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FORESTRY COMMISSION OF N.S.W.

TECHNICAL PAPER
No. 1

SEMINAR ON MANAGEMENT OF
LOW SITE QUALITY PLANTATIONS

MOSS VALE
MARCH, 1963
SEMINAR ON MANAGEMENT OF PLANTATIONS
OF LOW SITE QUALITY

MOSS VALE - 25-27th MARCH, 1963

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History of Low Site Quality Plantations and Present Position

The first forest nursery in N.S.W. was established in 1886 at Gosford under the administration of the Forest Branch which at that time was located in the Department of Mines. The nursery stock was distributed for park and street planting and for windbreaks and woodlots in the country. As a matter of interest the Gosford Forest Nursery became the locale of the first forestry cadetship scheme when the Narara school was established. The Gosford nursery was abandoned in 1940 in favour of the Narara and Forest experiment station which had been established at Pennant Hills in 1938.

Prior to the constitution of the N.S.W. Forestry Commission in 1916 plantation projects in P. radiata in emulation of those in New Zealand were initiated in N.S.W. with the establishment of 95 acres of P. radiata on the coastal sands of Tuncurry in 1914. In 1915 7.5 acres of Pines were planted at Armidale of which 3.2 acres were P. radiata.

After 1916, exotic pine planting became one of the chief activities if not the major activity of Forestry in N.S.W.

The new Commission commenced by planting land as accessible as possible to future markets, of which Sydney was the most important. The only land available was recognised as being of poor quality, consisting chiefly of Hawkesbury sandstone, but efforts were made to select the best of it with a view to converting otherwise valueless land to a profitable use. Although of necessity poor soils were chosen, barren wind swept areas were avoided and all plantation sites were carrying Eucalypts of at least 40 ft. in height growth. In this manner Olney, Newnes, Castlereagh, the Moss Vale plantations and those on the South Coast were started from 1919-1921.

The apparently satisfactory growth of Pinus radiata on poor sandy soils for the first few years after planting both at Tuncurry in N.S.W. and on extensive areas in South Australia proved to be definitely misleading. It soon became apparent that the Hawkesbury sandstone wastelands (comprising most of the land close to Sydney) and the coastal sands would not grow P. radiata successfully. The unsatisfactory results obtained with both P. radiata and other species on available land in proximity to the City market or on coastal areas from which cheap water transport was thought possible forced the Commission to seek other planting sites for an extension of plantations. Areas were sought therefore which were considered suitable from a soil and climatic viewpoint, irrespective of location to the main Sydney market. In this way the 1926-31 group of plantations was located in the South East highlands and in the country west of the Blue Mountains. The 1927 annual report of the Forestry Commission stated that the Southern Highlands was to be the future coniferous belt of N.S.W.

At the same time to make use of the wastelands near Sydney experimental plantings of other species, chiefly P. pinaster were made.

In 1934 in submitting a report on Forestry in N.S.W. Mr. S.L. Kessell commented as follows: (p.44)

"The New South Wales Forestry Commission has taken the lead in the introduction of softwood species from all parts of the world into Australia, and the extensive trial of the principal commercial species in local plantations. In 1920 an officer of the Commission was sent around the world to collect information concerning species likely to prove satisfactory in the various planting zones of this State, and to ascertain how seed of the most desirable strains might be obtained."
Pinus radiata (syn. Pinus insignis)

Despite the extensive experimental planting of numerous species of conifers, Pinus radiata remains the most desirable plantation tree for the rapid production of a satisfactory class of softwood which has been discovered to date."

In this report Kessel concluded that all of the Tumut plantations, and Jenolan gave every indication of satisfactory growth, and that although doubt existed concerning the Wagga and Bombala plantations they could ultimately prove to be equally satisfactory. The Moss Vale and Glen Innes areas, along with Lidsdale, Mullion Range and Banyabba were considered second class areas on which extension of operations were justified on account of local markets.

Criticism against the policy of planting exotic pines culminated in 1935 with an amending Forestry Act, which brought the coniferous planting enterprise under direct ministerial control. The operations ceased; and a comprehensive review of the results of the fifteen years' of planting was ordered.

There were by that time, thirty-one separate plantations, aggregating 39,000 acres, 27,000 of them devoted to Pinus radiata, and 12,000 acres carrying other exotic conifers, among which were:

- P. ponderosa 2,500 acres
- P. laricio 2,000 acres
- P. pinaster 3,800 acres
- P. muriicata 1,300 acres
- P. elliottii 1,100 acres

The remainder of the 12,000 acres was made up of small areas less than 100 acres in extent.

In 1935, section 13, part 4 of the Forestry Act 1916-35 was amended as follows: "No scheme of afforestation with exotic species of timber shall be undertaken or extended after the commencement of this Act except with the written approval of the Minister, which approval shall not be given unless evidence as prescribed has been adduced to the Minister satisfying him that soil, site and climate are such as to render the carrying out of the scheme desirable in the interests of the publico"

In order to satisfy the needs of the Forestry Act in respect to further plantings, a stocktaking of the 30 plantations was commenced in the latter months of 1935.

The stocktaking took 18 months to complete the field work and a slightly longer period to tabulate and map the results. Three field parties were employed with a staff of up to 30 men. The stocktaking was carried out by means of a strip survey. The strip interval was usually 5 chains giving a 2.4% sample. The strip enumeration consisted of measuring every tree on the strip row plus periodical measurements made in between the rows. The strip survey parties measured the d.b.h. of every tree on the strip and, in the case of normal trees, estimated the point at which the bole of the tree was four inches in diameter under bark. This height to four inches was then measured with a measuring pole. In the case of double leaders, diebacks etc., the diameter at the top of the log was estimated, the height to that point was then measured with the pole.

On every strip the changes in site quality, as shown by height, diameter, density of crown, general appearance of the trees, type and appearance of scrub, type and appearance of Eucalypt coppice etc., were plotted in the position and direction in which they occurred. The lines representing changes in quality were joined across the strip intervals and in this way a map was produced showing the relative or "field" qualities. Forest and undergrowth types were mapped in the same way and a similar map produced.
The volumes of all individual normal trees on the strips were obtained by applying a volume table q.v. to the strip measurements. In the case of abnormal trees, double leaders, diebacks etc., Burt's formula was applied to the strip measurements.

The volume table used was based on d.b.h.o.b. and "height to four" inches and was compiled from a large number of sample trees felled in various plantations.

The volumes of all the trees on each quality section of each strip were totalled and from them the total volume per acre was calculated. These figures for volume per acre were then charted on the field site quality plan and an average volume per acre for each "field" site quality in each compartment was obtained. By applying the South Australian Yield curve for the appropriate age to each of these average volumes per acre the site quality as per the South Australian Yield Table was determined.

On account of the immaturity of many of the stands in 1936 no assessment by volume was possible. Volume assessment was therefore usually restricted to areas planted up to 1927-28. The 1929/30/31 plantings were assessed by means of a local height curve while the 1932-35 plantings were assessed by means of original forest types as mapped during the strip survey.

The determinations of this survey were as follows:-

(1) Seven plantations were recommended for immediate abandonment.

On two of them viz. Broadwater and East Boyd the volume of timber production did not justify any attempt at salvage - they were a failure both economically and silviculturally. A third Jounama consisted of slow growing species located so remotely from the potential market that it would never be an economic proposition. The remaining four, Tuncurry, Olney, Penrose and Nemoes were located satisfactorily but the site was too poor and the silvicultural condition of the plantation too bad to warrant further expenditure. A volume of production could be salvaged from these areas however,

A feature of these poor sites was the heavy growth of scrub and the consequent fire hazard. The severe fire of 1939-40 burnt three of them viz. Newnes, Olney and Penrose.

(2) Four plantations were listed for abandonment at the end of the rotation.

According to the then current thinking two were situated in a climate of summer rainfall considered unsuitable for the species i.e. P. radiata. These two plantations were Armidale and Mt. Topper, to be clear felled at 40 years of age. The other two, Lisdale and Mullion Ranges were in a marginal climate on waste land unsuitable for economic growth. Both of these were planned for clear felling at 30 years of age. All four plantations contained stands which were subnormal and diseased.

(3) Three plantations were to be tended - two of them Weejasper and Nalbaugh were productive but were too remote from market to warrant further planting, whilst the other one, Belanglo was well enough located but no more suitable planting country was in sight.

(4) One plantation was in doubt - this was Woodburn. Pinus radiata had obviously failed but the Southern Pines were not old enough for any decision to be made. The policy recommended therefore was no more planting, salvage of radiata and maintenance and protection of P. elliottii.

(5) The remaining sixteen plantations were to be continued and in most cases extended as they had been located well enough to markets and growth was satisfactory.

In retrospect the interesting recommendations were:-
(1) Banyabba to be extended with P. elliottii.
(2) Wingello to be extended by 1,000 acres.
(3) Bondi to be maintained and extended but only by prison labour, whilst Nalbaugh was to be tended but not extended.
(4) Mt. Mitchell to be extended.
(5) Gurnang to be considered as a P. ponderosa plantation.
(6) Marraguldrie 1. and 2., particularly the latter were considered a silvicultural success and worthy of extension.

To quote from the Rural Reconstruction evidence "The sixteen years of exotic pine planting in N.S.W. from 1919 to 1935 must now be regarded as a boldly conceived silvicultural adventure into the unknown, assaying 50% success and 50% arrant failure. But the failures have surrounded the future with safety."

As a result of this survey it was claimed that the N.S.W. Commission now had precise information on:

1. Type of country and climate in which P. radiata could be expected to thrive.
2. Relative silvicultural value of all possible Radiata planting sites in N.S.W.
3. The relative economic value of plantations in various sites, available markets and economic relation between plantations and imported timber.
4. A yardstick for measuring the value of natural timbered country in terms of volume production of P. radiata.

The attitude towards fertilizers is best illustrated by again quoting from evidence submitted to the Rural Reconstruction Commission.

Fertilizers in Forestry:

"Forestry uses climate and the closed canopy and mycorrhiza to fertilize its soils: the farm fertilizer has small economic place in silviculture.

The C.S.I.R.O. has collaborated with the Commission however in research to study the effects of phosphatic fertilizers on the incidence of fused needle disease in plots of P. elliottii and P. taeda on a South Coast plantation where inferior soil conditions prevail. Marked response to treatment was obtained and the occurrence of "fused needle" was lessened. The fertilized plot showed a 50% growth increase compared with the control.

Fertilizer has been used on Brooklana plantation in an effort to increase Hoop Pine vigor and height growth and thus reduce weed competition. The plots (in 1943) have not been established long enough for results to be analysed.

The possible establishment of trees and undergrowth species within plantation areas for the purpose of increasing humus constituent will be investigated. It is interesting to note that the primary function of fertilizers was considered remedial with increase in volume production a secondary benefit.

Upon the completion of the survey the Commission set out to implement the findings. It was proposed to salvage all trees on failed areas and to dispose of thinnings from the remaining plantations. Hemlock however, had such a stranglehold on the case making industry it was virtually impossible to make any sales until the war caused a cessation of imports. Despite this impetus there are a few areas of post war planting which have still to receive their first thinning.

In 1946 a re-assessment programme was commenced using the H.R. Gray method of taper line volume calculation for single trees, volume line calculation for plots and a generalised volume table for the whole plantation.
From 1946-1950 most of the sixteen plantations classified as successful were re-assessed and mapped for site quality. To my knowledge no attempt was made to precisely define the relationship between this site quality mapping, based on height and the earlier mapping based on volume. The only one of the poorer plantations which was re-assessed was Mullion Range, probably because of the Orange case market. Following this re-assessment it was recommended that Furraguldrie 2 be allowed to revert to a eucalypt pole forest.

Early in the 1950's the method of assessment and management plan preparation was again changed with the use of continuous or periodic inventory plots and a multiple regression top height volume table. Once all the better site quality plantations had been assessed in this manner attention was turned to the poorer site quality areas and around 1953/54 plots were established on such areas as Belanglo, Wingello, Liddedale, Banyabba, Mullion Range. With the establishment of these plots it was obvious that some thought would have to be given to the second rotation, especially on areas such as Moss Vale, Liddedale and Mullion Range where there was a ready sale for all material. This was obvious as on the older plantings many of the trees had leaders which were coming heavily and dying back.

Prior to this a few areas had been clear felled for timber e.g. the Southern section of Belanglo and although no attempt was made to regenerate the area it was found that natural regeneration occurred readily. The first conscious attempt to naturally regenerate any of these poorer areas was probably on Compartment 3 Belanglo. This was an early 1920 planting and being next to the main road had been heavily thinned. Regeneration had occurred in the openings and in 1950 a group selection marking was carried out to extend the regeneration openings. The overstory was removed several years later in 1954 and the compartment now consists of regeneration which for increment purposes has been taken as dating from 1950 but which would actually predate this by several years.

In order to assess the suitability of various methods of obtaining regeneration the management plans prepared in 1953/54 prescribed strip fellings through several compartments on Belanglo, Liddedale and Mullion Range. These strips extended the length of the compartment, ran generally in a north-south direction, to take advantage of seed shed from prevailing westerly winds, were 2 - 3 chains in width and moved into the westerly wind to shelter seedlings. At Liddedale for example it was proposed that each compartment be divided into blocks containing three strips each. One strip was to be felled at the same time in each block and to ensure adequate seed fall from adjacent stands a three year regeneration period was proposed. The final strips were to be regenerated from seed trees so that the whole compartment would be regenerated over a 7-9 year period. On Belanglo both clear felling of strips and strips where stocking was reduced to 20 trees/acre was attempted. No quantitative measures in the form of quadrats were established to actually measure the incidence of regeneration as it was thought the results would be obvious, or if they were not obvious the system would have failed.

When the management plans were reviewed in 1958 attempts at natural regeneration were abandoned and clear felling and planting was undertaken. One of the reasons for undertaking clear felling was the heavy incidence of dead topping in the older stands, e.g. in the 1958 Mullion Range re-assessment a record was kept of all trees on the plots which were showing signs of heavy coming on the leader and of dead topping and the percentage was often of the order of 30. It was not known at that stage and is still not definitely known how long such trees will survive although Mr. Stark, pathologist at the Forestry and Timber Bureau considered that most of the sub-dominant and co-dominant effected with dead topping in a 33 year old stand on Liddedale State Forest would survive at least another 10 years.

In 1960 all of the Tamut, Bathurst and Wagga plantations were re-assessed when the basis of yield calculations and control was altered from stocking per acre to residual B.A./acre. The residual B.A.'s prescribed were 85-90 sq.ft. for first thinnings and 110 to 130 sq.ft. for subsequent thinnings. The basis for these figures have been published in an article prepared for the 8th British Commonwealth Forestry Conference. "The application of B.A. control to Thinning of E. radiata plantations in N.S.W." but the figures agree fairly closely with Cromer who concluded that in low site quality stands of E. radiata the M.A.I.

-5-
in basal area is relatively constant over a range in B.A./acre from 120-145 sq.ft. Cromer’s conception of low site quality however, was of a site with a dominant height of about 80 ft. at 20 years of age and this would represent a much higher Site Quality than the Lidsdales, Belanglos etc.

On the re-assessment it was found that many of the residual B.A.'s on the poorer areas were far below the general prescription. Because of yield requirements however it was essential that these areas be logged. There were two alternatives:

1. Continue the clear fellings.
2. Thin to a residual B.A. where loss of increment would probably occur.

The only area where it was possible to accurately measure the effect of 2. was on Lidsdale State Forest Compartment 5. This compartment being next to the main Western Highway had been a stand-by wet weather logging area and before the 1953 assessment portion of it had been reduced to a stocking of 40 trees/acre and B.A. of 52. When re-assessed in 1960 the B.A. increment was 4.0 sq.ft./annum and although no height increment had been recorded it was obvious that the heavy thinning had resulted in some side branches taking over from the dead leader and resuming height growth.

Although this B.A. increment was only 50-70% which could be expected from a stand where the standing B.A. was 90-100 sq.ft., the practice of carrying out seeding fellings to 40-50 sq.ft. of B.A. is now current on most of the poorer plantations such as Lidsdale, Belanglo, Mullion Range and Armidale State Forests. On all of these areas the quota which has to be supplied is equal to or in excess of the C.A.I. and it is therefore essential to retain as much of the growing stock as possible whilst meeting quota commitments. This will mean that in these areas the felling cycle will be shortened from 5 years to 3-4 years.

The effect of this seeding felling has still to be measured to determine:

1. Resultant increment on residual stand.
2. Resultant regeneration as distinct from regeneration already established.

Further research or experimental work is required on:

(a) Methods of Slash disposal. This was recommended in 1953 but thus far no work has been carried out.
(b) Cost of treating the irregular forest which will result from any form of natural regeneration.
(c) Relative productivity of regular and irregular stands, especially considering the difficulty of obtaining full even stocking with natural regeneration.
The Economics of Plantations in Relation to Location and Site Quality.

Introduction.

The Forestry Commission has been establishing plantations in N.S.W. on a reasonable scale since the early 1920's. A considerable amount of work has been done with regard to techniques for growing crops particularly of P. radiata but little attention has been paid to the economics of growing plantations. With increasing attention being paid to growing plantations on marginal sites there is obviously a need to find some means of evaluating such sites so that we may know how much we can afford to invest in work designed to improve the site.

Economic evaluation of proposed planting areas will enable us to fix orders of priority for their use. A state forest authority may not be required to return a profit but it has a duty to see that its funds are invested to best advantage. Economic factors are not the only criteria to be used in judging the worth of an area but they can be useful in reaching a decision on its future use.

The aim of an economic study of a plantation project is to determine its profitableness. Unfortunately there is no direct way of estimating profit. If a forest is producing the annual balance of returns against expenditure will show a profit or loss in one sense but without a knowledge of the capital investment in the forest the figure is rather meaningless. If we look on the forest a collection of individual stands the cost of each stand can be computed from the beginning onwards and the value of the crop which it yields can then be expressed in relation to this cost.

Obviously to do this would mean that results would be delayed for a long period. The results would have limited value because of changes in the purchasing power of money and because methods employed at the beginning of the rotation may be very different from those used at its end.

Because of these factors it is usual in forest economics to base computations on present costs and present returns. The method is unreal in the sense that we cannot take the results of our computations and say this is what we shall actually get x years hence. However we can compare Area A with Area B and reach valid conclusions regarding the economic worth of one compared with the other. Furthermore the investor in forests can bear in mind that in the long term money tends to devalue and that he will probably reap benefit from any such devaluation. In other words the actual financial return is likely to be better than the one we calculate.

In this talk we are dealing only with P. radiata but the methods we shall discuss can be used equally well for any even aged forest crop.

The criterion of profitableness used is the rate of compound interest which the returns obtained represent on the capital employed. The rates earned depend on the costs of establishment and maintenance. The rate of growth of the plantation and the prices which are eventually obtained for the timber we sell. Before we can consider financial yields we must therefore establish the costs and returns which we shall use in our calculations.

The Costs of Plantations.

The annual report statements of expenditure record all direct costs of works carried out by the Forestry Commission. These statements have been used as the basis for compiling the costs of establishing and maintaining plantations in various localities. No attempt has been made to allocate administrative overheads to these direct costs as our interest lies in the relative merits of one area, or treatment or species over another. It is worth bearing in mind, however, that if our interest lay in determining the absolute profitableness of an area the direct costs would need to be increased by something in the order of 50% to cover administrative overheads.
The costs need to be subdivided into three main groups (1) land establishment and (3) annual maintenance.

The cost of the land covers the cost of purchase (if any) and the cost of capital expenditure on roads, buildings and other permanent improvements. The cost of clearing is an item to be included in the land cost as it will not be required in subsequent rotations. In numerous cases the Commission plants land which it has acquired at no cost and in such cases the cost of purchase is nil.

The cost of establishment includes all operations from burning and planting to scrubbing. For the sake of ease of calculations the cost of low pruning discounted to the present value has also been included amongst the establishment costs. Pruning could be included as a separate item in the formula. The difference as a result of doing so would not be significant. The assumption has been made that all of the other items of expenditure on establishment are incurred at the start of the first year.

Annual maintenance includes all items of expenditure not included in the land or establishment costs and in our conditions is wholly comprised of expenditure on maintenance of capital improvements and protection. In the costs set out below temporary fencing has been included in the annual maintenance charge although it could more correctly be included as an item in the cost of establishment.

If works such as high pruning or non commercial thinning were being undertaken they would be treated separately as items for inclusion in the formula in the same manner that returns from thinnings are handled.

The table below shows the costs incurred in forming plantations on various areas. Some of the items are directly related to the planted area and for these items the costs shown are fair averages. Other items such as major roads and maintenance and protection costs are not directly related to the planted areas in all cases. Consequently in reducing these costs to a unit acre it is not always easy to decide the total area covered by the work in question. Provided these points are borne in mind the table provides a reasonable basis for costs of formation of plantations.

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Sunny Corner</th>
<th>Jenolan</th>
<th>Canobolas</th>
<th>Vulcan</th>
<th>Green Hills</th>
<th>Buccleuch</th>
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<tr>
<td>LAND(S)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Clearing</td>
<td>8.50</td>
<td>5.85</td>
<td>9.99</td>
<td>6.72</td>
<td>9.09</td>
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</tr>
<tr>
<td>Roads major</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot; minor</td>
<td>5.64</td>
<td>7.14</td>
<td>8.65</td>
<td>6.06</td>
<td>6.90</td>
<td></td>
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<tr>
<td>Buildings etc.</td>
<td>1.71</td>
<td>1.81</td>
<td>5.82</td>
<td>2.32</td>
<td>2.55</td>
<td></td>
</tr>
<tr>
<td>Surveys</td>
<td>0.38</td>
<td>2.39</td>
<td>0.98</td>
<td>2.05</td>
<td>1.78</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16.23</td>
<td>17.19</td>
<td>25.44</td>
<td>27.74</td>
<td>23.47</td>
<td></td>
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<tr>
<td>ESTABLISHMENT (C)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Burning</td>
<td>0.26</td>
<td>0.34</td>
<td></td>
<td>0.56</td>
<td>0.39</td>
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<td>Nursery</td>
<td>2.36</td>
<td>2.41</td>
<td>2.14</td>
<td>2.48</td>
<td>2.85</td>
<td>1.98</td>
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<tr>
<td>Planting</td>
<td>10.15</td>
<td>9.92</td>
<td>10.62</td>
<td>11.02</td>
<td>6.49</td>
<td>7.79</td>
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<tr>
<td>(inc. refilling)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrubbing</td>
<td>5.92</td>
<td>6.62</td>
<td>3.34</td>
<td>2.37</td>
<td>6.23</td>
<td>3.69</td>
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<tr>
<td>Low pruning</td>
<td>6.39</td>
<td>7.60</td>
<td>7.36</td>
<td>-</td>
<td>8.65</td>
<td>6.86</td>
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<tr>
<td>(present value)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25.08</td>
<td>26.89</td>
<td>23.46</td>
<td>24.78</td>
<td>20.73</td>
<td></td>
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<tr>
<td>ANNUAL CHARGES (D)</td>
<td>1.16</td>
<td>1.11</td>
<td>2.19</td>
<td>1.75</td>
<td>0.62</td>
<td>0.91</td>
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</table>
If we wished to take representative costs in order to examine the economics of an average area establishment costs of £25 per acre and annual charges of £1 per acre would be fairly near the mark at present. The land costs used would depend on whether it had to be purchased initially. To the purchase price, if any, it will be necessary to add about £20 to cover costs of capital improvements.

It will become obvious later that any saving that can be effected in any of the items making up the total costs can have quite a bearing on the subsequent returns. The plantation manager should therefore take care at all times to see that his costs are kept as low as possible and that unessential work is not performed.

The income from Plantations.

The income from our plantations is made up of money returns from sale of thinnings and final fellings and here we have to resort to the use of yield tables.

There are no published yield tables for P. radiata in N.S.W. but from increment data which is available a yield table has been constructed which is applicable to the marginal plantations such as Lidsdale and the Moss Vale plantations. Before this table could be accepted with confidence it would need strengthening with more data but it is sufficient for our present purpose. It shows basal area and volume development for main crop, thinnings and total stand together with numbers of trees and mean diameter development.

The yield table is shown in Table 2.

We know or can derive the stumpage rates applicable to any particular area so that we can now proceed to the construction of a money yield table which is simply a volume yield table expressed in terms of money. For ease of working I have expressed stumpage rates in terms of pence per cubic foot to coincide with the yield tables. As we use differential stumpage rates for log grades and sizes we have to derive a weighted stumpage for each felling and therefore we have to estimate the percentages of each grade and size in the various fellings.

The money yield can now be derived directly from the yield table volumes. If further refinement is required it is possible to produce a price size gradient by plotting the weighted stumpages against average tree volume from which a smooth curve of price against size is obtained.

As an example we shall derive the price size gradient for Lidsdale plantation. The current on dump prices for logs at Lidsdale are:

<table>
<thead>
<tr>
<th>No. 1 grade</th>
<th>12.6&quot; +</th>
<th>27/3 per hundred s.ft. hoppus</th>
</tr>
</thead>
<tbody>
<tr>
<td>9&quot; - 12.5&quot;</td>
<td>24/7</td>
<td>&quot;</td>
</tr>
<tr>
<td>No. 2 grade</td>
<td>9&quot; +</td>
<td>18/2</td>
</tr>
<tr>
<td>No. 3 grade</td>
<td>7&quot; - 8.5&quot;</td>
<td>16/6</td>
</tr>
</tbody>
</table>

Logging costs inclusive of marking and measuring have been allowed at 7/10, 6/10, 5/10, 5/4 and 4/10 for fellings at 20, 25, 30, 35 and 40 years respectively. A nett stumpage of 3/6 has been allowed for pulpwood. These rates have been converted to pence per cubic foot and the derivation of the weighted prices is shown in Table 3. From this table we can construct the price size graph in Figure I. The money yield table can now be drawn up and this is shown in Table 4 for Lidsdale plantation. This money yield table is a fair representation of the yields which will be obtained at Lidsdale plantation while prices remain as at present. Obviously if the grading system were changed by addition of a higher quality grade the price size gradient would be affected and recalculation of the money yields would be required.
The Financial Yield from Plantations.

Having collected our information on costs and returns we are now in a position to examine the profitableness of a plantation. Because of the long period which elapses between the establishment and final marketing of a forest crop there are serious difficulties in the estimation of profitableness. Under these circumstances it is not surprising that a number of methods has been developed. The most satisfactory one for our purposes is that in which the rate of interest is used as the basis of estimate.

This is the financial yield method described in a number of Textbooks. The best description is given in Hiley's "The Economics of Plantations" and for those interested in the subject it is well worth reading. The method can be applied to completed transactions but we have none of these which we could use as an example. Consequently we shall apply it to expected yields using current costs and prices. We must always bear in mind that the use of estimated financial yields is not so much to show the rates of interest that can be earned as to form a basis for comparison of profitableness between different treatments and areas. Future changes in prices and costs will more than likely upset the accuracy of the estimates of financial yield. On the other hand although costs and prices may vary in future the relation between treatments, species and areas should remain constant so that a comparison made now is likely to be valid in the future.

The financial yield is the actual rate of interest obtained on the capital invested in a plantation over a rotation. This being so if all expenditure on the one hand and all income on the other hand are carried forward to the end of the rotation at this rate of compound interest then the two amounts will be equal. Derived in this manner the financial yield formula is:

\[
S = \frac{Y_r + \sum Ta \times 1.0p^{r-a} - C \times 1.0p^r - e}{1.0p^r - 1}
\]

where

- \( S \) = the cost of land and improvement
- \( C \) = the cost of establishment in the year \( o \).
- \( e \) = the annual costs payable at the end of each year.
- \( Ta, Tb \) etc. are the standing values of thinnings in the years \( a, b \) etc.
- \( Y_r \) = the standing value of the final yield in the year \( r \).

All of these amounts are expressed in terms of a unit acre.

\( r \) = the rotation in years.
\( p \) = the rate of interest to be found i.e. the financial yield.

We know all of the terms in this equation except \( p \). Because of the high powers of \( p \) the equation cannot be solved directly. It may be solved indirectly by inserting various values of \( p \) in the equation and finding by interpolation the value which makes the expression on the right hand of the equation equal to the known value \( S \).

This involves a lot of laborious work but it can be reduced by the use of schedules.

The financial yield equation may be re-arranged and written:

\[
S = \left[ \begin{array}{c}
1 \\
(1.0p^r-1) \\
(1.0p^r-1)
\end{array} \right] Y_r + \left( \begin{array}{c}
1.0p^r-a \\
(1.0p^r-1) \\
(1.0p^r-1)
\end{array} \right) Ta + \left( \begin{array}{c}
1.0p^r-b \\
(1.0p^r-1) \\
(1.0p^r-1)
\end{array} \right) Tb + \cdots \\
C + \left( \begin{array}{c}
1 \\
(1.0p^r-1) \\
(1.0p^r-1)
\end{array} \right) e
\]

For any given rotation and any given value of \( p \) the amounts in the round brackets are constant and the amounts outside the round brackets are the actual items of income and expenditure. Schedules of multipliers for rotations from 20 years upwards and for values of \( p \) from 1\% to 10\% are available in Hilroy's Economics of Plantations.

In this form of the equation it will be seen that the multipliers discount items of expenditure and income for an infinite number of rotations to present values.

As an example we shall take the financial data for Lidsdale plantation and determine the financial yield for a 50 year rotation. The calculation is shown in Table 5. The establishment costs have been estimated at £27,300, and annual charges at £1,000. By solution we find that when

\[
P = 2 \quad \text{the expression on the right} = 268.6
\]

\[
P = 3 \quad " " " " " = 125.8
\]

\[
P = 4 \quad " " " " " = 61.2
\]

\[
P = 5 \quad " " " " " = 26.3
\]

\[
P = 6 \quad " " " " " = 4.6
\]

\[
P = 7 \quad " " " " " = -8.2
\]

\[
P = 8 \quad " " " " " = -15.2
\]

If these figures are graphed we find if \( S = £20 \) the financial yield is 5.2\% but if \( S = £30 \) the financial yield is 4.8\%.

The schedules also provide a ready means of analysing the effect of any item of income or expenditure on the financial yield.

By calculating financial yields for a number of rotations we can determine the one which gives the highest financial yield. This is the financial rotation. The results of the calculations of financial yield for a number of rotations from 20 years to 50 years are shown below in Table 6 for Lidsdale plantation.

### Table 6.

Test values of \( S \) for Lidsdale plantation

<table>
<thead>
<tr>
<th>Rotation in years</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of interest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.3</td>
<td>97.0</td>
<td>127.9</td>
<td>125.8</td>
</tr>
<tr>
<td>4</td>
<td>-8.8</td>
<td>49.5</td>
<td>63.4</td>
<td>61.2</td>
</tr>
<tr>
<td>5</td>
<td>-15.2</td>
<td>22.8</td>
<td>29.0</td>
<td>26.3</td>
</tr>
<tr>
<td>6</td>
<td>-20.1</td>
<td>6.1</td>
<td>8.2</td>
<td>4.6</td>
</tr>
<tr>
<td>7</td>
<td>-23.2</td>
<td>-4.8</td>
<td>-4.3</td>
<td>-8.2</td>
</tr>
</tbody>
</table>

The graphical relationship between land cost, rotation and financial yield is shown in Fig. 2. The financial yield for any rotation on land costing any known amount can be read from the indicator graph with reasonable accuracy. The most favourable financial rotation is given where the known value of \( S \) intersects the line \( A B \). In our example with \( S = £20 \) the financial rotation is 36 years and the yield is approximately 5.5\%. If the land cost £30 per acre the financial rotation would be 37 years and the yield slightly under 5\%. Incidentally, in this case the financial rotation is approximately the same as the rotation of maximum volume production.

By carrying out certain works we know that we can improve the site quality of marginal country. This in itself is not enough to justify expenditure on site improvement because we need to know how much we can afford to spend without decreasing the return on our investment.

Using the example of Lidsdale plantation again we shall find out what margin exists to carry out site improvement because we need to know how much we can afford to spend without decreasing the return on our investment.
Using the example of Lidsdale plantation again we shall find out what margin exists to carry out site improvement work. We shall assume that the site improvement increases the money yield by 30% and also that we shall achieve this increase both on thinnings and final fellings.

We have found that on a 40 year rotation we can earn 5% if the land costs £29. If the money yield is increased by 30% the total of the discounted income increases from £80.9.0 to £105.0.0 and the price we can pay for land to earn 5% becomes £53.1.0 instead of £29.0.0. Therefore we could afford to spend the difference of £24.1.0 in site improvement work. If the actual cost of site improvement were less than £24.1.0 the financial yield would also be improved, thus giving us an additional benefit.

Bearing in mind that we must know the costs and returns the financial yield can be used to test the merits of different thinning treatments, of high pruning, of different species or of different areas.

For example if we wished to find the relative profitability of growing plantations at Lidsdale or Jenolan we can calculate the financial yield for the latter area using appropriate cost and stumpage data together with a suitable yield table. If we do this the financial yield is actually 6.5% with a rotation of 41 years. At Lidsdale the financial yield is 5.5%. On economic grounds Jenolan seems to be a superior proposition to Lidsdale. Other considerations would have to be taken into account in deciding whether further planting is justified at Lidsdale.

This is a demonstration of the effect site quality has on financial yield. Although Lidsdale prices are better than Jenolan prices the better rate of growth at Jenolan far outweighs the price difference. In choosing planting land site quality has an important bearing on the financial yield.

The economic factors we have been looking at are by no means the only ones to be considered in plantation projects. However the aim of forest economics should be to reduce costs of production and enhance the value of the products. If we can do this economics are playing their part in the State's plantation programme.
Table 2.

Yield Table for P. radiata - Lidsdale Plantation.

Volumes in cubic feet true measure to 4" DUB.

<table>
<thead>
<tr>
<th>Age</th>
<th>Dom Ht.</th>
<th>Log Area</th>
<th></th>
<th>Volume per acre</th>
<th>Stocking</th>
<th>Mean Diam.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Main Thin-</td>
<td>Total</td>
<td>Total Prodn</td>
<td>Main Thin-</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crop Nings</td>
<td></td>
<td></td>
<td>Crop Nings</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------</td>
<td>-------------</td>
<td>-------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>10</td>
<td>34</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>715</td>
<td>715</td>
</tr>
<tr>
<td>15</td>
<td>52</td>
<td>80</td>
<td>25</td>
<td>105</td>
<td>1245</td>
<td>390</td>
</tr>
<tr>
<td>20</td>
<td>70</td>
<td>90</td>
<td>75</td>
<td>115</td>
<td>1890</td>
<td>440</td>
</tr>
<tr>
<td>25</td>
<td>80</td>
<td>95</td>
<td>25</td>
<td>120</td>
<td>2280</td>
<td>500</td>
</tr>
<tr>
<td>30</td>
<td>86</td>
<td>100</td>
<td>25</td>
<td>125</td>
<td>2580</td>
<td>535</td>
</tr>
<tr>
<td>35</td>
<td>90</td>
<td>100</td>
<td>30</td>
<td>130</td>
<td>2700</td>
<td>675</td>
</tr>
<tr>
<td>40</td>
<td>91</td>
<td>100</td>
<td>25</td>
<td>125</td>
<td>2730</td>
<td>570</td>
</tr>
<tr>
<td>45</td>
<td>92</td>
<td>100</td>
<td>25</td>
<td>125</td>
<td>2760</td>
<td>575</td>
</tr>
<tr>
<td>50</td>
<td>92</td>
<td>95</td>
<td>25</td>
<td>120</td>
<td>2620</td>
<td>575</td>
</tr>
</tbody>
</table>
Table 3.

Table showing estimated percentages of log grades at various ages and weighted prices in pence per cubic foot for Lidsdale plantation.

<table>
<thead>
<tr>
<th>Age</th>
<th>Type of felling</th>
<th>Log Grades:</th>
<th>Pulp</th>
<th>Weighted Price</th>
<th>Av. Vol. Per tree cu/ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No. 1</td>
<td>No. 2</td>
<td>No. 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Nett Stge</td>
<td>% Nett Stge</td>
<td>% Nett Stge</td>
<td>% Nett Stge</td>
</tr>
<tr>
<td>15</td>
<td>Thin</td>
<td>20% 18.9</td>
<td>30% 11.7</td>
<td>15% 9.8</td>
<td>100% 3.0</td>
</tr>
<tr>
<td>20</td>
<td>Final Thin</td>
<td>20% 21.2</td>
<td>20% 12.8</td>
<td>10% 10.9</td>
<td>50% 3.0</td>
</tr>
<tr>
<td>25</td>
<td>Thin</td>
<td>40% 22.7</td>
<td>40% 14.0</td>
<td>10% 12.1</td>
<td>20% 3.0</td>
</tr>
<tr>
<td>30</td>
<td>Final Thin</td>
<td>40% 23.3</td>
<td>25% 14.5</td>
<td>25% 12.6</td>
<td>50% 3.0</td>
</tr>
<tr>
<td>35</td>
<td>Thin</td>
<td>70% 24.2</td>
<td>20% 15.1</td>
<td>10% 13.2</td>
<td>100% 3.0</td>
</tr>
<tr>
<td>40</td>
<td>Final Thin</td>
<td>70% 25% 15.1</td>
<td>20% 15.1</td>
<td>10% 13.2</td>
<td>20% 20%</td>
</tr>
<tr>
<td>-----</td>
<td>-----------</td>
<td>------------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>--------</td>
</tr>
<tr>
<td>15</td>
<td>156</td>
<td>2.5</td>
<td>3.0</td>
<td>390</td>
<td>4.9</td>
</tr>
<tr>
<td>20</td>
<td>108</td>
<td>4.7</td>
<td>6.0</td>
<td>440</td>
<td>11.0</td>
</tr>
<tr>
<td>25</td>
<td>76</td>
<td>6.6</td>
<td>8.7</td>
<td>500</td>
<td>18.2</td>
</tr>
<tr>
<td>30</td>
<td>47</td>
<td>11.4</td>
<td>13.9</td>
<td>535</td>
<td>31.0</td>
</tr>
<tr>
<td>35</td>
<td>44</td>
<td>15.3</td>
<td>17.0</td>
<td>675</td>
<td>47.8</td>
</tr>
<tr>
<td>40</td>
<td>28</td>
<td>20.4</td>
<td>19.7</td>
<td>570</td>
<td>46.8</td>
</tr>
<tr>
<td>45</td>
<td>21</td>
<td>27.4</td>
<td>21.6</td>
<td>575</td>
<td>51.7</td>
</tr>
<tr>
<td>50</td>
<td>16</td>
<td>36.0</td>
<td>23.4</td>
<td>575</td>
<td>56.0</td>
</tr>
</tbody>
</table>

Table 4. Money Yield Table for *P. radiata* Lidsdale plantation.
Table 5.

<table>
<thead>
<tr>
<th>£</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
<th>6%</th>
<th>7%</th>
<th>8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y50</td>
<td>325.0</td>
<td>593.0</td>
<td>914.0</td>
<td>1525.0</td>
<td>2136.0</td>
<td>2747.0</td>
<td>3358.0</td>
</tr>
<tr>
<td>T15</td>
<td>4.9</td>
<td>1,183.0</td>
<td>2,932.0</td>
<td>5,832.0</td>
<td>9,732.0</td>
<td>13,632.0</td>
<td>17,532.0</td>
</tr>
<tr>
<td>T20</td>
<td>11.0</td>
<td>1,071.0</td>
<td>2,717.0</td>
<td>5,311.0</td>
<td>7,891.0</td>
<td>10,471.0</td>
<td>13,051.0</td>
</tr>
<tr>
<td>T25</td>
<td>18.2</td>
<td>970.0</td>
<td>619.0</td>
<td>437.0</td>
<td>323.0</td>
<td>246.0</td>
<td>191.0</td>
</tr>
<tr>
<td>T30</td>
<td>31.0</td>
<td>879.0</td>
<td>534.0</td>
<td>359.0</td>
<td>253.0</td>
<td>184.0</td>
<td>136.0</td>
</tr>
<tr>
<td>T35</td>
<td>47.8</td>
<td>796.0</td>
<td>460.0</td>
<td>295.0</td>
<td>199.0</td>
<td>138.0</td>
<td>97.0</td>
</tr>
<tr>
<td>T40</td>
<td>64.8</td>
<td>721.0</td>
<td>397.0</td>
<td>242.0</td>
<td>156.0</td>
<td>103.0</td>
<td>69.0</td>
</tr>
<tr>
<td>T45</td>
<td>51.7</td>
<td>653.0</td>
<td>342.0</td>
<td>199.0</td>
<td>122.0</td>
<td>77.0</td>
<td>49.0</td>
</tr>
</tbody>
</table>

| X  | 362.0  | 195.1  | 117.8  | 76.3   | 50.2   | 34.2   | 25.1   |
| C  | 27.3   | 1,59.4 | 31.6   | 1,16.0 | 31.6   | 1,06.0 | 28.9   |
| e  | 1.0    | 50.0   | 33.3   | 25.0   | 20.0   | 16.7   | 14.3   |
| Y  | 93.4   | 69.3   | 56.6   | 50.0   | 45.6   | 42.4   | 40.3   |
| S=X-Y| 268.6 | 125.8  | 61.2   | 26.3   | 4.6    | -8.2   | -15.2  |
Average Volume of Trees, cu. ft.

Fig. 1 Price - Size Gradient
Liddale Plantation

Rotation in Years
Fig. 2 Financial Yield
Indicator Graph
Liddale Plantation
SOIL AS A SYSTEM

(Based on Hans Jenny's "Factors of Soil Formation")

In the lectures which follow, much of the information will be rather specific. Soil properties such as acidity, elemental composition, and colloidal exchange characteristics will be given definite values. The values are the result of the agencies which shaped each particular soil. It is therefore most important to see soils as dynamic entities whose present existence in a particular situation is linked with a particular set of circumstances past and present. This lecture states the general case according to Jenny's analytic system. Its most obvious advantage is to focus attention on soil evolution, seeing the soil as a body in equilibrium with its environment and not as an unconnected series of profile descriptions.

The system has a practical importance of special interest to foresters. Because foresters deal with large land units, the broad analysis afforded by this system becomes a practical way of predicting soil potential. Soils can be examined in a systematic manner and results obtained elsewhere can be extrapolated more readily for the solution of an immediate problem occurring outside previous experience. In this lecture minute detail is avoided in the hope that following lectures will be easier to place within the main boundaries of soil-forest relationships, if those boundaries are mapped at this stage.

Defining the System

The soil is seen for purposes of analysis as an open physical system, to which substances may be added or removed. A system of this sort is defined if its characteristic properties are defined. Changes in one part of a dynamic system cause changes in other inter-related properties, and by change the system is said to alter its state. In the field, altered states are recognised as soil types. Theoretically the degrees of change are infinite, so it is only practical to impose restraints by using certain groups of soil forming factors which group and determine others. These restraining factors can be called independent variables.

To describe the system functionally within its restraints we need:

(1) Initial state of the system
(2) Reaction time
(3) Conditioning variables

In soils the parent material can be classified as (1), reaction time can be taken as time to the present soil state, and the independent "groups of conditioning variables as climate, organisms, and topography. The latter three factors overlap from soil to ambient environment to form a coupled soil/environment system (the equilibrium state referred to earlier) whose function can be written for any soil property, s,

\[ s = f(C_1, o, r, p, t) \]

The system is thus defined and from it can be concluded that any given combination of \( C_1, o, r, p, t \) will produce only one soil type. The sort of effect each factor, considered independently while the other factors are held constant, will have in a soil system will now be explored in general terms. To illustrate the complexities engendered by even this simple system, the coincident effect of a covariation of factors will be briefly examined where applicable.

Time as a Soil Forming Factor

Considered separately, time is of great importance in the genesis of Australian soils, since the land mass has been little affected by recent physical upsets such as glaciation or vulcanism. Aridity cycles, salinisation,
leaching over long uninterrupted periods, are all typical of the treatment
time has given Australian soils.

Time zero can be taken as the state of the system before parent
material has started to react in the direction of soil production. Maturity
can be taken as the state of the soil when it is in equilibrium with its
environment. Soil morphologists often define soils as mature when they have
well defined profiles, a state which may coincide with equilibrium but which
is in doubt where soils have multiple origins. A consistent classification
by degrees of maturity can only be obtained where the functional expression is:

\[ s = f(t) \text{ Cl, o, r, p...} \]

i.e. when Cl, o, r, p, are held constant while time alters.

In forestry many soils are skelatal but are nevertheless in equilibrium
with their environment. From a forest nutritionist's viewpoint they can be
considered mature because they are capable of being added to or drawn upon by
the forest community which establishes their equilibrium state.

Parent Material as a Soil Forming Factor

We have mentioned the importance of skeletal soils to forestry.
As we have noted forest material is the soil at time zero or the initial
state of the system. There have been clashes between groups of pedologists
over distinctions between weathering and soil forming processes. Many forest
soils are sufficiently close to the parent situation to make the distinctions
academic to foresters. The series is:

Rock ..... Weathered Rock......Immature Soil....,Mature Soil

Climate controls the early stages of the series almost exclusively
and as it is used as a restraint in Jenny's system a satisfactory exposition
of the parent material function is:

\[ s = f(p) \text{ Cl, o, r, t...} \]

There is no way of giving parent rocks a single numerical functional
value, but any correlation between parent rocks and soil properties becomes
a means of evaluating the parent material itself. For example Mulligan Range
plantation can be classed as being located on a Silurian series known as the
Mulligan Volcanics. Variations in the composition of the soils result in violent
fluctuation in P. radiata production from high quality stands to total failure.
Variations can be expressed in terms of the exchangeable Ca\(^{2+}\) content of the
whole profile, a value which is itself determined by the flow of lava on
which the soil formed.

For the general equation

\[ s = f(p) \text{ Cl, o, r, t...} \]

we substitute

\[ \text{Ca}^{2+} = f(\text{lava flow}) \text{ Cl, o, r, t...} \]

The constants being

Cl = Climate of Central Tablelands - Western section
o = Dry sclerophyll forest (Eucalyptus spp.)
r = Undulating plateau
t = Pleistocene to the present

It is possible to make broad divisions in assessing fertility as a
function of parent material provided the conditioning factors are relatively
constant. It is well known that soils formed on granites are usually lower
in exchangeable Ca\(^{2+}\) and in P than those formed on basalts and that both groups
are superior in most cases to those formed on acid sedimentary rocks. However, if the factor "Climate" varies it is possible for most infertile laterites to form on basalt or if vegetation types change (o) for soil genesis to diverge on comparable parent materials.

Topography as a Soil Forming Factor

The functional equation for topography is

\[ s = f(r) Cl, o, p, t \]

Soil variations as the result of relief varying independently are mainly associated with the soil water regime and with the erosional pattern when equilibrium conditions are upset. On certain slopes at Glenwood State Forest overstocking and clearing had the effect of eroding the topsoil from a deep red loam. Eroded and non-eroded profile would not be described very differently, but the topography which lost its topsoil has also lost major amounts of available N, organic matter, and perhaps micronutrients such as S, all of which losses are being repaired as pines close canopy over the eroded slopes.

Drainage factors influence soil properties which influence forest composition, excluding situations in this consideration where increased soil water per se is the only cause. Bloodwood (E. gummifera) has been shown to disappear from sites in favour of E. saligna where available manganese levels closely linked to soil drainage, rose to levels toxic to it.

Climate as a Soil Forming Factor

Climate has had more attention as a soil former than any other factor, mainly because its two most potent components, temperature and moisture have such far reaching effects. Where results are being extrapolated for prediction in another locality it is vital to consider the effect of climate in deflecting soil genesis. Basalts in the cool winter rainfall of the Central and Southern Tableland form fertile deep red loams. 500 miles north at Mt. Tupper State Forest, under warm summer rainfall conditions they give rise to infertile laterites. In the more humid subtropical rainforest of the North Coast they develop a fierce phosphorus-fixing power which alters their fertility markedly as compared with the position in temperate climates.

Past climatic changes have also affected soil formation. In Southern Australia past periods of salinisation resulting from cyclic salt deposition in arid periods has produced widespread areas of solodic soils. Where the parent material was calcium-rich this did not happen, but in forests such as Mullion Range, Lidsdale, or the Hawkesbury sandstones at Belanglo almost complete solodisation has occurred.

In cool moist climates forest soils frequently develop problems of N availability due to the interlocking effect of climate, vegetation and microbial populations. Mineralisation of N to a form available to plants is delayed and litter builds up, eventually playing its part in producing a podsol. In warmer climates mineralisation is rapid and in the extremes cases N is again unavailable because it is mineralised and leached too swiftly for plant assimilation.

The complexity of climate as a soil former of independent status can lead to confusion because it operates in such close association with vegetation and microbial life. It may resolve the concept if Jenny's reasons are explained in terms of the presence of a pedocal, as of a series of soils containing a lime horizon. In Jenny's system the presence of a lime horizon will be constrained by:

1. Whether the soil has been altered by man e.g. irrigated
2. Whether relief is normal i.e. not too steep for horizons to form or too flat to prevent gleying or solubilisation
3. Whether the parent rock can supply lime minerals
4. Whether sufficient time to produce the horizon has elapsed.
Organisms as Soil Forming Factors

Restating the basic concept, organisms can be allowed a place as independent variables in soil formation

\[ s = f (\alpha) C_l, r, p, t, \ldots \]

only if they have the capacity to change while parent material, climate, relief and time are held constant. Under this definition the quantity of organism cannot be considered a soil forming factor because quantity is constrained by climate and the other independent factors. The species of organism within the groups micro-organism, vegetation, animals and man, and its relative frequency is what is important.

In virgin forest vegetation acts with maximum (although usually over-rated) effect in the formation of soil. In managed forest man forces the rate of formation chiefly by his interference in the nutrient cycle and through his effect on the climatic environment. Forests probably act most importantly in preserving a status built up over long periods of time under the influence of all factors. Equilibrium has been neatly summarised by Tamm

Brown forest soil \[\rightarrow\] podsol
(Vegetation)

In the slow growing Swedish forests this sort of reaction is not spectacular. Under conditions of rapid growth by demanding species whether it be in British moorland re-afforestation or in S.E. S. Australia the results can be most spectacular. In both cases organisms incapable of coming into functional equilibrium with the environment have induced a rapid and major trend in soil formation as shown by greatly reduced productivity in the second rotation.

Productivity

We have been considering theoretical bases in an abstract, philosophical manner. In practical, concrete terms these factors are all focussed in one term, productivity. Its function is:

\[ \text{Yield} = f (\text{climate, plant, man, soil, time}). \]

The bracketed factors are all productivity factors and each capable of treatment as an independent variable. Yield becomes the numerical index of a general producing system of which soil is only one component. To compare productivities due to soil therefore it is necessary to have climates, plants, time and management identical and then to solve the equation.

\[ \text{Productivity} = \text{Yield} = y = f (\text{Soil}) \text{Climate, crop, management, time} \]

The term fertility revolves more narrowly around nutrient input-output relationships. In other words it is less integral in its conception than productivity. The various factors making up fertility (pH, exchangeable bases, P content etc.) can be integrated in one term yield, which becomes the quantitative expression of productivity.

The aim of our work in plantation soils has been to integrate the fertility factors in a yield term (Site Index) so that productivity can be expressed as a function of soil. For P. radiata and P. elliottii this is close to achievement. The very important fact remains that the fundamental equation \[ s = f (C_l, \alpha, r, p, t, \ldots) \] serves to define the soil and that every observation that more clearly evaluates the influence of the independent variables, will more clearly evaluate the yield rating of the soil.
PLANT NUTRIENTS AND THEIR AVAILABILITY IN FOREST SOILS

INTRODUCTION

In common with other living things the elements required most abundantly by trees are carbon, hydrogen and oxygen. These they obtain from air and water and will not concern us in this part of the symposium. When we speak of nutrient elements we mean those which are required by the plant as essential to its vital functioning. Without these elements, the carbon, hydrogen and oxygen could not be organised into the protoplasm, cell walls and so on which go to make up the framework of the tree. They are necessary for enzyme systems, buffering cell sap, catalysis and other biochemical processes.

Although many elements can be detected in plants, only a comparative few need concern us here. They are:

Ca, Mg, K, Al, Na, Fe, Mn, Zn, N, P, S, Si, B, Mo.

Each of these is usually present in the forest soil. Not all appear to be necessary for plant growth. Their importance may merely arise from the fact that they are present in quantity. In too great a quantity almost all are detrimental.

The question which usually puzzles the person who thinks about the existence of these elements in the soil is — how is it that these elements, some of which normally are found in water soluble form, are still present in the soil which has been leached with rain for thousands of years? This is particularly the case with forest soils which have usually been lying apparently undisturbed since they were formed. The answer lies in the fact that the soil is a natural dynamic body and its properties change with time as we have seen in the previous section of the symposium. New material is being brought into the system slowly but continually. Probably most important is the fact that what is there is held by various factors which we will deal with later and which are associated with its mineral and organic components. The more these elements resist removal by leaching the more the plants require special mechanisms to obtain their requirements.

We all know that trees will grow quite well at least for a limited period, without soil at all if some means of support is devised and an aerated solution containing the necessary nutrients is supplied to the roots. This is in fact what is done in a good deal of laboratory work when the effects of various nutrients are being tested. If we support the roots in a bed of inert quartz we will get good results provided that we water with a solution which contains the necessary elements in the correct proportions, at the correct pH etc. While, in forestry, we may approach this condition very closely at such places as Tuncurry State Forest where the soil is mostly inert sand and the nutrient solution sea-spray, even here we find a considerable accumulation of some elements in the top three inches of the soil which has apparently defied all the removing powers of the climate to dislodge it.

What we usually find is that the soils which have evolved over a great period of time contain mineral particles (and usually also organic particles) which are very small. Those which are particularly important are called colloids and are less than 200 millionths of a millimeter in size. The mineral colloids are the clays. These are various crystalline minerals which like all other crystalline materials have an electrical charge on their outer surfaces. When a crystal is large this charge is unimportant but it assumes very important properties indeed on minute soil particles. The charge on the surface of the clay mineral is negative along the major surface which attracts positively charged ions such as Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\), Na\(^{+}\), Al\(^{3+}\), etc. The smaller the particle the greater the charge because more surface is exposed for a given weight of material. The area of electrical influence around a colloid particle is called the electrical double layer.
Clay minerals consist of a number of different types of crystals, variously named such as kaolin, montmorillonite, illite and so on. All are built out of two definite building units:

a) 4 oxygens at the corners of a tetrahedron usually with a Si ion in the centre (Si in 4-coordination).

b) 6 oxygens or hydroxyls at the corners of an octahedron typically with Al or Mg at the centre. (Al or Mg in 6-coordination).

They can be visualized as follows:

An important property of the ions which become attached to the minute crystal surfaces is that they are not fixed but can be exchanged or displaced by other ions. For example, if a clay mineral is shaken with a solution of calcium chloride the ions present on the crystal surface will almost all come into solution and Ca$^{2+}$ will occupy all the available space. This is not the case of course with those elements which make up the structure of the crystals or those which are sandwiched between crystals — (lattice bound).

There can also be organic colloidal particles in the soil possessing similar properties. While these are not of great importance in forest soils in the drier regions, they are often of paramount importance in rain forest soils. Organic substances can also hold mineral substances as complexes, both soluble and insoluble in water.

At this stage we can list the various important categories in which nutrients exist in the soil.

1. Dissolved in the soil solution.
2. Adsorbed onto the surface of colloidal mineral particles or organic particles and exchangeable with other ions.

Availability of Nutrients.

The various nutrients are very dissimilar in the way they are distributed between these four categories. For example, Cl$^{-}$ is found almost only in the first, Ca$^{2+}$ and Mg$^{2+}$ in the second, while K$^{+}$ is found mostly in the third. The nutrients divide naturally into two opposite classes:

a) The positively charged ions — cations (Ca, Mg, K, Na, Fe, Mn, Cu, Al, Zn) and

b) The negatively charged ions — anions (P, S, Cl, Si, B, Mo).

Nitrogen is anionic when in the nitrate form but cationic in the NH$_4^+$ form.
a) the parent material
b) kind of vegetative cover
c) degree of leaching
d) existence of a period of salination in the geological evolution of the soil
e) extent to which it receives ions from the precipitation (particularly important in coastal and near coastal areas).

A good cation distribution is one which contains about a 4/1 Ca/Mg ratio, sufficient K and little Na. A good soil in this regard is the Tumut soil in the table hereunder. An example of a poor soil is the Mullion Range soil.

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>Ca meq%</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumut 158</td>
<td>9.27</td>
<td>1.91</td>
<td>0.13</td>
<td>0.65</td>
<td>nil</td>
</tr>
<tr>
<td>Mullion Range</td>
<td>0.19</td>
<td>0.68</td>
<td>0.14</td>
<td>0.55</td>
<td>3.62</td>
</tr>
</tbody>
</table>

The cations on the exchange sites are in equilibrium with the soil solution. If ions are taken away from the latter then there is desorption to restore the equilibrium. If ions are added there is adsorption for the same reason.

Not as much can be said about anions exchange as about cations exchange because it has not been as thoroughly investigated. This can be said however, that Cl\(^-\), NO\(_3\)\(^-\), SO\(_4\)\(_{2-}\) < PO\(_4\)\(_{3-}\). The matter is being actively studied at present and many papers are appearing on the subject. It is fairly clear that phosphate is not adsorbed onto clay in many of the cases in which this was formerly thought to be so. In these cases the main action when a phosphate is added to a clay appears to be precipitation. For example when superphosphate is added to a soil containing clay it is said to be rapidly 'fixed' or 'sorbed' or 'adsorbed'. What appears to happen is the following:

Superphosphate contains about 40% CaSO\(_4\). This has an appreciable solubility giving Ca\(^{2+}\) ions and SO\(_{4}\)\(^{2-}\) ions. The Ca\(^{2+}\) ions are released in sufficient concentration to displace some of the Al\(^{3+}\) on the clay and thus bring Al\(^{3+}\) ions into the soil solution. The soil solution is well supplied with (H\(_2\)PO\(_4\))\(^-\) ions from the associated Ca(H\(_2\)PO\(_4\))\(_2\) which is quite soluble and also supplies Ca\(^{2+}\) ions. The free Al\(^{3+}\) ions unite with the (H\(_3\)PO\(_4\))\(^-\) ions to form an aluminium phosphate compound which is very insoluble in water thus removing the phosphate from the soil solution. During our work on the Penrose experimental plots and the Wingello experiment we have been able to show that almost all the phosphate in the superphosphate applied has, after a period of years, become Al-P. This has also occurred at Barcoongere although one site seems to have produced Fe-P presumably by a similar process.

Non-Exchangeable ions in Mineral Compounds.

These ions form the main part of the nutrient capital of the soil. They become available by dissolving very slowly or by chemical weathering. Some ions such as those of potassium are held in the lattice of the clay minerals and are released very slowly.

In our soils the more soluble components have long since gone and we have the silicates, hydrated oxides, and very insoluble phosphates. The solubility of most of these increases with falling pH. As far as we are concerned the most important are the insoluble phosphates. It is clear from
Soil Solution.

Nutrients in the soil solution are readily available to plants. The soil solution can be defined as the water with dissolved electrolytes and gases which is held against gravitational forces and which tends to be in chemical equilibrium with the soil material.

Data on the composition of the soil solution for uncultivated soils, particularly forest soils, are scanty. What exist can hardly be transferred to the highly leached soils of the coast and tablelands which are our immediate problem. The samples which we have examined have usually shown the presence of small amounts of sodium and potassium but little else. It is commonly held, however, that all the elements which are taken up from the soil by plants can be found in the soil solution even though the concentration may be very low indeed.

Exchangeable Ions.

Ions present in exchangeable form in soils are available to plants but not as readily as those in soil solution. All cations can be adsorbed onto soil particles. Anions, however, are not so readily adsorbed, some not being adsorbed at all under field conditions as far as is known. This follows from the model outlined earlier on which the diffuse electrical double layer was shown to be negatively charged and this would naturally attract cations. In acid soils, however, the broken edges of the crystals can acquire a positive charge and this is the site of attachment of the anions.

The amounts of cations and anions adsorbed depend on:

a) The mineralogical composition of the soil
b) the amount of organic matter
c) the pH
d) the total amount of nutrients present.

If the clay minerals consist mainly of kaolin then the cations adsorbed will tend to be low and the anions high compared with other clay minerals such as montmorillonite, illite, etc. This follows from their crystal structure and particle size. It is seldom that the clay minerals are definitely of one type or another. The usual thing is a mixture with some type predominant.

The negative charges on clays can hold any cation, even quite large ones such as proteins but they hold the various ions with different intensities. Generally, it can be said that the higher the valency of an ion and the greater its atomic weight the more intensely it is held. Thus lithium and sodium are more easily exchanged than K or NH₄, Mg < Ca < Al < Ca. It appears also that the clay minerals themselves differ in their ability to hold cations. For example, if a pure montmorillonite and a pure kaolin were each put into separate solutions containing KCl and CaCl₂, the kaolin would take up relatively more K than Ca when compared with the montmorillonite i.e., kaolin has a greater affinity for K and lesser affinity for Ca than montmorillonite. Expressed in another way, plants growing in a montmorillonite soil with a given ratio of exchangeable K to Ca will be able to extract the K more easily than plants of the same species growing in a kaolin soil with the same analysis and so the former will end up with a higher K/Ca ratio than the latter.

What is normally reported as exchangeable cations in a soil sample is the total of each and no account is taken of their availability to the plant and this must be kept in mind when interpreting results.

What is found in acid soils is of greatest concern to us because, with few exceptions, our soils are acid. There are five cations which go to make up the exchangeable ions in normal soils. These are Al³⁺, Ca²⁺, Mg²⁺, K⁺, Na⁺. Normally Ca²⁺ dominates but in some of our soils Mg²⁺ or Al³⁺ dominates and Ca²⁺ is almost or is absent. Just what the ratio of these cations to one another is, depends on the history of the soil, that is:
our work at Penrose that P. radiata can obtain ample P from Al-P formed from superphosphate as already outlined. However, when Al-P is found in soil as a minor mineral it is much less soluble and, as the work of others has shown, much less readily available to P. radiata than superphosphate. The very thorough study of the mineral phosphates in recent years has revealed some very important details. The size of the mineral particles is most important — the smaller they are the more surface they have and the more readily available to plants they are. During the dissolution of, for example, iron phosphate, a film of hydrated Fe₂O₃ forms around the particle which can prevent further dissolution of the phosphate. Work which I have in progress at the present time indicates strongly that one of the reasons for soil improvement arising from intense heating under burnt windrows arises from this situation. I have found that if unheated soil from Sunny Corner S.P. is heated to 350°C, for 4 hours then the amount of Al-P is more than doubled, the Fe-P increased substantially and the Ca-P increased little or not at all. This could arise from the destruction of the Al(OH)₃ and Fe(OH)₃ barriers around the phosphate minerals or from the organic P in the soil. The effect of heating soil can also be used to illustrate another important property of the organic section of the soil. If we have a particle of any pure variscite Al(OH)₂H₂PO₄ it will give rise on solution to Al³⁺, (OH⁻) and H₂PO₄⁻ ions. The solubility product of this compound Kₛₚ can be written

$$Kₛₚ = (Al³⁺)(H₂PO₄⁻)(OH⁻)^2$$

In other words the total amount of phosphorus in solution supported by variscite depends on the concentration of (Al³⁺) and (OH⁻) ions from other sources because if these are high the (H₂PO₄⁻) must be low to keep Kₛₚ constant. Now if we draw a graph of the solubility in water of Al-P at various pH's in the absence of other sources of (Al³⁺) ions we obtain the following

![Graph showing solubility of Al-P with respect to Al(OH)₃](image)

This shows a general decrease in solubility of Al-P as the pH rises. But in the presence of Al(OH)₃ there is a drop in the solubility of Al-P. This follows from the fact that Al(OH)₃ solubility shows a very sharp decrease with increased pH. Because of the presence of Al³⁺ from the Al(OH)₃ in the acid solutions the solubility of the Al-PO₄ now actually rises as the pH rises and the (Al³⁺) falls. Soils with high exchangeable (Al³⁺) may have a seriously reduced (H₂PO₄⁻) availability because of this effect and therefore any treatment which can reduce this will be beneficial where P is a limiting factor in growth. Heating appears to do this too as we find that after a Sunny Corner soil has been heated for say 350°C for 4 hours it no longer has any exchangeable (Al³⁺). Instead of the phosphorus availability following 2 it will now follow 1. This, combined with the increase in the availability of these minerals for dissolution, is probably the reason for the ash-bed effect. This is of course a highly simplified picture but nevertheless gives an idea of the types of processes which can account for varying P availability in acid soils.
Ions present in the Organic Matter.

In the better soils and on the coast and particularly in rain forests these ions can be quite important. They can occur as:

a) water-soluble salts
b) adsorbed in exchangeable form on organic acids
c) insoluble salts and compounds such as Ca (COO)₂, Fe-Al tannate (polyphenols) complexes, inositol phosphate-metal complexes, metal protein complexes and so on.

The actual composition of course depends on the vegetation type.

Having considered what the soil has to offer the tree and something of the manner of its distribution in the soil we will now discuss how these nutrients are brought to the tree from their various locations in the soil, that is, the movement of the nutrient from the soil to the root surface.

Two processes appear to be involved:

a) mass flow of water adsorbed by the plant
b) diffusion.

In our forest soils we have noted that the soil solution which would be brought to the tree by mass flow of water is a poor source of nutrients (unless ground water is being tapped as is probably the case on some parts of Whiporie S.F.). It is probable therefore that diffusion is the dominant factor. Absorption of cations and anions by the plant root creates a gradient along which nutrients diffuse to the root. Those soil factors which influence the size of the concentration gradient and the magnitude of the diffusion coefficient will influence the rate at which the nutrient reaches the plant root and hence its availability. A plant root absorbs ions from its immediate vicinity, usually from a few mm behind the tip to where it becomes suberized. The concentration gradient established for any particular ion depends on:

1. The initial concentration of the ion in the soil solution;
2. The rate of uptake of the ion per unit of root area;
3. The rate of diffusion of the ion to the root surface;
4. The rate of movement of the ion to the root surface by mass-flow (i.e. in the water);
5. The rate of diffusion of the ion along the surfaces of soil particles;
6. The rate of replenishment of the ion associated with other ions in solution, from ions held by the soil;
7. The capacity of the soil to replenish.

Most of these points can be illustrated diagramatically.
Some examples of why a careful examination of this root-soil relationship is important to forestry may not be out of place. Recent work using radioactive isotopes has shown that if the soil solution contains more ions of a certain type than the plant requires, then this ion will accumulate around the root. This can only be reduced by back diffusion (or by movement of water past the area by some other agency such as rainfall and gravity). Clearly, when this occurs diffusion towards the root cannot occur and the plant can only be supplied by mass flow. Differences in plant species in their ability to absorb nutrients under conditions where diffusion governs availability may be due to the extent of their root system, their transpiration ratio and their ability to lower the concentration to a very low level at the root interface.

The movement of P to the roots would be enhanced by an accumulation of + ions at the root surface. However, when the P ions arrived they would probably be limited in their further movement towards the root by the existence of the + ion barrier. This would particularly occur if Al³⁺ were accumulated around the root. It is not difficult to see that in acid clay soils a plant which is able to take Al³⁺ into itself without being harmed thereby and thus removing this barrier to P from the environment immediately external to the root would have an advantage over plants which could not do this. They would not reject P as it came into the vicinity of the root surface. P would be more readily admitted and the plant could separate Al and P in its biological system, it could then utilize the additional P made available. This may be why Pinus radiata grows so well on soils which support such a poor stand of eucalyptus. Eucalypts do not take in more than a normal (scall) amount of Al whereas P. radiata will take up very large quantities and survive apparently unharmed. We also have evidence that the plant has some mechanism for separating the Al and P in its system. It may be that one of the functions of the tannins (polyphenols) which are so abundant in eucalypt foliage is to complex the ions collected around the roots, thus clearing the way for P entry.

Another important thing that flows from the diagram is that in our forest soils the root-soil relationship is probably confined, to all intents and purposes, to (2) and (3). Because of this, when trying to assess the fertility of a soil for growing trees a factor of great importance is the likelihood of roots coming into close proximity of a source of nutrients. If we consider that P. radiata feeding roots will not operate as such below a certain depth in most soils, it is clear that the presence of a large number of impenetrable barriers such as stones will severely limit the fertility of the site. This would have little to do with the fertility in the soil solution - mass flow dominated the site. This leads us to the important conclusion that instead of saying that a certain site's soil solution has 100 ppm P, it is necessary to know also the stone/soil ratio because the P is estimated on the soil only — not on the stones. If the soil is 50% stones then the effective P for trees (which occupy the whole site) is 50 ppm. Using this concept we have been able to predict soil fertility from P, Al and Ca by means of a regression equation whereas the data previously had been quite intractable.
SUMMARY

Trees need certain elements which the soil contains if they are to grow satisfactorily. These can be supplied from the soil solution, the elements adsorbed on mineral colloids, minerals in the soil, the organic matter in the soil. Of these, the most important for tableland and a good deal of coastal forestry are the adsorbed elements and the minerals in the soil. The availability of these is governed by the relative and absolute amounts of the necessary nutrient in the soil and capacity of the tree to handle certain aspects of these relationships.
The starting point for any consideration of forest nutrient cycles is a study of the tree's capacity to move the various nutrient elements from roots to crown and thence to storage, immobilised states, or back to the soil. In spite of empirical studies going back almost 90 years very little is known of the finer detail of translocation in forest trees. This lecture is therefore drawn from horticultural and agricultural, as well as from forestry sources. The next lecture treats the subject quantitatively from the viewpoint of total amounts of nutrient moved. In this lecture we consider the movement pattern within the tree, the partition of elements between various organs, and the remobilisation system so far as it is known.

Minerals are translocated in two main streams. The transpiration stream to the leaves carries the bulk of the minerals upward. A phloem flow transports elements away from the leaves. The flow is not steady but surges. Ca and N flow at relatively steady rates while K and Mg vary considerably over a 24 hour period. Limits to elucidating the flow occur as a result of experimental difficulties. The radioactive tracer technique is best suited to this sort of study but suffers from difficulties in introducing the tracer and from effects (as yet not well understood) of radiation from the tracer affecting the plant enzymes. The main effects for each major element and some of the micronutrients will now be considered.

Nitrogen

The element N is absorbed chiefly by the plant as nitrate - $\text{NO}_3^-$, It proceeds to the growing points of the tree in the xylem sap. Before transport however the nitrate is transformed to compounds belonging to two main groups - amino acids and ureids. In pines the amino acid glutamine, $\text{CH}_2\text{CH}_2\text{NH}_2\text{COOH}$, seems to provide the means of transport for the bulk of the N. N is used mainly to produce protein which with water makes up protoplasm. Protein not found as protoplasm makes up the enzyme systems and the nucleoproteins of chromosomes. The framework of the grana in which the chlorophyll molecule is incorporated also contains proteins. The adenosine TP which acts as energy carrier in the photosynthetic cycle also contains nitrogen. Deficiencies of nitrogen thus limit every major metabolic process in the plant.

In trees well supplied with N, the protein level of the leaves, allowing for dilution by increased cellulose production in the developing leaf, is fairly constant from young to mature stages. Where the N supply is deficient leaf proteins are remobilised to favour the development of younger leaves or fruiting bodies. In Douglas fir the direction to the fruiting body is so strong that needles formed beyond the cone can be 25% lower in N than those formed below it on the twig. A deficient leaf rapidly increases its N content if supply is improved either via the roots or by foliar spray. Water stress will cause temporary translocation of N from the leaf.

In P. radiata the N contents of mature trees and the relevant dry matter figures are:

<table>
<thead>
<tr>
<th></th>
<th>Dry matter %</th>
<th>N %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needles</td>
<td>2.5</td>
<td>25</td>
</tr>
<tr>
<td>Branches</td>
<td>5.5</td>
<td>14</td>
</tr>
<tr>
<td>Bark</td>
<td>12.0</td>
<td>20</td>
</tr>
<tr>
<td>Wood</td>
<td>80.0</td>
<td>41</td>
</tr>
</tbody>
</table>
The N level has important effects in inducing the translocation of other elements. In the following table the ratios refer to high N trees/low N trees.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Dry Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>All leaves</td>
<td>5.82</td>
<td>1.20</td>
<td>1.78</td>
<td>2.24</td>
<td>2.60</td>
</tr>
<tr>
<td>Bark</td>
<td>3.20</td>
<td>2.05</td>
<td>0.64</td>
<td>1.03</td>
<td>0.91</td>
</tr>
<tr>
<td>Wood</td>
<td>3.97</td>
<td>1.93</td>
<td>0.83</td>
<td>1.08</td>
<td>1.04</td>
</tr>
<tr>
<td>Whole Tree</td>
<td>5.18</td>
<td>1.58</td>
<td>1.26</td>
<td>1.34</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Phosphorus

Phosphorus is absorbed from readily available sources probably as the orthophosphate in the region 1-2 cm behind the root tip. In trees the less readily available sources such as Al - Phosphate are drawn upon by the mycorrhizae. As chief carrier of energy for metabolic processes, P is rapidly converted to organic forms. The chief compound concerned is the nitrogen bearing substance ATP mentioned earlier which largely serves to accept the energy derived from the breakdown of glucose. All parts of the plant in which growth occurs therefore have highly mobile P constantly in supply in both organic and inorganic forms.

Without these organic phosphates the photosynthetic cycle would not function. The cycle is basically:

Lipids \[\rightarrow\] Pyruvic acid \[\rightarrow\] Krebs cycle (Amino acids + proteins) \[\rightarrow\] O₂

3. Phosphoglycolytic Acid

\[\text{CO}_2 \rightarrow \text{Ribulose Di-Phosphate} (C_5)\]

\[\text{6 ATP} \rightarrow \text{Triose} (C_3)\]

\[\text{Sucrose} (C_{12}) \rightarrow \text{Hexose} (C_6) \rightarrow \text{Cellulose} (C_x)\]

\[\text{3 ATP} \rightarrow \text{Fucose} (C_5) \rightarrow \text{Heptose} (C_7) \rightarrow \text{Acetyl (active)} \rightarrow \text{Lipids}\]

In the tree younger organs freely remobilise P from older organs. Eucalypts have a very efficient mechanism for withdrawing P just before the abscission layer cuts off supplies prior to leaf fall. The phloem sap is particularly efficient in all species in carrying P from aging leaves to maturing fruit. In the deciduous trees Platanus and Fagus sylvatica the level of P falls from about 4000 ppm in mid-summer to about 1500 ppm by the time leaf-fall occurs. Fruits in forest trees do not account for a high % of the total P but in agricultural crops the figure is very high. Sunflower seed has been measured as containing 42% of the total P absorbed while in maize the amount has been measured at 52% of the total.
By comparison the partition in *P. radiata* is:

<table>
<thead>
<tr>
<th>Component</th>
<th>Dry Matter % of Total</th>
<th>P% of Total</th>
<th>K% of Total</th>
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</thead>
<tbody>
<tr>
<td>Needles</td>
<td>2.5</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>Branches</td>
<td>5.5</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Bark</td>
<td>12.0</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Wood</td>
<td>80.0</td>
<td>49</td>
<td>52</td>
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</table>

**Potassium**

Potassium differs from other elements in being absorbed and transported almost entirely in water soluble ionic forms. It is not concentrated specifically in any growing part of trees but when deficient, younger tissues can receive it at the expense of older structures. Because of its loosely held ionic status, potassium is freely leached from the leaves by rain and dew and may be used several times in one season within the forest nutrient cycle.

Potassium is characteristically taken up in large amount and immobilised to some extent in the heartwood. The rapid re-cycling however needs to be considered in any appraisal of nutrient deficiency.

**Calcium**

Calcium appears to be transported only in the transpiration stream. The sulphate is probably the main form transported as it is not found precipitated except in the tree families *Tamaricaceae* and *Cuporidaceae*. Redistribution of Calcium is insignificant so that deficiency symptoms will occur in the newest formed tissues. These are forced to draw their Ca requirement directly from the calcium freshly supplied to the root.

Bamber of the Division of Wood Technology has been able to note a re-mobilisation of Ca from Eucalypt bark, a unique discovery which may account for the success of Eucalypts on totally deficient soils. Calcium is also unique among the major nutrients in its capacity to accumulate in the heartwood of trees. It accumulates through the season in leaves, both deciduous and evergreen. Root growth is entirely dependent on the calcium supply of the surrounding medium.

In *P. radiata* only 18% of the total Ca is contained in the needles and branches. 82% is contained in the wood and bark.

**Magnesium**

The element magnesium is contained in chlorophyll at the rate of one atom per molecule, which accounts for about 20% of the total Mg. The value rises in leaves as they age and also as they age the Mg becomes more soluble in water and more susceptible to leaching by rain.

**Sulphur**

Sulphur is taken up as sulphate or if the concentration is low, from atmospheric SO₂. It is transported readily within the plant and after reduction to sulfide is found within the proteins Cystene, Cysteine, and Methionine.

**Other Elements**

Iron and boron are not particularly mobile but other trace elements are freely transported in the growing parts of most plant tissues. Excessively high levels of Fe supply can prevent the translocation of Mn from roots to shoots, although adequate supplies of K tend to overcome the Fe effect.

Zinc has been of special interest in Australian plantations. It has been most characteristically a deficient element in tree crops. In addition
to *P. radiata*, pecan, apple, pear, stone fruit, almonds, citrus, tung and grapes have shown severe deficiency symptoms. It translocates freely but when the supply is deficient the production of the amino-acid tryptophan is curtailed and through this step the production of auxin is also curtailed.

**Aluminium**

Much of our work on phosphorus in *P. radiata*, *P. elliottii* and *P. taeda* plantations has shown that Al levels exert a massive effect on P translocation. Although regarded as toxic many crops, Al in the case of these pines is freely translocated to the foliage and accumulates in the bark although not in the wood. *P. taeda* accumulates very high levels in the foliage.

Translocation is probably by way of complexes, or chelates formed in the root sap. This complexing system appears to operate in competition with the phosphate translocation system, meaning that higher concentrations of P are required in the sap stream to overcome the effects of Al. The Eucalypts appear to have evolved a mechanism which separates the competing systems and so allows P to be used most efficiently.

This account has been sketchy due to the dangers inherent in extrapolating the cases of crop plants too far in considering the mineral picture in forest trees. A great deal of research is needed to remedy the situation, but in the meantime the knowledge available is most useful as a background to the management and fertilization of nutrient deficient forests.
The nutrient cycle or mineral cycle takes into account the amount of nutrient absorbed by the forest crop, its redistribution in plant organs and its return to, or removal from, the cycle. The classical outlook on the cycle was that trees did not have a high demand for nutrients and that forest cover in some undefined way conserved soil fertility. Increased production as the result of newer theories in silviculture, studies based on careful measurement rather than presumption, and on accounting in absolute values for the nutrients, has led to a reversal of this outlook. In highly productive forests on good sites the input of mineral usually counterbalances the drain, but on poor sites under the same conditions drain may not be balanced and production declines unless the nutrient deficit is made good.

The more important nutrient cycle considerations are based not only on the concentration of an element in a particular tissue, but on the gross production of the tissue itself. Where litter fall is involved, not only the litter produced but the defoliation characteristics of the tree are important. Pines rarely retain needles more than three years, Douglas fir perhaps five years at most, but some coniferous genera (Picea, Abies) often contain needles which are aged ten or more years.

As we shall see further in the next lecture two processes are vitally important in forest nutrient cycles. These are immobilisation of nutrients, either in litter or in wood and bark, and export of nutrients, a function dependent on the product being harvested. To assess the quantities of nutrients involved in each process it is necessary to have data showing how the gross nutrient uptake of the stand varies with age, site and species and also how the re-cycling process varies with the same factors. The following table from a wide range of Russian forests shows the type of data used to assess the cycle.

### Consumption of Nutrients in Different Forest Types by Age and Recycling in the Litter of these Nutrients. (after Remezov)

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<th>Forest Type</th>
<th>Age</th>
<th>N</th>
<th>Kg/La. Annually*</th>
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<td><strong>Ca</strong></td>
<td><strong>K</strong></td>
<td><strong>P</strong></td>
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* Kg/La = lbs./acre very approximately.
The trends are fairly obvious. The coniferous forests have put a smaller total amount of nutrient into circulation than have the hardwood forests but have also returned smaller amounts to the soil. This is particularly so for the bases Ca and K.

This type of balance sheet was accepted as a general proof that coniferous forests needed small nutrient quantities and that hardwood forests improved the soil by improving its base status until Rennie pointed out that the managed forest tied up more nutrient over a rotation than it recycled. His calculations, based on all data capable of analysis published in the period 1876-1955, showed that thinnings in the managed conifer forest removed about 35% of all the Ca and K absorbed and 25% of the P while in hardwoods they removed 50% of the Ca absorbed, 46% of the K and almost 40% of the P. Stated in another way, one cubic foot of thinnings removed nutrients as follows:

<table>
<thead>
<tr>
<th></th>
<th>lbs./acre removed (Rennie)</th>
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<tbody>
<tr>
<td></td>
<td>Ca</td>
</tr>
<tr>
<td>Fine</td>
<td>0.08</td>
</tr>
<tr>
<td>Hardwoods</td>
<td>0.39</td>
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</table>

In *P. radiata*, Kaingaroa site II A the total figures are, in lbs./acre:

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>Ca</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slash</td>
<td>83 (42%)</td>
<td>9 (36%)</td>
<td>22 (15%)</td>
<td>59 (29%)</td>
</tr>
<tr>
<td>Logs</td>
<td>114 (58%)</td>
<td>16 (64%)</td>
<td>94 (81%)</td>
<td>141 (71%)</td>
</tr>
</tbody>
</table>

The fallacious basis of arguments advocating the use of mixed hardwood species as soil improvers can be readily seen. Although more bases are put into circulation by hardwoods, relatively more are immobilised by the capacity of the woody organs to accumulate Ca. A base-rich soil is likely to remain a good soil irrespective of species because nutrients are coming into the cycle at a high rate. An inherently poor soil will remain so unless its base status is enriched by means other than a species change. Leguminous tree species may enrich the N supply but often these species need a soil of good base status to thrive.

We have considered uptake and export of nutrients immobilised in the bark and wood of the forest crop. There remains the return of litter nutrients to the cycle to consider. Nutrients returning to the soil are added in two ways. The greater percentage comes from mineralisation of humus, but a significant portion of the Na and K is recycled by the leaching action of rain and dew. Hardwoods probably re-cycle more potassium in this way than do conifers.

The breakdown of humus is not often a problem in the fertility of Australian commercial forests, but in the cooler, high latitude regions of the northern hemisphere the nutrients immobilised in humus often make the difference between efficient production of forest products and failure. The problem probably occurs also in the sapling stages of establishment in the tropics where high organic production rates by weeds are possible. In northern Europe measures to release litter nutrients revolve around increasing the biological activity of soil microfauna chiefly by raising the pH and/or calcium content of the raw humus layer. Where there is a climatic limit to the efficiency of this process nitrogen fertilizers are usually used at rates between 100 and 200 lbs./acre.

Data from a *P. sylvestris* plantation growing in Britain show the relative size of the pools of immobile elements.

<table>
<thead>
<tr>
<th>Element</th>
<th>% in Forest Ecosystem</th>
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<tbody>
<tr>
<td>K</td>
<td>42</td>
</tr>
<tr>
<td>Ca</td>
<td>59</td>
</tr>
<tr>
<td>Mg</td>
<td>39</td>
</tr>
<tr>
<td>P</td>
<td>66</td>
</tr>
<tr>
<td>N</td>
<td>82</td>
</tr>
</tbody>
</table>

Data from a *P. sylvestris* plantation growing in Britain show the relative size of the pools of immobile elements.

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<tr>
<td>N</td>
<td>82</td>
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Data from a *P. sylvestris* plantation growing in Britain show the relative size of the pools of immobile elements.
Mineralisation of the humus proceeds at a variable rate but in a definite order. Remesor has determined this order as $K > P > N = Mg > Ca > S$ which corresponds roughly to the degree of ionic involvement in organic compounds, as discussed in the lecture on translocation. The released elements move into the profile in a different order $Al > Ca > Mg > N > K > Si > P$. Leaching losses in the forest soil profile are reflected by this order. Continuous forest cover is thus needed to conserve elements like Ca which tend to be concentrated in the upper profile by the activities of vegetation and tend to leach rapidly where denudation occurs in climates receiving above 25" of rainfall annually. In low rainfall areas the opposite effect occurs, namely concentration of bases in the surface soil, mainly as the result of excessive evaporation.

To sum up, it can be seen that the losses of nutrient in intensively managed forest are far from negligible. It can also be seen that there are numerous opportunities in the nutrient cycle to conserve or control the direction of nutrient movements. These possibilities will be considered next. Whether the soil can make up the deficit in the cycle is the important measure of the importance of the value shown as deficient for a particular element at the end of the rotation. Two elements are probably critically balanced in the good sites in our forests. These are $N$ and $Ca$. On poor sites $P$ can almost always be added to the list of factors limiting production.
SOME LIMITATIONS IN THE USE OF FOLIAGE AND SOIL ANALYSIS.

There are at least three basic limitations to the use of soil and foliage analysis.

1. There is the overall limitation which arises from trying to estimate what is happening in a dynamic situation by means of a static procedure.

2. There is the sampling difficulty, present in all heterogeneous systems.

3. There is the relevance of what is determined by chemical procedures to the plant situation and also the fact that each plant has its own special relationship to the soil.

Each of these can be overcome to a considerable degree once their extent and the way they interfere in the prediction process is understood. For example, we are fortunate in being interested mainly in one species. Its special relationship to the various elements can be studied at the laboratory level thoroughly — given time and facilities. As we accumulate knowledge at this level the relevance of the various chemical results to the plant situation becomes clearer and more specific. For example, using laboratory methods we have found that P. radiata is very tolerant indeed to Al³⁺ provided ample P is available but that under these circumstances more P than normal is taken up by the plant for the same growth. These facts can be used in evaluating foliage P results where high Al³⁺ availability in the soil is found.

Again when we understand the extent of the spread of various nutrients in, say, Hawkesbury sandstone derived soils (or which is associated with certain Eucalypts) we can estimate the number of soil samples we require to achieve a certain result.

Returning to point (1), the difficulty of trying to estimate what is happening to a dynamic system by a static procedure is particularly germane to the foliage, bark or wood analysis. It also exists in soil work, however. At Lidsdale, for example, for certain nutrients it appears that the older the stand the less there is in the soil. It would, therefore, be unwise to assume that the present analysis is the same as would have been obtained when the pine was first planted. This effect could be neglected, however, on a good site such as Green Hills. Soil dynamics are much slower, however, than the fluctuations and variations which are found in the foliage. When a tree is actively growing the ratio of various elements such as P, Ca, K, Mg, to the total weight of organic material present (expressed as the dry weight) is in a constant state of flux. For this reason, not a great deal of information can be obtained from the analysis of foliage during these periods. To overcome this, foliage samples are taken when the tree is in its period of least activity — winter. It appears that the end of May or beginning of June is the best time. The further north we go the more insoluble this problem becomes. Nevertheless, we have been able to obtain fairly satisfactory results on the North Coast in July.

Another factor in foliage analysis is the sampling position on the tree. Different procedures will be used according to what is required. If, for example, we were engaged in nutrient cycle studies we would have to sample the whole tree in a representative way to arrive at an estimate of its total nutrient content. But if we want to find what the nutrient status of a tree is for the purpose of relating this to site quality, it is necessary to sample from a consistent place on the crown, preferably using dormant foliage less than one year old. Work which we have done with P. elliottii at Barcoongera shows that no systematic difference can be found between foliage collected in winter of the previous spring's growth from anywhere in the crown. Nevertheless, it has appeared to us that it is a prudent precaution to always sample from the top whorl where this is possible and to take sufficient samples to allow for a fortuitous spread of about 200 ppm P between samples.
At this stage it may be as well to interpose that, compared with sampling and other sources of error, the methods used for estimating the various elements, P, Al, Ca, etc. are very accurate and can be neglected as sources of uncertainty or limitation for the purposes of this discussion.

Using the sampling procedures as outlined we have been able to show that very good relationships exist between foliage P and tree height for both *P. radiata* and *P. elliotii* after age has been duly taken into account. As these figures represent all stages of development from 5 years old to 40 years old, it appears that we can predict at a very early age what the site quality of a planting will be and whether any fertilizer amendment will be required to bring production up to any desired level.

But it would be clearly much better if, instead of waiting until establishment costs have been net, we could predict with greater accuracy than at present, the prospective productivity of a proposed planting site and what additional fertilizer amendment is likely to be required to bring it up to the desired production level.

Only three ways of doing this appear to be open to us:

1. Soil analysis;
2. The existence of a native stand known to be associated with various levels of productivity;
3. Foliage analysis of the native stand.

All three are important. From the work we have done to date it is fairly clear that we will be able to make a very close estimate of the overall productivity of a site. We still have a long way to go with (2) and particularly (3). But the soil analysis aspect looks, at the moment, very hopeful.

However, the limitations of soil analysis for prediction of plant production are certainly very great — so great in fact that some leading authorities are quite pessimistic about it. It should not be forgotten, however, that in forestry we have considerable advantages in this regard. We have a single crop whose relationship to a particular soil can be assessed after a long period of what amounts to complete occupancy of the site. Climatic factors are ironed out over the period and need not be the source of variation found in agricultural crops. It is not a nutrient demanding crop in the sense that agricultural crops are, and it can use sources of nutrients which agriculturally are almost useless. It also uses soil which has been undisturbed by cultivation. Where agriculture has had to deal with a single crop such as wheat, in the one climatic zone, it has been found possible to develop techniques which can predict, from soil analysis, the yield of wheat and the fertilizer required. Something similar should be possible in the central tablelands pine plantation area.

One source of variation in soil analysis is the sampling. How many levels should be taken? How deep should the sampling go? What weight should be attached to each level sampled? We started our work at Lidsdale sampling the A1, A2, B1, B2, C horizons in the conventional way, using the various profiles as a guide. However, it has become fairly clear from the Lidsdale, McIlion Range and particularly the Penrose results that *P. radiata* is basically a top soil feeder as far as nutrient elements are concerned. The soil below 15" contributes very little to the total supply. We have now standardized on 0-3" and 12-15" samples. The 0-3" appears the more important of these with the 12-15" telling us more about the possible root development of the trees — if, for example, the 12-15" sample has no Ca$^{2+}$ then the root development will be severely limited which will probably have important general forestry consequences.
The soil is not homogeneous laterally although nearly so, except for the occasional sample which, unknown to the sampler, has had an atypical history. An animal's unnoticed remains could make the Ca and P results quite high in an otherwise lower set of results. An example of this occurred in the Sunny Corner S.F. burnt windrow investigation. One sample contained 431 ppm P compared with 11 others which ranged from 153 to 319 ppm P. The site was resampled a few feet away and was found to be well within the range of the others (212 ppm P). Another cause of lack of lateral homogeneity is change in soil type. At Wingello, for example, on the large experimental plot there are three distinct soil types, geologically and chemically. These are not particularly obvious to the observer, particularly on a piece of ground covered by native vegetation. One is Hawkesbury sandstone soil, another is a red soil and the third is a Nowra soil - similar to Hawkesbury sandstone soil in appearance. The Hawkesbury sandstone is low in all nutrients, the red soil is low in P but not in Ca while the Nowra grit is low in Ca but not in P. The experiment is one which tests the effect of Ca and P amendments in various ways. It is well laid out with plenty of replication. The results will, however, be very difficult to analyse because while one is responding to both Ca and P the others are responding to P and Ca only.

This example could be repeated for each of the forests we have sampled so far and it is quite clear that sampling must take due regard of the geology of the area.

Another matter concerning sampling is the importance of ensuring that a good estimate can be made of the % stones in the soil. We have found that this is a very important factor in assessing the productivity of a site. At Lidsdale we found that the correlation of total P to site quality was 0.29 in other words the two were apparently unconnected. This could be put down to many things, but it nevertheless appeared unlikely. By taking the percentage stones into account the correlation coefficient came up to 0.71 which for the large number of samples we have is highly significant. Even more important, it made the figures at Lidsdale more comparable to those found at Mullions Range where the stone percentage was generally very low. It appears that we are dealing with the probability of the root contacting or coming close to a particle and also the total root development possible.

Another limitation of technique arises out of the analytical methods. These are in themselves very accurate, but they are all empirical procedures which are difficult to associate with any plant requirement in an absolute way. They are very useful when comparing one soil with another when we have been able to establish some relationship between the chemical results and the plant to be grown. We can tell quite accurately, for example, just how much Ca\(^{2+}\) is available on the soil exchange sites. After some experience with the requirements of radiata pine, we are now in a position to relate this figure to the plants needs. But we still cannot say how easily the plant will get the Ca\(^{2+}\). We have been able to establish the danger levels for Ca\(^{2+}\) by these procedures and this is a very important contribution to central tableland pine plantation nutrition. Before we leave exchangeable ions, it should be mentioned that soils that are derived from limestone or which have been heavily limed cannot be readily compared with acid soils for exchangeable Ca\(^{2+}\). This is not serious, however, because these soils are adequately supplied with this element. The amount of free lime can be estimated fairly readily. Another matter that should be mentioned is that soils with a pH above about 5.5 (1/5 HCl) will not have any exchangeable Al\(^{3+}\).

The estimation of N gives us an absolute and total N figure. This is quite accurate but is time consuming and should only be done when absolutely necessary. At Lidsdale all the samples were examined for N. The result of this large expenditure of time and effort was nothing of value. This does not mean that it never will be advisable to look at forest soils for N or that N is unimportant. It merely means that until more is known about the role of N in forests and how it comes to be there in such large quantities despite the fact that it appears to be easily removed and only replaceable with difficulty, it will be as well to not spend much valuable laboratory time on its estimation.
pH is a measure of the divergence of the soil from neutrality. The pH scale goes from 0 - 14, a pH of 7 meaning that the soil is neither acid (less than 7) nor alkaline (more than 7). With the important exception of our limestone derived soils the soils we deal with are acid - their pH is below 7, some being as low as 4. The measurement of pH in the laboratory is extremely accurate, a very delicate instrument being used for the purpose. Unfortunately, the pH must be estimated in the presence of more water than normally occurs in the soil and after the soil has been made into a slurry with the water. These are not the same as the field conditions where intimate mixing of water and soil is rare (certainly in forestry) and where the soil to water ratio can be almost anything. The pH of soil is different when various soil/water ratios are used. Another cause of variation is the presence or absence of the soil particles in the liquid being measured. To illustrate this a soil from Wingello State Forest (0-3 horizon) has been mixed with various amounts of water and the pH estimated.

![](image)

You can see that it is quite important just how much water is present for a given amount of soil. To overcome this we always use the same soil/water ratio 1/1. Some laboratories use a soil paste while others use 1 soil/5 water; generally the latter laboratories centrifuge and estimate on the clear layer.

Another cause of variation in pH values as reported is the presence of dissolved electrolytes in the water used. For this reason some workers prefer to use a strong electrolyte solution. We always do a pH this way as well as with pure water. We also report a 1/5 soil/NKCl clear solution pH. These are done because, for the small amount of extra work involved, the extra data may prove useful at some future date as physico-chemical researches on soil develop.

The value of pH in diagnosing soil troubles is not great in our case. We concluded from our Penrose work that pH in itself was of little importance and that it could not be relied upon to point to any particular soil deficiency. On one occasion pH values found on some nursery soils at Woolgoolga gave a clear indication that these had been grossly interfered with. Unknown to the present staff very large quantities of lime had been placed on the soil in the past and this was the cause of the poor growth experienced.

Phosphorus is the most important of all the nutrients as far as we are concerned. It has been shown to be the basic deficiency wherever there has been deficiency and this must be rectified before any other deficiency can be dealt with successfully. From the chemist's viewpoint there are a large number of ways of estimating P in soil. These have been developed and found suitable for a certain set of conditions and situations insofar as they are useful for predicting how much superphosphate is needed.
to bring a crop up to a certain yield in average weather conditions. They have been the work of people in the agricultural field where the problems are very different from ours in many ways. Agricultural crops will not survive or at least not grow successfully on land which we have been able to use. Trees clearly can either use P sources unavailable to many plants or alternatively they do not require as much for a vastly greater growth rate; or a combination of both. To our knowledge no forestry soil investigations have revealed a good P vs site quality correlation using any of the so-called available P methods.

In general it can be said that most of the available methods were developed before the complexity of the soil P was realised and were all aimed at estimating easily extractable P. One method uses water as the extractant. The soil is shaken with water and the P estimated. Our attempts to use this method have yielded, as might be expected, nil results. Another method which has proved most successful with wheat farming is to extract the soil with NaH CO₃ solution while others use dilute acid extractants such as citric, sulphuric and lactic acids. In our soils we find with these extractants such low results that differences are often meaningless. This is not always the case with citric acid but we have not pursued this because there seems little theoretical or practical justification for it in our case. Dilute H₂SO₄ estimates the amount of calcium phosphate in the soil. In acid soils this is very low indeed and is not necessarily the controlling factor for trees. Aluminium phosphate appears to be much more important. During the last five years a method has been available which will allow the estimation of the Al-P, Fe-P and Ca-P in the soil. There are also methods for estimating the organic P in the soil. It appears to us that the best approach for us is to determine the proportion of each of the "active" forms of P in the soil and ascertain whether this can be correlated with pine growth. A correlation of this nature may be obtained in soils with a low P absorptive capacity such as some sandy soils as at Whiporie. But in most cases the absorption capacity of the soil is considerable and it seems likely that this is a measure of the difficulty the pines have in obtaining what P is in the soil. The measurement of 'absorptivity' of the soil is not technically difficult but is time consuming. There is also no agreement amongst the workers in this field on the exact technique to be used. None of the "available" P procedures tells us anything about this aspect of the matter. Neither do any of them tell us anything useful about the P "capital" available which is very important information for forestry practice.

Because of these factors we have settled on the following procedures:

In the first instance we extract the soil for some hours with boiling concentrated hydrochloric acid and estimate the P. This is an accepted technique for finding "total" P in the soil - that is, total as far as plants are concerned. P locked up in silicious minerals or present in some more mineral forms is not estimated but these types of P do not even interest a long term occupier of the site such as the forester. From this estimation then we obtain an overall picture of the P "capital" in the soil. More important still we have an estimate of the frequency with which P is likely to be net in the soil by the roots as they grow. What we have not got is any idea of the form of the P. We can make certain assumptions, however, which are valid in our case. Firstly, there will be little, if any, calcium phosphate present in our acid soils. Secondly, the organic P content will be fairly low. Thirdly, soils developed from similar geological formations and in similar climates will have a fairly close Al - P to Fe - P ratio and somewhat the same proportion of P occluded by Aluminium and iron oxides.

We still need a measure of the soil's capacity to hold P compared with the plants roots ability to obtain it. We can obtain some idea of this by measuring the exchangeable Al. This we carry out on every sample. Further, P does not appear to be absorbed as readily in low Ca soils as in those with a reasonable level of this element and so we take this into account.
Having obtained these three analyses we then make an estimate at the probable site quality for *P. radiata* using the following equation derived from regression analysis of Lidsdale and Mullion Range soil samples.

\[ S.Q. \text{ (dominant height at 20 years)} = 5.8 + 35.24 \log P - 4.8 \log Al + 2.2 \log 100 Ca \]

Where further work requires it such as in the examination of the experimental plots at Penrose, Barcoongere, Wingello and Woodburn, the P is fractionated into its major components and the absorbitivity of the soil found by more elegant methods.

* P, Al and Ca figures are ppm, meq % respectively.
  Each is modified by the amount of stone present.
The silvicultural treatment afforded a nutrient-deficient forest in Australian latitudes will often be at variance with much of the classical doctrine evolved for northern hemisphere forests. The reasons lie in the relative values of light and root competition in the two environments. Light is rarely a limiting factor where production rates are considered in our part of Australia. In areas receiving 35" or more of rainfall annually, soil could be said to constitute at least 60% of the environmental influence on production rates and climate 40%. In latitudes above 45° the opposite relationship probably prevails.

The silviculturist controls three factors in his management of the forest. These are the degree of canopy closure, the species composition and nutrient additions and subtractions from the stand. On nutrient-deficient sites three processes are uppermost in his considerations. These are nutrient immobilisation, nutrient export and nutrient addition.

Canopy closure is controlled by thinning the desired species and/or eliminating weed species. Where the nutrient supply is deficient both operations act to increase the speed at which nutrients are cycled. Thinning may slash to the forest floor as does clearing, and at appreciable rates. Twelve pounds of P per acre in the litter is equivalent to the addition of 1 cwt. per acre of superphosphate, and as Remsor's table shows is achieved without adding thinning to the litter-fall. A heavy thinning could easily add nutrients such as P at rates up to 3 cwt/acre applied as superphosphate. Pruning would have a similar effect, and would improve matters by speeding up the return of nutrients from small branch material which would otherwise take years to return its nutrients to the cycle.

Thinning further speeds up the cycle by preventing undue immobilisation of nutrients in the litter layer. The opening of the canopy allows more favourable decomposition conditions to prevail. Radiation reaching the floor of the forest increases as does rainfall. Logging assists further by stirring up the humus layer. Aeration improves, and the result of all factors resulting from the thinning is to prevent the looking of critical amounts of nutrients, as often happens in cold northern forests.

Burning, whether controlled or of a broadcast nature, dramatically unlocks all nutrients. P becomes more available, Ca and K are immediately available and N is volatilised and lost from the cycle. Provided restocking of the site occurs immediately little damage is done by burning, unless N is critical. This may be true of second rotations in some poor sites. Mr. Waring's work at Belanglo S.F. certainly shows that N losses by the time of the second rotation need careful accounting. In Eucalypt forest burning might well play a part in maintaining fertility by keeping back nutrients in mobile forms.

Thinning also makes available to each tree a greater volume of soil from which its roots draw nutrient. For an element such as calcium, for which roots make physical contact in order to absorb the result is the transformation of a sub-optimal nutrition evidenced by dead-top etc. to a nutritional status which is more nearly adequate. Needle weight per tree is increased while each tree increases production so that the stand rarely loses total production as compared with total growth in the unthinned state. Wood production per unit of nutrient capital employed is thus more efficient. Within the capabilities of the tree's root spread, the poorer the site, the more nearly the capabilities of the site will be realised in wood production if this spacing is kept wide.

Species composition as already mentioned is altered with the elimination of weed species. It is also altered if the major species is tailored to the site capabilities. Hardwoods accumulate high percentages of certain elements in their wood and bark, while relatively speaking softwoods re-cycle a greater percentage. Unit for unit of wood therefore, or hardwood will need more nutrients in circulation than a conifer. The classical 'nurse' or 'soil improving'
hardwood species therefore need a critical appraisal on poor sites. It is true that useful symbioses do occur but well proved cases are rare.

Eucalypts are a special group of hardwoods whose nutrient cycling capabilities are unknown. It is true that Eucalyptus bark is much richer in nutrients than that of P. radiata but it is also a genus able to utilise very low grade sources of P and Ca. Total vegetative production in organs other than the bole constituent is probably low by comparison with deciduous hardwoods and litter deposition is likewise very low by comparison. In their management however it is unlikely that the basic tendencies of deciduous hardwoods in nutrient cycling will need much alteration to conform with Eucalyptus, if it is remembered that Eucalyptus is adapted to sites inherently worse than those utilised by deciduous hardwoods.

Export of nutrients is a case in point. Figures for a mature stand of P. laricio are: (lbs./acre).

<table>
<thead>
<tr>
<th>Dry Matter</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bark</td>
<td>19,000</td>
<td>41.5</td>
<td>5.8</td>
<td>27.5</td>
</tr>
<tr>
<td>Wood</td>
<td>66,000</td>
<td>46.0</td>
<td>3.8</td>
<td>33.5</td>
</tr>
</tbody>
</table>

It can be seen that a big saving in nutrient export would be effected by leaving the bark in the forest. In hardwoods the percentage of elements in the bark is even higher and correspondingly greater economics in nutrient export are possible by dobarking in the bush.

Finally the silviculturalist can seek to make good the deficiencies in the nutrient cycle by placing fresh nutrient capital into it. A poor choice of the artificial addition can result in immobilisation within the soil. Simple substitution at Penrose State Forest for instance of rock phosphate for superphosphate would ensure a steady supply of Ca - P for species unable to use Al - P, (the soil reversion form), produced by the soil-superphosphate reaction.

In making good the nutrient deficiencies it is necessary finally to consider the placement of the addition. Under closed canopy, broadcasting has many advantages from the economic angle. Little of the nutrient will go to any except the forest production cycle, and little will be lost by leaching, even including soluble nitrates. However, in young stages under competing conditions, it seems better to avoid adding nutrients to weed cycles if it is economically possible to avoid doing so. Placing the fertilizer in close proximity to the plant not only favours the plant, but limits the soil/fertilizer reaction. By contrast broadcasting allows soil and fertilizer to react at maximum rates and gives the manager a further opportunity to gain more mileage from the applied nutrients.
Costs determine exclusively what fertilizers can be applied to forests. The objective in this lecture is to review the factors influencing costs as well as to point out the capabilities of some of the more commonly used fertilizers. For forestry the only practicable fertilizers are of chemical origin. Certain organic materials such as blood and bone may have limited use in nurseries but the major fertilizers for forest use are all inorganic.

The fertilizer industry divides its fertilizers into two groups, "pure" or "straight", and "mixed". Superphosphate would be an example of a straight fertilizer and 'Banana Special' of a mixed fertilizer. There is usually some confusion over fertilizers and as ammonium phosphate which is not mixed but by its chemical nature supplies both N and P as nutrients.

Fertilizers are sold by 'grade', a term denoting the relative percentages of the elements, N-P-K, known as the primary nutrients. For forestry, Ca is also a primary nutrient but it is not conventional to record it in the grade rating. For reasons connected with 19th Century chemistry, the figures for P, K and Ca are quaintly expressed as the oxides P$_2$O$_5$, K$_2$O and CaO. Ratios are also used in fertilizer terminology to express the proportionality of the elements. A fertilizer graded 10-10-10 is said to belong to the ratio 1:1:1. Ratios are chiefly of interest where it is desired to apply two or more elements at once. By working these back as a ratio it is simple to select a fertilizer which will supply them ready mixed or to select a fertilizer which is easily amenable to alteration to the desired ratio. Applications are easily obtained by dividing the application rate per acre by the percentage indicated in the grade.

From the economic side much depends on the concentration of the element in the fertilizer relative to its price. The more concentrated sources will require least handling, but this may be offset by their greater cost in the first place. It is therefore necessary to look at the cost per unit of nutrient supplied.

Costs vary considerably. A unit of N as blood and bone costs £4. 0. 0, while as urea it costs £1. 8. 0, as sulphate of ammonia £1. 9. 4; or as nitrate of soda £2. 7. 4. Citric acid soluble super P costs 18/6 per unit while in blood and bone the corresponding cost is £2. 5. 8. Potash supplied as the chloride costs 11/1 per unit, while as the sulphate the cost is 16/7 per unit of K.

The following table shows the interaction of fertilizer concentration, application cost, fertilizer application rate and stumpage. It is drawn from a study on Douglas fir in Western Washington.
<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>N</th>
<th>Stumpage</th>
<th>Cost-Return Ratios for 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs./acre</td>
<td>mbf</td>
<td>Application Cost Rates per lb.</td>
</tr>
<tr>
<td><strong>UREA 46% N</strong></td>
<td>50</td>
<td>5</td>
<td>$0.025$</td>
</tr>
<tr>
<td>@ $7.75 per lb.</td>
<td>100</td>
<td>7</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>7</td>
<td>3.64</td>
</tr>
<tr>
<td><strong>AMMONIUM NITRATE 33%</strong></td>
<td>50</td>
<td>5</td>
<td>$0.035$</td>
</tr>
<tr>
<td>4.5 $ per lb.</td>
<td>100</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>(4.22 $ based on urea price + %)</td>
<td>200</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><strong>AMMONIUM SULPHATE 20%</strong></td>
<td>50</td>
<td>5</td>
<td>$0.050$</td>
</tr>
<tr>
<td>3.25 $ per lb.</td>
<td>100</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>(2.56 $ based on urea price + %)</td>
<td>200</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

The most interesting aspect is that the least concentrated fertilizer has produced the worst return on the investment. At the higher unit spreading cost it is virtually impossible to secure an adequate return.

Fertilizers are now available in a wide range of grades and a fairly wide range of chemical combinations. Particular situations will determine which source of a particular nutrient is most suitable. Climatic factors play a big part in deciding which way a soluble nutrient combination should be applied. Experience is the most valuable prerequisite to testing fertilizers and should always be sought out, whether it is gained personally or is available from industrial sources. A very general review of the major sources will now be given, remembering that specific cases may not conform to the general pattern.
Nitrogen

Although not yet used in plantation forestry in Australia to any great extent, it is probable that nitrogen will play a part in second rotations, as it has in the Northern Hemisphere. Whether this part will be of widespread importance remains to be seen. Jenny's approach to climate in soil formation would lead to a general conclusion that nitrogen in our N.S.W. latitudes may not be a major problem.

Supplying nitrogen to the forest cycle, particularly in temperate latitudes seems to be without the problems of supplying it to agricultural cycles in the same conditions, for the reasons discussed in the lecture on forest nutrient cycles. Sources of importance are urea (46%) ammonium phosphate (11% or 21%), calcium ammonium nitrate, (20%), or ammonium sulphate (20%). Urea is a good source because of its concentration and slow breakdown in the general run of forest soil types. Slight impurities (biuret) can induce injuries as can excessive concentrations of this rich material. The main handling disadvantage is a slight tendency to become sticky on contact with the air. C.A.N. is valuable because it combines N in the readily available NO, form with N in the slower releasing NH₄ form. Hardwoods and Douglas fir respond to it exceptionally well. The major disadvantage with ammonium sulphate is its tendency to acidify the soil, especially when application rates are heavy.

Phosphorus

Superphosphate is a valuable source of P for forestry. Its main disadvantage compared with rock phosphate or ammonium phosphates is its relative bulkiness. This is offset for some areas by its capacity to supply Ca in the soluble form from its gypsum component. Lime superphosphate a 50:50 mixture of superphosphate and calcium carbonate is even better for forestry where a high analysis P fertilizer is not so important. There is considerable evidence in the Moss Vale sub-district that P becomes more easily available to $P_{\text{radiata}}$ from the mixture than from the pure superphosphate source.

On acid forest soils such as the Hawkesbury sandstone, rock phosphate, (about 38% P₂O₅) is as good a source of P as superphosphate, unit for unit. On higher rainfall areas its relative insolubility may give it an advantage over superphosphate. Its high analysis is its greatest advantage for forestry.

The ammonium phosphates are N-P fertilizers which in their straight form are either the monosalt, NH₄H₂PO₄, on 11-45-0, compound or the di-salt (NH₄)₂PO₄, 21-53-0. A low percentage of Ca is usually present as an impurity. These compounds are of exceptional potential for forestry where N x P interaction is important and for cases where P needs to be supplied in difficult situations. The weight advantage in such situations may counterbalance the added expense. These fertilizers are pelleted and are therefore very easy to handle in spot applications, as compared with non-pelleted sources. At present the di-salt suffers from the disadvantage of being hygroscopic but the fertilizer industry believes this will be overcome in future by better pelleting techniques.

Ammonium phosphate complexes freely with the transition elements to form relatively insoluble compounds. The complexes with Fe, Ca, Zn, are now being tested at Wingello State Forest. Another complex, ammonium phosphosulphate, made by reacting ammonium phosphate with ammonium sulphate and pelleting, has now been launched on the Australian market. Its grade is 16-20-0. Nitro-phosphates, made by reacting rock phosphate with nitric acid in the presence of ammonia, have become popular in horticulture. A wide range of grades is available.

Potash

In Australia, potash is not often needed, especially in forestry. Two simple sources are available. Potassium chloride, known in the industry as muriate of potash is the cheaper source and of high analysis (0-0-60). Its main disadvantage is that it supplies chloride to which some plants are particularly sensitive.
The other source is potassium sulphate (40 - 0 - 50) which is more expensive, safer to use and provides 24% sulphur as a bonus. In mixed fertilizers the source of K should always be stated and for forestry practice should always be requested as the sulphate.

**Calcium**

The two usual sources of calcium are gypsum and limestone. Gypsum is cheaper per unit of weight but contains 23% CaO as against limestone with about 50%. Per unit of element both are cheap fertilizers. Calcium sulphate (gypsum) is readily soluble and for most forestry uses has the advantage of not raising the pH. Ground limestone gradually raises the pH and is not so soluble, and therefore not so fast acting as gypsum. If magnesium is ever needed it can be added by using ground dolomite limestone which will supply about 20% MgO.

Fertilizer technology is a rapidly expanding field. Products are highly competitive in price, and as tariff barriers fall will become even more competitive. In time fertilizers specifically priced and formulated for forestry use will appear. The expensive processing to fit raw nutrient sources for agricultural use is mostly not needed in forestry. Those who use fertilizers in forestry should therefore keep clearly in mind what they require in a fertilizer, because their need can often be filled with very little change in plant design or raw material input.