MICROSITE EFFECT ON *EUCALYPTUS REGNANS* GROWTH

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(Received for publication 5 April 1993; revision 30 November 1993)

ABSTRACT

In 11.5-year-old stands of *E. regnans* F. Muell. with highly variable growth, trees of below-average size and health occurred in small discrete clumps suggestive of microsite influence. Microsites were found to have a variable thickness of Taupo tephra overlying earlier Tirau tephra. The Taupo tephra had lower concentrations of phosphorus and of feeding roots than the Tirau tephra. Where Taupo tephra was thicker than 50 cm in the soil profile, basal areas averaged one-third lower than other microsites and correlated positively with phosphorus concentration in the A horizon.

Foliage samples suggested trees on soil with greater than 50 cm of Taupo tephra have more variable concentrations of foliar elements and lower concentration of phosphorus than trees on soil with predominantly Tirau tephra. These differences attributed to the thickness of Taupo tephra accounted for only some of the total growth variation.

Keywords: microsites; tephra; fine roots; phosphorus; nutrition; foliar analysis; *Eucalyptus regnans*.

INTRODUCTION

Central North Island *Eucalyptus regnans* plantations amount to about 8000 ha. As these age, a number of them are showing an apparent sensitivity to local site conditions with wide variation in growth and health. To date this variation has not been associated with causal factors clearly enough for amendment to be possible.

Since about 1985 *E. regnans*' relationship to site parameters has been complicated, in some years more severely than others, by a dieback (termed Barron Road Syndrome) which particularly affects new spring foliage. Depleted canopies result in mortality in severe cases, e.g., after a recurrence of symptoms over several years. A suite of fungal organisms are presumed to be involved but none has been clearly identified as the primary pathogen (M. Dick, pers comm.). Initially this disorder was associated with isolated sites presumed to be particularly unsuited to *E. regnans*, but now it has been reported from a variety of age classes, sites, and localities (M. Kay, unpubl. data).

Although the exploratory investigation into variation in *E. regnans* growth reported here was at the microsite (individual tree) scale, it was coupled to a wider investigation being conducted at the site (stand) level.

MATERIALS AND METHODS

Site Description

Two adjacent compartments in Kinleith Forest (Fig. 1) were chosen for study. The site was on rolling hills between 200 and 300 m altitude, consisting of short slopes (average 20°) between V-shaped gullies and rounded spurs. Stands included pockets of dead trees presumed to result from the dieback mentioned above and were chosen for their wide within-stand variation in tree size and foliar health. The 11.5-year-old stands had been planted at 1700 stems/ha and thinned at age 6 to a 700 stems/ha target, with 10% allowable variation.

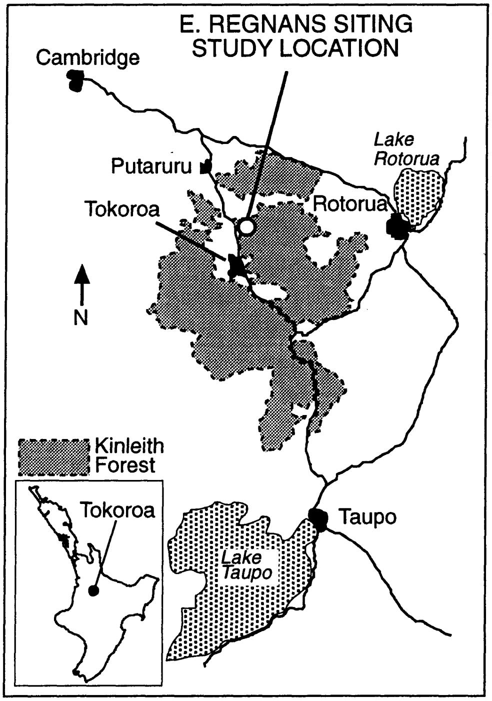

FIG. 1–Location of study sites

Sites were sampled in five (20 × 60 m) transects. These were orientated at right angles to contours to capture maximum stand variation. Few live trees remained in gully bottoms so these extreme sites were avoided. Transects averaged 591 live stems/ha and 707 total stems/ha. Average tree size was 20 cm diameter at breast height (dbh) and 28 m top height. The base of each tree was located three-dimensionally (X, Y, and Z co-ordinates) within the plot, and its dbh and foliage health score were recorded (1 = healthy, 2= slight defoliation, 3 = heavy defoliation, 4 = dead).

Soil Sampling and Analysis

Forty-eight soil pits were excavated at the grid intersections of a 4 × 5-m grid overlaid on each transect. The soil pit was excavated to a nominal depth of 90 cm, well below the main concentration of roots. Field descriptions were made (Taylor & Pohlen 1962).

The vegetation and terrain within 2 m of each soil profile were measured for microsite parameters. Five topography classes were used: crest, upper-, mid-, lower-, and toe-slope. Percentage of ground covered by understorey vegetation and its species composition were noted. Average slope and aspect of each 2-m-radius "microplot" were recorded.

Forty-five soil samples spread evenly among the different horizons and soil types were taken from randomly selected pits for laboratory analysis of inorganic and total phosphorus concentration by a modified (shaking time was reduced to 1 hour) 0.5 M HCl extraction (Blakemore *et al.* 1987). Standard particle size analysis was also done (Blakemore *et al.* 1987).

Foliage and Root Sampling and Analysis

Foliar samples were taken from 10 trees (two from each transect) of average dbh (17–23 cm) and health (score 2). Half the sampled trees were from microsites with more than 50 cm thickness of Taupo tephra, and half from microsites with little or no Taupo tephra. About 50 current-season leaves that were nearly or just fully extended were taken from the upper canopy of each tree and dried at 60°C. Concentrations of phosphorus, potassium, calcium, sodium, magnesium, manganese, iron, copper, zinc, and boron were determined on digests using perchloric acid oxidation, and nitrogen was determined on Kjeldahl extractions. Where two trees grew within 3 m of a profile ($n = 79$) a 2.2-litre soil sample from each horizon was sieved to determine fine root (<2 mm diameter) concentration (millimetres of root per cubic decimetre of soil) using a grid intersection technique (Bohm 1979).

Spatial Analysis and Statistical Methods

Data on profiles and associated attributes were stored within a geographic information system (GIS). Location of profiles and trees by X,Y, and Z co-ordinates allowed easy visual representation of data. Maps of altitude at 1-m intervals, tree espacement, diameter, and foliar health were produced for comparison of patterns. The Minitab statistical package (Data Tech Industries 1989) was used to compute linear regressions and paired T-tests for the data.

RESULTS

Soil Profile Descriptions

The upper 50 cm of some soil profiles had been disturbed by logging machinery, V-blading, pig rooting, or erosion, sometimes stripping the A horizon or creating buried horizons. Thickness of litter varied from 0 to 8 mm. An A horizon of dark-brown loamy sand with a crumb structure ranged in thickness from 10 to 45 cm with a mean of 20 cm according, in part, to site disturbance. On V-blade scrapes, 2 cm of A horizon indicated the rate of organic soil formation in 11.5 years.

Colour and textural differences of the B horizon suggested two soils. These soil types are designated Taupo loamy sand where the thickness of Taupo tephra (a rhyolitic tephra deposited 1800 years BP) exceeds 50 cm in the profile, and Ngakuru silty loam where the thickness of Taupo tephra is less than this (Vucetich & Wells 1978). The B horizon derived from Taupo tephra varied in thickness from almost 0 to 60 cm, overlying a silt loam of consistently darker colour and higher clay content. This horizon derived from Tirau tephra varied from 35 to 55 cm thick. Tirau is a composite of tephra parent materials from some 20 000 years of episodic deposition and subsequent erosion, mixing, and weathering (Froggatt & Lowe 1990). While primarily rhyolitic, Tirau does include a variable andesitic component which forms more fertile soils than rhyolite (Molloy & Christie 1988). (At Lake Rotongata, 26 km west of the study site, a quarter of all tephra deposition in the last 15 000 years has been andesitic — Lowe 1988).

On sites steeper than about 22° Taupo tephra was usually absent, although traces of coarse (5–10 mm) lapilli often remained in the lower A horizon. Deep accumulations of fine Taupo tephra occurred locally in gully bottoms.

Laboratory tests confirmed the presence of the two soils (Table 1). Tirau has higher clay and phosphorus content, presumably reflecting its more weathered nature. Significant differences (p = <0.01) were found between inorganic phosphorus concentrations in the Taupo and Tirau horizons (Table 1).

TABLE 1–Soil characteristics of A horizons and horizons derived from Taupo and Tirau tephras

	A			Taupo B			Tirau B		
Texture	loamy sand			loamy sand			silt loam		
Colour	7.5 YR 3/2			10 YR 6/4			7.5 YR 5/8		
Thickness (cm)	10 $(_{\overline{20}})$ 45			0 $(_{\overline{30}})$ 60			35 $(_{\overline{45}})$ 55		
Particle size (μm)	Percentage composition								
< 2	0.1 (+ 0.1)			1 (+ 1)			3 (+ 1)		
2–6	6			7			6		
6–20	22			20			12		
20–64	29			20			28		
64–250	29			28			38		
250–500	8			7			9		
> 500	10			7			4		
Inorganic P	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n
(mg/kg)	21.1	3.53	12	29.5*	2.64	9	84.8*	2.39	21

* Significant difference ($p < 0.01$).

Tree Growth and Soil Patterns

In all transects large healthy trees tended to occur in a number of discrete clumps separated by clumps of poorer trees (Fig. 2). A positive correlation between clump stocking and mean dbh (Fig. 3) suggests that locally adverse conditions (such as dieback) have for some time influenced both survival and growth, i.e., the higher dbh clumps have the higher stockings.

Tree performance (clump basal area and mean health) correlated poorly with A horizon depth, and with terrain and understorey parameters. Basal area of trees on (within 5 m radius of) Taupo profiles did correlate with B horizon inorganic phosphorus ($r^2 = 0.84$) and with A horizon total extractable phosphorus ($r^2 = 0.88$; Fig. 4). No correlation was found for trees on Tirau profiles.

Like profiles were aggregated into contiguous soil microsites, Taupo microsites where Taupo was greater than 50 cm thick and Ngakuru microsites where it was less than 50 cm. These 74 Taupo and 166 Ngakuru microsites were compared, by transect, for mean basal area (Table 2). Taupo microsites had lower stockings, a higher percentage of unhealthy trees, and carried overall about a third less basal area than the Ngakuru microsites. While stockings will have been influenced by a range of factors, including thinning, the consistent pattern of five transects does suggest that soil type is involved.

Root Distribution and Foliar Nutrition

Analysis of fine root distribution suggested that the Taupo tephra may be nutritionally limiting. Overall the mean concentration of root length per volume of soil decreased with depth. However, the Tirau tephra had higher mean root concentration than the overlying Taupo tephra (Table 3). Mycorrhizal roots appeared to be more frequent in Tirau tephra.

Comparison of foliar concentrations of major elements suggests nutritional differences between microsites. Mean concentration of phosphorus was significantly lower ($p < 0.01$) in the trees (Table 4a) on the Taupo loamy sand. Concentrations of other elements, while not different between microsites, were relatively uniform in the trees on the Ngakuru soils (Table 4b), perhaps suggesting balanced nutrition.

DISCUSSION

Differences in foliage nutrient concentrations between the Taupo and Ngakuru soils suggest that phosphorus is limiting tree growth. Whether a 0.12% foliar level does represent a limitation to growth is uncertain; some *Eucalyptus* species are adapted to low phosphorus availability (Ashton 1976; Attiwill 1980). Pot trials with 1-year-old trees have been established to address this. Nutrition may be complex, and factors other than nutrition could be involved as well. Soils from recent rhyolitic tephra such as Taupo are regarded as having greater limitations for agriculture than more-developed volcanic soils (Gibbs 1980).

The tendency for Taupo microsites to have lower basal area than Ngakuru microsites suggests that B horizons are nutritionally important. B horizon phosphorus (inorganic) concentrations, while similar to those of the overlying A, typically represent a larger supply because the B is nearly always thicker than the A horizon (*see* Table 1). Where Tirau tephra is overlain by more than 50 cm of Taupo tephra, then investment in feeding roots required

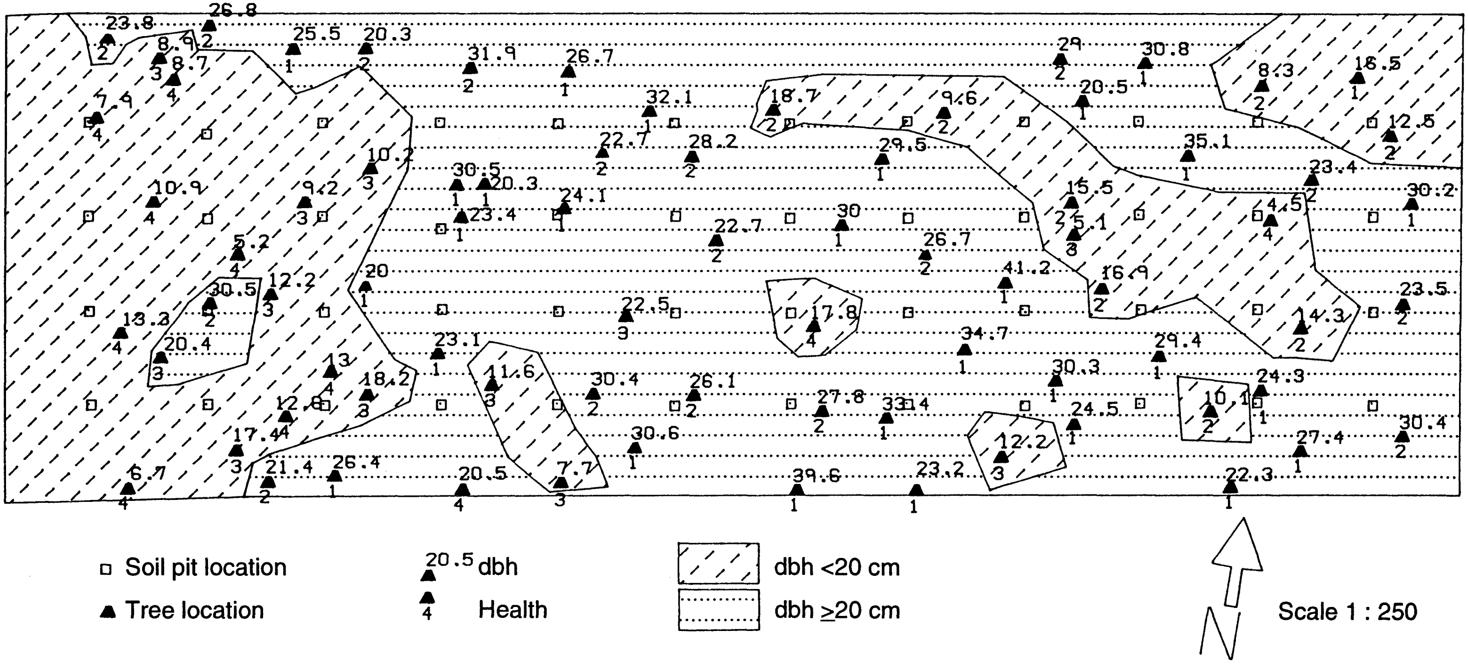

FIG. 2–Map of one of the five transects, showing tree and soil pit location, tree health, and dbh, with the site divided into areas of good (dbh ≥20 cm) and poor (dbh <20 cm) growth.

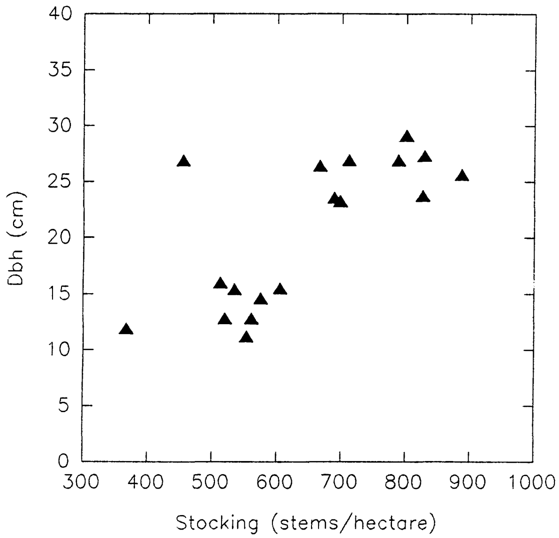

FIG. 3–Plot of tree stocking *v.* mean dbh within clumps of good and bad growth.

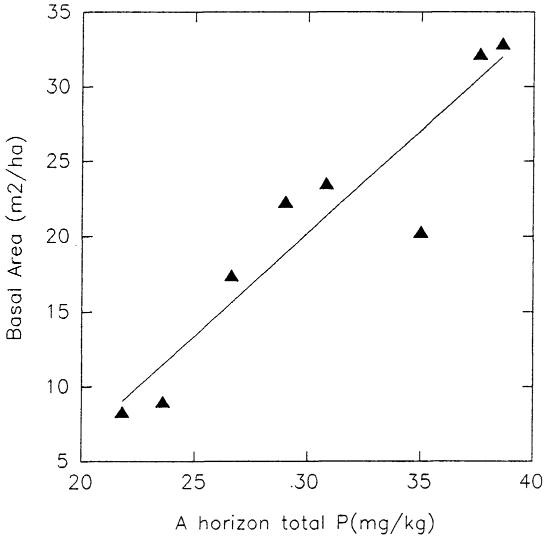

FIG. 4–Plot of stem basal area *v.* A horizon total phosphorus concentration. Trees growing on soils with a greater than 50 cm thickness of Taupo tephra.

to tap into the Tirau B could be a handicap, particularly for stressed trees. Importantly, the differences ascribed here to Taupo and Ngakuru microsites can account for only some of the observed variation in performance of *E. regnans*. While Ngakuru soils are comparatively uniform in phosphorus content (and foliar nutrition cautiously suggests other elements too),

TABLE 2–Comparison of tree growth on Taupo loamy sand and Ngakuru silt loam microsites

Transect number		Basal area (m^2/ha)	Stocking (stems/ha)	Dieback* (%)	Area (ha)
1	Taupo	25	602	31	0.04
	Ngakuru	27	700	17	0.08
2	Taupo	26	745	19	0.06
	Ngakuru	30	788	14	0.06
3	Taupo	10	650	13	0.03
	Ngakuru	23	963	20	0.09
4	Taupo	13	359	82	0.03
	Ngakuru	36	794	35	0.0
5	Taupo	23	607	24	0.05
	Ngakuru	31	793	18	0.07
All	Taupo	21	607	39	0.22
All	Ngakuru	30	812	28	0.39

* Trees with health scores 3 and 4.

TABLE 3–Fine root density* and mycorrhizal development†

Horizon		Sampled depth (cm)	$\bar{x}$	s.d.	n	Range test‡	Mycorrhizas
A	All	0–10	1119	145.52	79	a	3.3
B	Taupo	20–30	60	3.32	38	c	1.3
B	Tirau	30–40	310	7.68	41	b	1.7
B2	All	55–65	30	5.81	79	d	1.0

* Millimetres of roots <2 mm diameter per cubic decimetre of soil.

† Abundance index: 1 = absent; 2 = rare ; 3 =common; 4 = abundant.

‡ Different letters indicate significantly different means @ $p < 0.01$.

Ngakuru microsites are quite variable in tree performance. Clearly factors other than the nutrients examined are responsible. In fact, the large number of trees affected by dieback (32%) has masked the more subtle microsite influences that this study sought.

Assuming the microsite differences are nutritional, soil fertility amendment offers limited benefits here for two reasons. Taupo microsites are not consistently poor; some have moderate phosphorus levels and basal areas. Also, Taupo microsites are a minority. However, most eucalypt plantings in the region lie to the south of the study area on thicker Taupo deposits, suggesting that accurate soil mapping to delineate Taupo isopachs is important for eucalypt management.

ACKNOWLEDGMENTS

The study was enabled by an overseas student scholarship from the Ministry of External Relations and Trade. Valuable support was provided by NZFP Forests Ltd, Tokoroa, and the NZ FRI / Industry Management of Eucalypts Cooperative.

TABLE 4a–Concentrations of foliar macro-nutrients in *E. regnans* planted on Taupo loamy sand or Ngakuru silty loam

Element (% dm)	Taupo		Ngakuru		P > F
	Mean	Standard deviation	Mean	Standard deviation	
N	1.96	0.445	2.06	0.155	NS
P	0.12	0.013	0.15	0.008	< 0.05
K	0.97	0.450	1.33	0.033	NS
Ca	0.33	0.186	0.16	0.026	NS
Mg	0.30	0.061	0.24	0.054	NS

TABLE 4b–Concentration range of micro-elements in *E. regnans* foliage planted on Taupo loamy sand or Ngakuru silty loam

Element (mg/kg)	Taupo	Ngakuru
Mn	200–1400	240–550
Fe	36–96	41–51
Cu	8–60	11–22
Zn	22–49	31–49
B	6–11	7–11

REFERENCES

ANDERSON, G.; PIGEON, J.D.; SPENCER, H.B.; PARKS, R. 1980: A new hand-held recording penetrometer for soil studies. *Journal of Soil Science 31*: 279–96.

ASHTON, D.H. 1976: Phosphorus in forest ecosystems at Beenah, Victoria. *Journal of Ecology 64*: 171–86.

ATTIWILL, P.M. 1980: Nutrient cycling in a *Eucalyptus obliqua* (L'Herit.) Forest. IV. Nutrient uptake and nutrient return. *Australian Journal of Botany 28*: 199–222.

BLAKEMORE, L.C.; SEARLE, P.L.; DALY, B.K. 1987: Methods of chemical analysis of soils. *New Zealand Soil Bureau Scientific Report 80.* 103 p.

BOHM, W. 1979: "Methods for Studying Root Systems". Springer Verlag, Berlin. 188 p.

DATA TECH INDUSTRIES 1989: "Minitab Statistical Software". Valley Forge, USA.

FROGGATT, P.C.; LOWE, D.J. 1990: A review of late Quaternary silicic and some other tephra formations from New Zealand: Their stratigraphy, distribution, volume and age. *New Zealand Journal of Geology & Geophysics 33*: 89–109.

GIBBS, H.S. 1980: "New Zealand Soils, An Introduction". Oxford University Press. 115 p.

LOWE, D. J. 1988: Stratigraphy, age, composition, and correlation of late Quaternary tephras interbedded with organic sediments in Waikato lakes, North Island, New Zealand. *New Zealand Journal of Geology & Geophysics 31*: 125–65.

MOLLOY, L.; CHRISTIE, Q. 1988: "Soils in a New Zealand Landscape, the Living Mantle". Mallinson Rendel. 239 p.

PULLAR, W.A.; BIRRELL, K.S. 1973: Age and distribution of late Quaternary pyroclastic and associated cover deposits of the Rotorua and Taupo area, North Island, New Zealand. *NZ Soil Bureau, New Zealand Soil Survey Report 1.*

TAYLOR, N.H.; POHLEN, I.J. 1962: Soil survey method, A New Zealand handbook for the field study of soils. *DSIR Soil Bureau Bulletin 25.*

VUCETICH, C.G.; WELLS, N. 1978: Soils, agriculture and forestry of the Waiotapu region, centralNorth Island, New Zealand. *DSIR Soil Bureau Bulletin 31.* 100 p.