NITROGEN DISTRIBUTION IN STANDS OF *PINUS RADIATA* WITH AND WITHOUT LUPIN IN THE UNDERSTOREY

RUTH GADGIL

Forest Research Institute, New Zealand Forest Service, Rotorua

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ABSTRACT

Above-ground dry matter and nitrogen distribution were estimated in 4-year-old stands of **Pinus radiata** where lupin growth in the artificial ecosystem was normal (L), and where lupin had failed to regenerate after the trees were released at age 6 months (NL). Dry matter totalled 32 tonnes/ha in each case. In L the dry weight of litter and tree tops was lower, but slightly more non-lupin understorey growth was present. Biomass plus litter contained 90 kg/ha more nitrogen, much of which was in the lupin plants themselves. Litter and tree tops contained less nitrogen (5 and 15 kg/ha, respectively) than in NL, but the non-lupin understorey contained almost twice as much nitrogen as that in NL. Consideration of nitrogen concentrations in biomass components suggested that trees in NL were under nitrogen stress.

Stocking differences between the two stands precluded investigations on tree growth after canopy closure.

INTRODUCTION

At Woodhill State Forest, a dune-reclamation site north-west of Auckland, the distribution of nitrogen is being studied in young stands of *Pinus radiata* D. Don. As a result of the stabilisation techniques used to prepare the sand dunes for tree planting (Restall, 1964), these stands normally have a dense ground-cover of marram grass (*Ammophila arenaria* (L.) Link) and yellow tree lupin (*Lupinus arboreus* L.). During the first year after planting, the trees are released by an aerial application of 2,4,5-T. This kills the growing lupins, but not the marram, and allows free growth of the trees. A subsequent generation of lupin plants grows from seed buried in the sand, but further releasing is not necessary.

In 1970 an area was noticed in Compartment 139 where lupin had failed to regenerate after the trees were released. The effect of aerial spraying could be seen clearly because narrow strips of live lupin had been left at the edges of the spray paths, whereas the sprayed areas were free of lupin. An unusual opportunity existed for comparing this area with one in which lupin had developed normally. This paper reports comparisons made on the basis of a study of nitrogen distribution in the ecosystem carried out in 1972.

Throughout the paper the word "biomass" is used to denote standing plant material and fauna adhering to it. The word "litter" denotes plant material which has fallen, and includes colonising flora and fauna.

MATERIALS AND METHODS

Sites

Severe nitrogen deficiency (counteracted by the incorporation of lupin into the ecosystem) and seasonal moisture stress are the only edaphic factors known or suspected to limit plant growth at Woodhill Forest.

Compartment 134 (L = lupin present) is about 4 km northwest of Cpt 139 (NL = lupin absent) and, although each is about 1 km from the sea, Cpt 139 occupies a more sheltered position, being on a gentle slope facing south-east. The area of Cpt 134 selected for sampling faces north-west near the top of a long gentle incline from the sea. Both areas were planted with marram in 1965, sown with lupin in 1966, and planted with *P. radiata* in 1968 at a nominal stocking rate of 2224 stems/ha. Aerial application of 2,4,5-T (1.8% in water, 114 litres/ha) was carried out at the end of 1968. At the time of sampling the trees were approximately 4 m tall.

Sampling Techniques

The remaining strips of lupin plants in the NL area were carefully avoided during sampling.

Trees

The stand biomass and nitrogen content of the above-ground portion of the trees were determined by a logarithmic regression method, using diameter at breast height (d.b.h.) as the independent variable (Crow, 1971). Measurement of d.b.h. of all trees in a randomly selected 0.04-ha sample plot gave an estimate of the frequency distribution of d.b.h. in the population. Five trees with d.b.h. reflecting the population distribution were selected for destructive sampling. Each stem was severed at ground level, and the fresh weight of needles, branches, stem wood, stem bark, and dead twigs was determined. A subsample from each category was sealed in a polythene bag and taken to the laboratory for dry weight determination and nitrogen analysis. Total dry weight and weight of nitrogen were calculated for each sampling category of each tree and estimates of above-ground dry weight and nitrogen content in the stand were made from these data. Allowance was made for bias due to logarithmic regression (Mountford and Bunce, 1973).

Understorey and Litter

In each stand, 3 quadrats (1 × 1 m) were laid in areas considered to be representative of the stand as a whole. The use of only three small selected sampling areas to estimate dry weight and nitrogen content of the understorey was a compromise between a complete lack of information and an unacceptable work load. A vertical projection of each quadrat through the vegetation was delineated with stakes and string, and all plant tops within the defined volume were removed and placed in polythene bags after separation of lupin and non-lupin material. Litter and lupin seeds (which had all fallen) were collected separately. Animals such as snails and insect larvae were collected with the plant material. The cubic metre of sand lying vertically below each marked square was excavated and root material was separated by sieving (16-mm mesh). After transport to the laboratory, the roots were washed free of sand on a fine sieve (0.5-mm mesh). All material was oven-dried at 70°C. Each litter sample was hand-sorted for lupin seed and separated with an 0.5-mm mesh sieve into a "litter" and "litter-sand" fraction.

Sand

During root excavation, three core samples of sand (3.3 cm long × 4.6 cm diam.) were taken at each of three levels — (1) before digging commenced, and when the floor of the pit was (2) 50 cm and (3) 100 cm below the sand surface. Each sample was sealed in a polythene bag and its dry weight and nitrogen content were determined in the laboratory. An estimate of the total nitrogen content of the sand to a depth of 1 metre was derived, using the volume/weight data from the core samples.

Laboratory analysis

All plant material was dried at 70°C in forced-draught ovens, and ground in a Wiley mill. Subsamples were analysed for total nitrogen by a semi-micro Kjeldahl technique (Bremner, 1960). Sand was air-dried and root material was removed by sieving (0.5-mm mesh). Subsamples were used to obtain a factor for conversion to oven-dry weight. Total nitrogen content was determined by Bremner's method after pre-treatment to ensure quantitative assessment of nitrates and nitrites (Bremner and Shaw, 1958).

RESULTS

The two sample plots showed a difference in stocking. The NL plot contained 93 trees while the L plot contained 76. Missing, dead, or stunted trees totalled 1 and 4, respectively.

Dry Matter Production

In terms of total above-ground dry matter production the two stands were remarkably similar. The contributions made by the different plant types were, however, very different (Table 1). Tree weight in L was only half of that in NL, while the weight of the understorey was more than twice as great. More litter was present in NL and root weight was greater. Lupin seed made only a small contribution to total dry matter production in L and was entirely absent from the area sampled in NL. Dry weight data for tree components (Table 2) show that the distribution of dry matter was broadly similar in trees from both stands.

Nitrogen Distribution

In L the above-ground biomass plus the litter contained 90 kg/ha more nitrogen than in NL. Table 1 shows that the extra nitrogen was present in the understorey, and that both trees and litter in L in fact contained less nitrogen than those in NL. As might be expected, the lupin component of the understorey was responsible for a large proportion of the additional nitrogen in L. However, marram and other species also contributed to the higher total and contained almost twice as much nitrogen as in NL, even though dry matter production was similar in both stands. Lupin seed accounted for almost 6 kg/ha of the L nitrogen and the understorey roots were richer in nitrogen by about 15 kg/ha in this stand.

Sand analysis figures indicate that more nitrogen (to a depth of 1 m and including

TABLE 1—Dry matter and total-nitrogen distribution in the ecosystem of 4-year-old **P. radiata** stands, 1972.

	NL (No lupin since Dec 1968)				L (Lupin growth normal)			
	Dry matter (tonnes/ha)		Total-N (kg/ha)		Dry matter (tonnes/ha)		Total-N (kg/ha)	
Tree tops	12.2	9.5*	61.1	48.0	6.0	4.4	44.8	34.1
		15.0		74.8		7.7		56.9
Understorey tops	6.6	7.6†	26.1	28.0	16.4	20.5	133.1	153.2
		3.3		17.7		7.9		80.8
		8.9		32.6		20.7		165.3
Lupin tops	0.0		0.0		9.2	13.4	83.1	109.7
						6.2		60.9
						8.1		78.7
Marram, etc., tops	6.6	7.6	26.1	28.0	7.1	7.1	50.0	43.5
		3.3		17.7		1.8		19.9
		8.9		32.6		12.5		86.6
Total tops	18.8		87.6		22.5		178.3	
Lupin seed	0.0		0.0		0.1	0.2	5.8	10.7
						0.1		3.5
						0.1		3.2
Biomass (above-ground only)	18.8		87.6		22.6		184.1	
Litter	13.0	17.0	113.4	134.6	10.0	11.2	107.9	132.1
		11.9		128.0		14.5		154.9
		10.2		77.7		4.1		36.8
Biomass + litter	31.8		201.0		32.6		292.0	
Understorey roots	9.1	11.7	32.6	44.1	7.4	8.6	47.1	57.2
		6.4		22.9		6.3		42.8
		9.3		30.7		7.3		41.4
Sand to 1 metre	—		1442.8	1423.2	—		1197.1	1439.4
				1368.2				846.5
				1540.0				1305.4

* 95% confidence limits.

† For this and subsequent rows, the second column in each case gives actual values for the three sample areas.

TABLE 2—Tree biomass and nitrogen content in 1972 (tops only)

	NL (No lupin since Dec 1968)				L (Lupin growth normal)			
	Dry matter (tonnes/ha)		Nitrogen (kg/ha)		Dry matter (tonnes/ha)		Nitrogen (kg/ha)	
Foliage	3.57	2.79* 4.36	42.76	33.69 52.15	2.10	1.58 2.69	32.44	24.59 41.26
Branches	2.47	1.91 3.04	7.33	5.73 9.01	1.49	1.12 1.94	6.36	4.98 8.06
Stem wood	5.24	4.08 6.41	5.79	4.54 7.08	2.09	1.53 2.66	3.16	2.40 3.98
Stem bark	0.82	0.64 1.00	4.62	3.61 5.66	0.37	0.28 0.48	2.85	2.14 3.61
Dead twigs	0.11	0.11 0.11	1.01	1.01 1.01	0.06	0.04 0.07	0.43	0.33 0.58

* 95% confidence limits.

litter sand) was present in NL than in L. It would be unwise to attach any importance to this difference since the significance of the very low value recorded for one of the L sample areas cannot be assessed. Figures given in Table 1 represent the total, rather than the available, nitrogen content of the sand.

DISCUSSION

Because the study was based on an unusual occurrence, it was not possible to replicate the observations. However, results from the two stands investigated allow some conclusions to be drawn about the effect of lupins in the ecosystem.

Regeneration Failure

The absence of seed in the NL area indicates that lupin regeneration was prevented by lack of seed rather than by local soil or climatic conditions. The remaining strips of lupin flowered and produced seed normally. It can be assumed that the factor(s) causing the difference in lupin development had ceased to operate in the post-releasing period. The most likely explanation for failure of lupin regeneration in NL is that a localized attack by kowhai moth larvae (*Mecyna maorialis* Feld.) weakened the plants and prevented seed formation before release spraying was carried out.

Distribution of Nitrogen

The above-ground lupin component (including seed) of the L ecosystem contained almost 90 kg/ha of nitrogen. Since Woodhill sand is known to be deficient in plant-available nitrogen before lupins are introduced (Gadgil, 1971a; b; c) it can be assumed that most of the nitrogen would have been fixed from the atmosphere through symbiotic association with *Rhizobium.* Root material would have contained an additional amount but was not estimated separately for lupin. The ecosystem, both before and after spraying, would have received symbiotically-fixed nitrogen from healthy lupin plants (Gadgil, 1971a) and from those attacked by kowhai moth (Gadgil, 1971b).

Tree tops were the only component of the biomass which contained more nitrogen in NL than in L. The confidence limits suggest that the means for the population might not have been significantly different. The litter contents were very similar and the non-lupin understorey fraction was lower by 24 kg/ha. It is interesting to note that a greater amount of understorey root nitrogen was present in L, due no doubt to the lupin component.

The fact that the non-lupin component of the understorey contained more nitrogen where lupins were present is hardly surprising. Marram grass, the predominant species, is known to require a substantial supply of nitrogen for vigorous growth (Willis, 1965). It has an extensive underground system of stems and roots which are well adapted for thorough exploitation of the sand. In L, the non-lupin understorey was clearly utilising symbiotically-fixed nitrogen. In NL, where supplies of this nitrogen had not been available for 3 years, there is evidence that the understorey plants were currently under stress for nitrogen. Both dry matter production and percentage nitrogen were lower than in the non-lupin understorey of L. This suggests that litter and soil were not releasing nitrogen at a rate adequate for both understorey and tree growth.

The higher dry weight and nitrogen content values for tree tops in NL must have reflected to some extent the differences in stocking and site exposure which existed between the two stands. If we assume (1) that the net effect of these differences was an increase in nitrogen uptake by the tree component of NL, and (2) that the presence or absence of lupins had no effect on nitrogen availability to the trees, it is very difficult to explain the consistently lower concentration of nitrogen in all living categories of the NL trees. If assumption (2) is incorrect, it can be argued that the lower nitrogen concentrations indicated a recent decrease in the availability of nitrogen resulting from the depletion of the main source of supply, i.e., decomposing lupin plants which had been killed by release spraying.

The similarity between the two plots in terms of litter nitrogen content is of interest. The NL area contained 5 kg/ha more nitrogen in this component but this was associated with a higher dry weight accumulation. The percentage nitrogen content was in fact lower than in L. Litter nitrogen in NL could have been the residue of nitrogen fixed before the stand was sprayed.

Effects on Tree Growth

Thus in 1972, in spite of differences between the two stands in terms of exposure and stocking, there was reason to suspect incipient nitrogen stress in NL. Some nitrogen losses from the sand through leaching and volatilisation could be expected. Additions of nitrogen in rainfall would not exceed 10 kg/ha annually (Miller, 1963; Egunjobi, 1971) and, since no further large-scale input of nitrogen was likely, it seemed very probable that the trees would eventually show a slowing down in growth rate when compared with those in L.

Unfortunately the remeasurement of trees in the two areas is unlikely to provide further useful information on the role of lupins in tree nutrition. This is because after canopy closure a comparative increase in individual tree growth rate in L would be attributable to the effect of the lower stocking rate on between-tree competition. With no restraint on stocking, it would be impossible to consider the influence of lupins as a separate effect. An investigation involving experimental removal of lupins from a site at Woodhill Forest is now in progress and will provide more information about effects on tree growth.

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