CENTRES OF CPT ON OLD SKID SITES. PHAEOCRYPTOPUS PRESENT. NEEDLES CHEWED AND TORTRICID WEBBINGS.
KAINGAROA	GOOD ESTABLISHMENT AND SURVIVAL. SCATTERED CHLOROSIS BY COMPETITION.
KAINGAROA	CHLOROSIS. MODERATE PHAEOCRYPTOPUS - OLDER FOLIAGE.
LEITH'S EDENDALE	SOME SLIGHT YELLOWING. GOOD MYCORRHIZAL GROWTH HOWEVER. 20 BEDS X 170m
LISMORE	TOP DIEBACK + SEVERE CHLOROSIS
LISMORE	GROUP TOP DIEBACK +LOCALLY SEVERE CHLOROSIS
LISMORE	DISCOLOURATION ON OLDER NEEDLES
LISMORE	CHLOROSIS QUITE STARTLING ON SOME TREES.
LISMORE	NO EVIDENCE OF DISEASE OR INSECTS. APPEARS TO RELATE TO DROUGHT STRESS & POSSIBLE NUTRIENT DEFICIENCES FOLLOWING THINNINGS. UNTHINNED AREAS SHOW SIMILAR SYMPTOMS.
LISMORE	SATURATION LEVEL OF PHAEOCRYPTOPUS INFECTION, CHLOROSIS.
LISMORE	CHLOROSIS + PHAEOCRYPTOPUS ESTABLISHED SLOW, INCONSISTENT GROWTH.
LISMORE	CHLOROSIS ZONES.
MANGATU,	CHLOROSIS OF NEEDLES
MAWHERA	PALE PATCHES ON SLOPES-NUTRIENT LEACHING. NO PHAEOCRYPTOPUS FOUND
MINGINUI	SEVERE CHLOROSIS ON SCATTERED TREES
NGAUMU	CHLOROSIS OF NEEDLES
OWHATA NURSERY	PATCHES OF YELLOW SMALL TREES MAINLY IN DEPRESSIONS, PROBABLY DUE TO WATER TABLE AND NUTRIENT. TREES SMALL AN VARIABLE.
OXFORD	SOME CHLOROSIS AND NEEDLE LOSS WHERE EXPOSED TO NORTH WEST WIND. NEEDLES YELLOWISH IN DAMP AREAS.
PATUNAMU	CHLOROSIS OF OLDER FOLIAGE.
POKA RANKLEBURN	PHAEOCRYPTOPUS. 5-6 YR NEEDLE RETENTION. ROADSIDE CHLOROSIS.
POMAHAKA	MODERATE PHAEOCRYPTOPUS CAUSING(?) DEFOLIATION AND CHLOROSIS. 3 YR NEEDLE RETENTION.

PUREORA SFP PURE TIHOI	NUMEROUS TREES YELLOW LOOKING - NUTRIENT DEFICIENT?
RAI PT SF002 RAI	PATCHES OF CHLOROSIS RANDOMLY IN BLOCK.
RAI PT SF002 RAI	POOR FORM ON EXPOSED RIDGE SITES. SOME CHLOROSIS IN SCATTERED PATCHES.
RAI VALLEY	CHLOROSIS
RANKLEBURN(POMA)	SEED SOURCE TEST. PHAEOCRYPTOPUS ON 3RD YR FOLIAGE. SOME CHLOROSIS/ YELLOWING OF TREES ON "PUGGY" SITES.
RANKLEBURN(POMA)	SOME THIN CROWNS AND CHLOROSIS OF OLDER NEEDLES. 3-4 YR NEEDLE RETENTION ON WORSE TREES. MOD/HEAVY PHAEOCRYPTOPUS ON 80% OF NEEDLES.
ROTORUA CONSERVANCY	NEEDLE DISCOLOURATION.
ROWALLAN ROWL	NO PHAEOCRYPTOPUS SEEN. SLIGHT CHLOROSIS [ISOLATED] DUE TO MOSS/LICHEN GROWTH.
SELWYN PLANTATION BOARD NEWTONS	YOUNG TREES ON WETTER SITES ARE YELLOW WITH FEW LIVE ROOTS. MOST HAVE ESTABLISHED WELL & ARE STARTING TO GET GOOD MYCORRHIZAL DEV'T ON SURFACE ROOTS.
SILVERPEAKS	TREES SHOWED MARKED CHLOROSIS, SOME COULD BE DUE TO POOR PLANTING ROOTS OFTEN BENT AT ROOT COLLAR GRASS COMPETITION
SILVERPEAKS	AREAS OF CHLOROSIS DUE TO ESTABLISHMENT STRESS AND LACK OF APPROPRIATE MYCORRHIZAL GROWTH.
TASMAN FORESTRY NORTHBANK	NEEDLES BRICK RED, DISCOLOURATION OF BARK SOME RESIN BLEEDING AT TREE BASE
TASMAN TASMAN MT ALLAN	USUAL CHLOROSIS AFTER PLANTING. OTHERWISE OK.
TASMAN TASMAN TARAWERA	LIGHT PHAEOCRYPTOPUS. ODD YELLOWISH TREE WITHIN STANDS - POSSIBLE COMPETITION AND MYCORRHIZAL DEFICIENCY.
PUREORA FOREST	LEAVES BECOMING DISCOLOURED AND FALLING OFF. 90% TREES IN THIS AREA AFFECTED. UPPER CROWNS DENUDED FIRST.
TE WERA	CHLOROSIS LEADING TO MORTALITY
TE WERA TEWR	PHAEOCRYPTOPUS HEAVY ON 1-2 AND 2-3 YEAR OLD NEEDLES. SCATTERED CHLOROSIS BUT NO DEFOLIATION
TFL TAUHARA	SCATTERED CHLOROTIC TREES MAINLY DUE TO LOW NUTRIENTS SMALL BUSHY TREES COMMON MAINLY DUE TO OLD RABBIT BROWSING
TFL TAUHARA	SITE LOW IN NUTRIENTS, HARD SITE TREES PLANTED IN VERY LOW MOUNDS. MOST TREES IN LOWER PARTS STILL ALIVE BUT NO GROWTH DUE TO SITE. ONLY THE HIGHEST PART OF STAND REASONABLE
TFL TAUHARA	SCATTERED CHLOROTIC TREES PROBABLY DUE TO LACK OF MYCORRHIZA OR LOW NUTRIENTS. OVERALL GROWTH POOR, DUE TO PEST, SUPPRESSION OR LOW NUTRIENTS.
TFL WAITAHANUI/OPEPE	SCATTERED CHLOROTIC TREES DUE NUTRIENTS.
WCC NIGHT CAPS	SOME CHLOROSIS EVIDENT WITHIN STAND. SITE HAS BEEN SCRAPED AND DRAINAGE APPEARS POOR.
WEST DOME	USUAL CHLOROSIS (28%). SEEM TO DO BETTER ON SPILL.
WEST DOME	CHLOROSIS DUE TO PERSISTING PLANTING STRESS + ROCKY SITES. REMAINING TREEES SHOW GOOD GROWTH. INCIDENCE OF CHLOROSIS = 28% IN FEB 1985.
WHAKA	ISOLATED DIEBACK AND CHLOROSIS
WHAKA	LIGHT TO MODERATE PHAEOCRYPTOPUS. YELLOW/MOTTLED STAND - COMPETITION AND MYCORRHYZAL DEFICIENCIES.
WHAKAREWAREWA	1971-84 D. FIR IN CPTS 11, 12, AND 16 HAVE THE ODD PALE PATCH WITHIN THE STANDS. THESE ARE CAUSED EITHER BY SEEPAGE AND/OR LACK OF MYCORRHIZA PHAEOCRYPTOPUS IN MOD TO HEAVY.
WHAKAREWAREWA	SCATTERED CHLOROTIC TREES CONCENTRATED MAINLY ON OLD SKIDSITES AND ROADSITES.YELLOWING MORE SEVERE ON CURRENT FOLIAGE.ALMOST CERTAINLY SITE AND/OR NUTRIENT RELATED.
WHAKAREWAREWA	LARGE SCATTERED PATCHES WITH SEVERE CHLOROSIS AND SOME SLOW DIEBACK. PROBLEM SOIL RELATED. POOR STOCKING IN PATCHES.