FERTILISER USE IN FORESTRY

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In opening the 19th Symposium, Dr Bassett reminded those present that the first Forest Research Institute symposium, held over 16 years ago, dealt with the same topic of forest fertilising and set the informal tone that has been the characteristic of FRI symposia ever since. He expressed some disappointment at the lack of follow-up from previous symposia, other than from personal initiatives, and suggested that this might be remedied (at least in the Forest Service) by formation of a small follow-up working group. I must agree that such follow-up would be worth while, and one could envisage its taking the form of special recommendations on forest policy in the field concerned.

Mr Bunn stressed the need for full participation. He then did his best to ensure this goal by the gentle prodding and skilled rhetorical questions which we have come to expect and to value. He in effect set up the major objectives on the production side by asking why, if currently proven techniques could be applied over an area four times as great as they are at present, and wood is likely to be in tight supply, are proven techniques not being more widely applied?

Before attempting to summarise the discussion of the four days, it may be of interest to refer back to the 1961 symposium. It presented far fewer problems to the summariser. At that time the only significant use of fertiliser had been on the phosphate-deficient sites of Auckland, again referred to so often during this week. In Wellington, Nelson, Canterbury and Southland the potential for fertiliser use in forestry was completely unexplored, and this in spite of many symptoms of unhealthy growth in Nelson. It was concluded that soil maps, while useful, did not compare with foliar analysis in giving early warning of nutritional needs. Difficulties of sampling foliage were emphasised, and further studies were to be done on the use of wood and inner bark as alternatives. More study was also recommended on relating the deficiency levels revealed by analysis to rates of application. Wood volume and wood quality were seen as the most important criteria for establishing the success of response to fertilisers.

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It was considered necessary that future trials should be discussed fully with the chemist and biometrician. In short, similar ground was covered to this week, but obviously in much less depth.

Dr Ballard[1] began this symposium by tracing very adequately the pattern of fertiliser usage since the 1961 symposium — the dramatic increases in application to existing production forests, beginning in 1968, and to new crops and protection forests from 1970. He made the point that there is not a single forest in New Zealand which would not give some response to application of nitrogen. The rapid expansion he outlined had a variety of reasons, not the least of which was the diagnostic skills being progressively built up by the Forest Research Institute and the close working relationship between the FRI group and field foresters. He predicted that urea would continue to be the principal source of nitrogen, and superphosphate of phosphorus, but with use of rock phosphate increasing if a suitable granulated product became available. He predicted an increase in the use of liquid fertilisers at time of establishment. During discussion he made the point, reiterated later on several occasions, that the fertilisers used could obscure the effect of specific elements — for example, calcium and sulphur, as well as phosphorus, could be having a real effect when superphosphate is applied. Mr Humphreys (NSW) stressed the role of calcium in root development.

Dr Sutton touched upon the "economist's complaint" — lack of adequate data. A number of important points made in his paper included (1) the fact that as land becomes scarcer fertilising will be seen as the means of increasing total yield, (2) interaction of fertilising with other tending operations is particularly important, and (3) that unit costs of overheads —roading, harvesting, etc.—are reduced by increasing production from a given area. Discussion turned from economics to how adequately to measure responses, particularly for the forests in the hidden hunger zone that were now receiving greater attention in the current fertilising programme. Change in site index as a criterion was resurrected, cut down, and finally buried by Dr Whyte (in a later session). Dr Ballard plumped for change in rotation length, particularly if trying to forecast the economic significance of responses in young stands, and Mr Hall (APM) suggested increases in dry matter production as the ideal. He also argued that management

[1] Symposium papers presented by authors mentioned in this article appear in the *Proceedings of Forest Research Institute Symposium No. 19,* Use of Fertilisers in New Zealand Forestry, published in 1977.

should be aimed at minimising cost per unit of dry matter produced, a goal research had shown to be achieved at much higher management inputs (particularly weed control and fertilising) than currently used in most forestry operations. The change in cost per tonne of dry matter in relation to rates of application was essential basic information for those who have to make decisions on fertiliser use. Dr Whyte suggested that rather than talking about stand models, economic analysis must be concerned with whole forests.

The same points often arose (with changing emphasis) in different sessions; an example was the paper by Dr Madgwick. Despite strong qualifications — one species, one set of conditions, one site — his paper laid a basis for understanding the pattern of nitrogen usage over a 20-year period, including the dramatic effect of thinning on net uptake. Later contributions from several participants (New Zealand and Australia) seemed to establish reasonably clearly that a response to nitrogen was dependent on the crown having room for expansion, and was thus limited to (1) the period from establishment to initial crown closure, (2) the period immediately after thinnings and (3) to those closed stands with thin and inadequate crowns. The last observation drew the suggestion from an agriculturalist for a simple diagnostic technique — if you can see the sky, fertilise. Such simple prescriptions are greatly welcomed by forest managers! The longevity of nitrogen in the system, including that in understoreys, seemed to be conjectural at this stage; so was the response in subsequent thinnings to previous applications, and more fundamental studies are still required. Nonetheless, the manner in which various trials and experiments have corroborated one another and led to a plausible hypothesis on how nitrogen works represents real progress, and gives a sound lead to the sort of management decisions that have to be made.

The other important part of Dr Madgwick's paper concerned the distribution of nutrients in the above-ground portion of the stand. This type of information is essential to understanding the full effects of whole tree logging, root-raking and other management practices.

Dr Gadgil added further to the nitrogen story by highlighting the role that legumes are capable of playing. The neatness of the nitrogen producing and sustaining role of lupin and marram, introduced primarily for sand stabilisation, is quite remarkable and illustrates the need for careful observation and understanding of biological processes even in the simplified pine plantation ecosystems.

The greater reliance of our fertilising programme on sensitive well calibrated diagnostic techniques, as it progresses

from one of treating obviously deficient stands to one of sustaining growth or increasing productivity of apparently healthy stands, was emphasised by Dr Ballard. He outlined the current foliage and soil testing techniques used, their limitations, and the need for more work relating the magnitude of response to appropriate variables, perhaps with better site and stand stratification to improve prediction. Because of his abhorrence of fixed prescription-type systems, which tend to be imprecise and wasteful of fertiliser resources, he cautioned against using soil mapping units or other criteria which do not actually measure nutrient status directly. The importance of the relationship between fertiliser response and silvicultural treatment, particularly for nitrogen fertilisation, was stressed, as was the need for well designed and appropriately measured field trials for calibration purposes — points further stressed by Dr Whyte and Mr Woollons.

I am entirely sympathetic to Dr Whyte and Mr Woollon's insistence on well-defined objectives, carefully conceived plot-designs, and precise forms of measurement. Dr Whyte's evangelism in this respect extends, with good reason, into the field of mensuration generally and may he not be discouraged! Although well replicated trials and a sound underlying basic biological model were clearly preferred, Mr Woollons accepted that regression analysis represented one of the better ways of pooling data from various sources. The need to measure volume changes accurately was brought out on a number of occasions; there is commonly no height response to fertilising marginal sites, and basal area does not account for changes in stem and branch form of the type described by Dr Barker. Hence dendrometers, and not 2-way volume tables, are clearly desirable — but the use of these must have a precise underlying mensurational base.

Dr Mead's paper on fertiliser sources was a very useful reference for forest managers, outlining the fertiliser sources available and those which were likely to be the most suitable in particular management situations. This was supplemented by a paper on the future supply of fertilisers by Dr Rogers. He indicated that the long-term supply prospects for both N and P fertilisers were good, but we must expect some increases in prices although these were likely to be at least balanced by improved prices for wood. Future supplies of rock phosphate were discussed by Dr Rogers. Throughout the symposium, the effectiveness of various types of fertiliser was discussed. Dr Adams suggested lime for better mineralisation in low pH areas and Dr Ballard indicated little response to lime in many forestry trials. Dr Bengston cautioned against possible leaching losses from excessive nitrification resulting

from lime application. Superphosphate in New South Wales gave strikingly better root distribution than rock phosphate but some mixture of the two was suggested to prolong effectiveness. In the Southern States rock phosphate had lasted after 7 years when the effects of superphosphate had given out.

Possible disadvantages of urea were discussed at length. Dr Crane made the point that all forms of nitrogen were characterised by strong proponents or opponents.

The burning effect of urea arising from free ammonium could perhaps be countered by adding triple super or superphosphate and Dr Bengtson made the general observation that N almost always works better with adequate P — hence the good results reported for Magamp. The problem of urea volatilisation was not seen as a major one in New Zealand with rain likely over very short periods. Overseas figures of 30 to 40% retention of particles in the foliage for several hours were quoted, and the possible significance of this in volatilisation losses was speculated on. Dr Bengtson in his very interesting address remarked that there had been a swing from urea to ammonium nitrate in Sweden where heavy raw humus tied up the urea. He warned against translating this to the New Zealand situation, particularly because of the danger of entry of nitrate into streams. Dr Will's Kaingaroa studies confirmed the relative immobility of urea-borne nitrogen in the upper soil of pumice profiles, and its safety from this point of view.

In summary there appeared to be plenty of scope for more work on the efficiency of various fertilisers, different formulations of both single and multiple nutrient sources, and the physical form of fertilisers as it affects distribution from the ground or from the air. It was feared that forest interests were too small to influence fertiliser manufacturers in at least some of these prospects.

As well as legumes, Dr Gadgil's paper had other suggestions on nutritional inputs that did not involve artificial fertilisers. Sewage and wastes were discussed. On the field trip a very clear example was seen of the type of nutrient loss through a management practice (in this case root raking) that Dr Gadgil spoke of. The effects of burning on nitrogen were discussed, with the suggestion that fixation by stimulated microbes balanced volatilisation in the burn.

Discussion on use of fertilisers at the time of establishment raised a variety of questions. First the efficacy of spot applications was queried. It was reported that the utilisation of P in this method was less than 4% and one application lasted only 3 or 4 years, necessitating early aerial topdressing to prolong the response. Applications in excess of 170 to 200 g

superphosphate per tree produced no additonal response. The reasons appear to be limited root exploitation at the spot and interaction with water uptake. The solution was seen as mechanical incorporation of the fertiliser into the soil during site preparation (*e.g.*, bedding); but steep slopes remain a problem, and a fairly high proportion of our current establishment is on quite steep land.

The problem with applying N at the time of establishment was its ephemeral nature and the difficulty of applying big doses without burning. More work in biological fixation may provide a solution, and trees such as *Acacia* and alder were mentioned, as well as legumes.

A strong plea was made by people from Auckland Conservancy for combining site preparation with fertilising, as the two are normally synergistic. They pointed out that cultivation can prevent root/shoot imbalance and hence toppling improve soil structure and rooting medium, improve drainage, aerate the soil and rejuvenate nutrient supply. To this impressive list were added weed suppression and increase in volume of available soil. The point was made that trees themselves improved soil structure markedly on poor sites, *e.g.*, stands on heavy clays at Riverhead Forest treated with a heavy application of superphosphate and Westland pakihi sites where tree growth had been stimulated by N and P.

Mr Bunn put in a plea for the man who had to carry the fertiliser. Mechanisation of establishment applications was considered highly desirable. Combining site preparation and fertilising operations, or using liquid fertilisers, was seen as the best means of achieving this. The latter also offers the prospect of simultaneous application of weedicides.

In dealing with the fertilising of established stands I must quote from the paper of Dr Whyte and Mr Woollons. "The manager who can specify without any prompting exactly what response variables he is concerned with, the total population to which he wishes to extend the results, and a broad indication of the size of the response that might be worth acting on, is a rarity if he exists at all."

Mr Bunn began by repeating the question — why are we fertilising only 25% of the area which would respond, most of which involves established stands? As fertilising is essentially an investment decision, what order of improvement or gain would be necessary? The managers who responded were few, but did exist. Mr Olsen expressed satisfaction with a 10% gain. Mr Hall felt that if the grower must supply wood according to some pattern, then options including fertiliser can be examined in relation to cost. Mr Handiside was ready to accept a positive net worth gain of 10% and Dr Sutton an annual gain of 1 m^3/ha — *i.e.*, about 5%.

Important qualifications were added, by Dr Madgwick on distance from forest to plant, and by Mr Gleed on alternative costs of new land and associated developments. If the opportunities set out by Dr Ballard are to be realised, and these depend largely on adding nitrogen to existing stands, then there is a big question for further analysis by managers. There appeared to be no simple criteria for management. If one is the owner of a single woodlot without opportunity to plant another, then it may be reducible to simple cash flow analysis of return with and without fertiliser. For a large company or State organisation the problem is not nearly so simple, and it requires analysis at the forest or regional, not the stand level. The first requirement is a wood production target, expressed in terms of the quantity and quality of wood required at specific times to maintain current levels of output and provide for new sales, or further steps in industrial expansion. Given such a target the most effective way of meeting it can theoretically be analysed by setting up models to explore the effects of new planting, silvicultural manipulation, clearfelling earlier or later, tree breeding and of course application of fertilisers. It has become abundantly clear that all of these are interrelated, and it is doubtful whether the complex interactions are fully understood. For example, are they, as asked, additive or multiplicative? The answer is complicated further by the fact that the manager of a large forest estate works within a budget constraint, and when the analyses are laid out it is the dollar return per dollar invested in pursuit of the target that is of prime concern. This is applied irrespective of whether quantity of fibre or quality of sawn timber is his dominant objective. It is therefore simplistic to suggest that, because a significant response can be got from a fertiliser, it should automatically be used.

The problem for the manager in setting up the appropriate investment models is the one raised by Dr Sutton — uncertainty. Although fertiliser gains are doubtless substantial, and the opportunity is therefore real, a very carefully measured experiment as indicated by Dr Whyte can come up with confidence units of only $\pm$ 40%. This slop is characteristic of other inputs in any model, and what it means is that the approach will not achieve any sort of deterministic solution to the manager's problem. He can narrow the probabilities with complex trials such as those mentioned by Mr Woollons, but this will take time and the uncertainty will never be entirely eliminated. At best he has a variety of solutions with very rough probabilities for each. His problem is even further confounded by appropriations of funds on a year-to-year basis, which may erratically expand and contract the budget constraint, con-

tinuously producing an entirely new ranking of opportunities. I am not trying to apologise for managers but to indicate that the application of research results requires very clear managerial objectives, sound related planning, and a highly flexible response.

It is true that we face a tight wood situation for a decade or so and it is clear that fertilisers can help; but if they are to do so it will require an act of faith based on the information we have received (incomplete though it might be), because by the time all responses and interactions are clarified we will be out the other side and into the land of plenty again.

In the longer term the more advanced phase of the mensuration and fertiliser trial programme for determining optimum regimes, spoken of by Dr Mead, will allow important future decisions. These will indicate whether more land, or more intensive use of existing forest lands, is the best solution to expanding forest production when the real boundary between agricultural and forest use of our limited land area is approached.

One session dealt at length with the question of quality control, particularly in aerial topdressing operations. Better communication with firms involved was stressed, as well as man-to-man communication with the pilot by ground observers. More powerful fixed-winged aircraft with better spreaders may help, and good compartment layout certainly would, not only in spreading but with respect to sampling and other costs. Large settings which allow easy topdressing conflict with Dr Will's suggestion of small settings to minimise N runoff: thus environmental requirements run quite contrary to operational ones. With the need for riparian strips perhaps helicopters are the answer, as suggested by Dr Neary. It is also obvious that some more work is required if the uncertainty factor involved in moving from ground experiments to aerial application is to be understood, let alone overcome.

The session on nurseries was in a sense just an extension of the "fertilising at time of establishment" discussion. The desire to send young trees on their way in prime nutritional condition, and gain the obvious advantages of feeding them when closely assembled rather than spread over the planting block, needs to be tempered by the problem of excesses (particularly of nitrogen) which can reduce field survival. If trees leave the nursery in tip-top condition they establish quickly, and they can take advantage of a further application a year later. The importance of this was discussed; the opportunity to hit the top growth curve thus begins in the nursery. The greencrop story seems to have been well documented, at least

on pumice, and the advantages of good organic content confirmed. But the timing of the addition of specific elements, and interactions of each with conditioning, appear to leave many questions unanswered.

Time precluded detailed discussion of Mr Knight's major contribution, but it will remain an excellent review of the New Zealand nursery position.

The results outlined for seed orchards were variable and somewhat disappointing; they may be explicable by Dr Bengston's observations on Southern pine orchards, that nitrogen advances rather than increases cone production.

Mr Nordmeyer's brief but vivid description of high country work will have given some idea of the scope for fertilising in these extremely difficult situations. The problem is enormous in scale, its solution is costly and, as one speaker observed, very difficult to relate to the benefits.

The final session picked up and consolidated ground previously covered. Dr Webber's paper pulled together the nutrient flow story as it relates to management practices, and in particular alerted us to effects of shortening rotations. Dr Will's and Dr Neary's contributions put many of the environmental effects of having to add nutrients (inevitable in the long term) in perspective. Monitoring to date of several aerial applications of fertilisers to forests has shown that increased nutrient concentrations in streams are largely confined to the day of the operation and the first succeeding period of heavy rain; after that concentrations return to within the range found normally. The total quantity of a nutrient reaching the stream is usually only a fraction of one percent of that applied. These early results are reassuring, but leave no room for complacency, and further work in this area will be watched with great interest by a wide spectrum of people. I think it is a good thing that the Research Institute has become involved in this field so that we can get some specific answers for New Zealand situations. With respect to water quality the effect of brief flushes of applied nutrient needs to be understood, particularly where these significantly exceed such flushes from normal natural events. The biologist needs to be involved closely.

Finally, referring to Dr Barker's paper, Mr Bunn raised the very important point that the routine application of fertilisers may necessitate an entirely new approach to silviculture of pine plantations. This would present a major investigatory challenge on an integrated multidisciplinary basis involving the mensurationalist as well as the tree breeder, the silviculturalist, the soil scientist, the biologist and the forest manager.