F.R.I. PROJECT RECORD

NO. 1779

FOLIAGE SAMPLING:THE SCIENTIST'S VIEW

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Introduction

Foliage sampling is done with one simple objective in mind:- to determine whether or not a collection of trees needs fertilising. It follows therefore that the end point (fertilising) is also the start point. Before any foliage is collected the forest owner should very clearly define the area that will be/can be fertilised should it be shown to be deficient. For example if it is known that there is insufficient finance available to fertilise more than 50 hectares it is pointless to send in one sample from a 100 hectare unit. If it is impossible to site transponders so that all of a compartment can be "seen" at once it is less than optimal to sample that compartment as one unit. Once a sampling unit has been decided upon it is then essential to sample it with sufficient intensity to guarantee the most cost effective result.

Sampling Intensity

Samples sent for analysis display an approximately normal distribution of concentrations (Figs 1a-c) The mean concentration lies very close to the intervention level for fertilising.

For phosphorus it is 0.13%

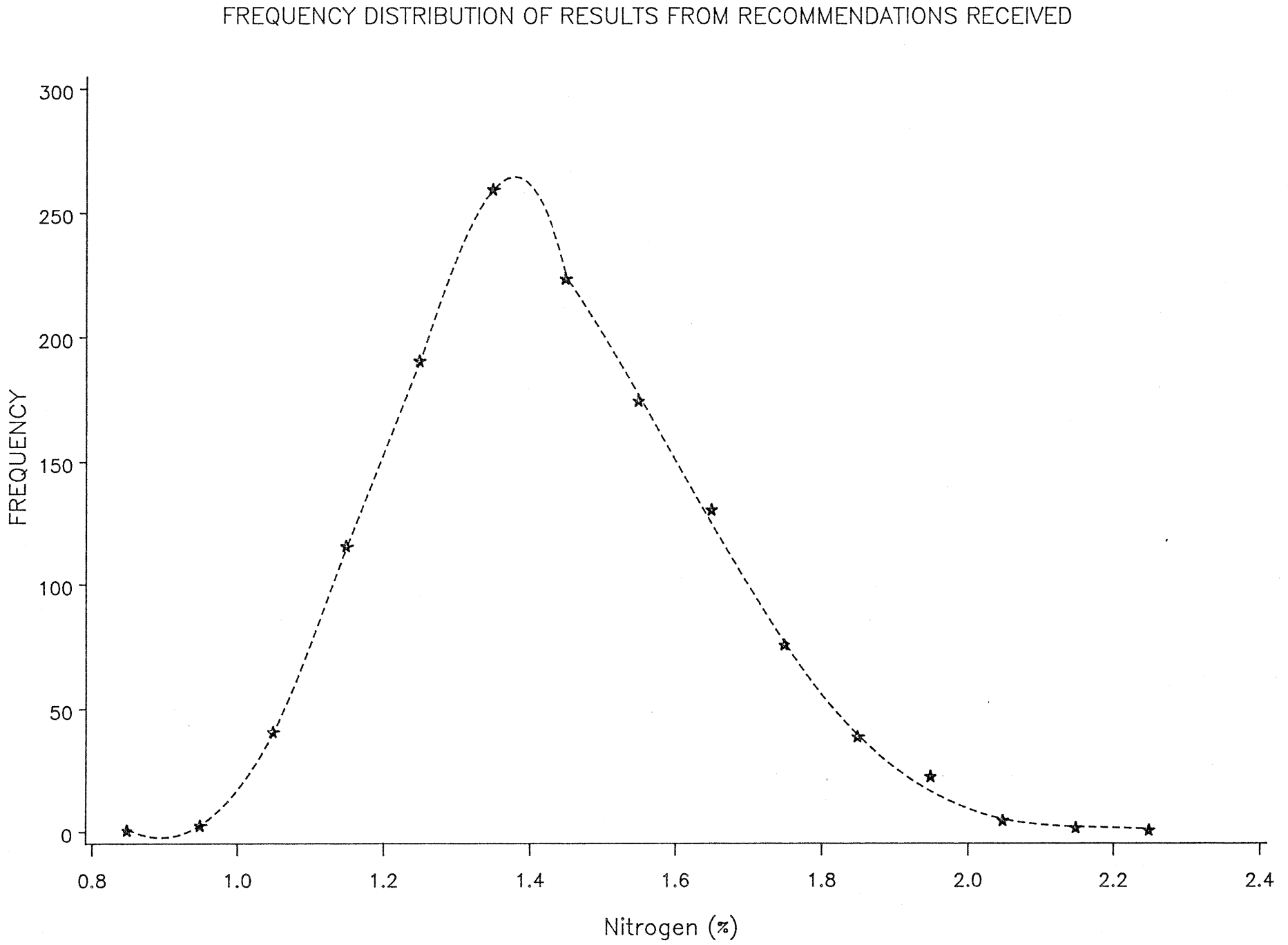
For boron it is 12 ppm

For nitrogen it is 1.46%

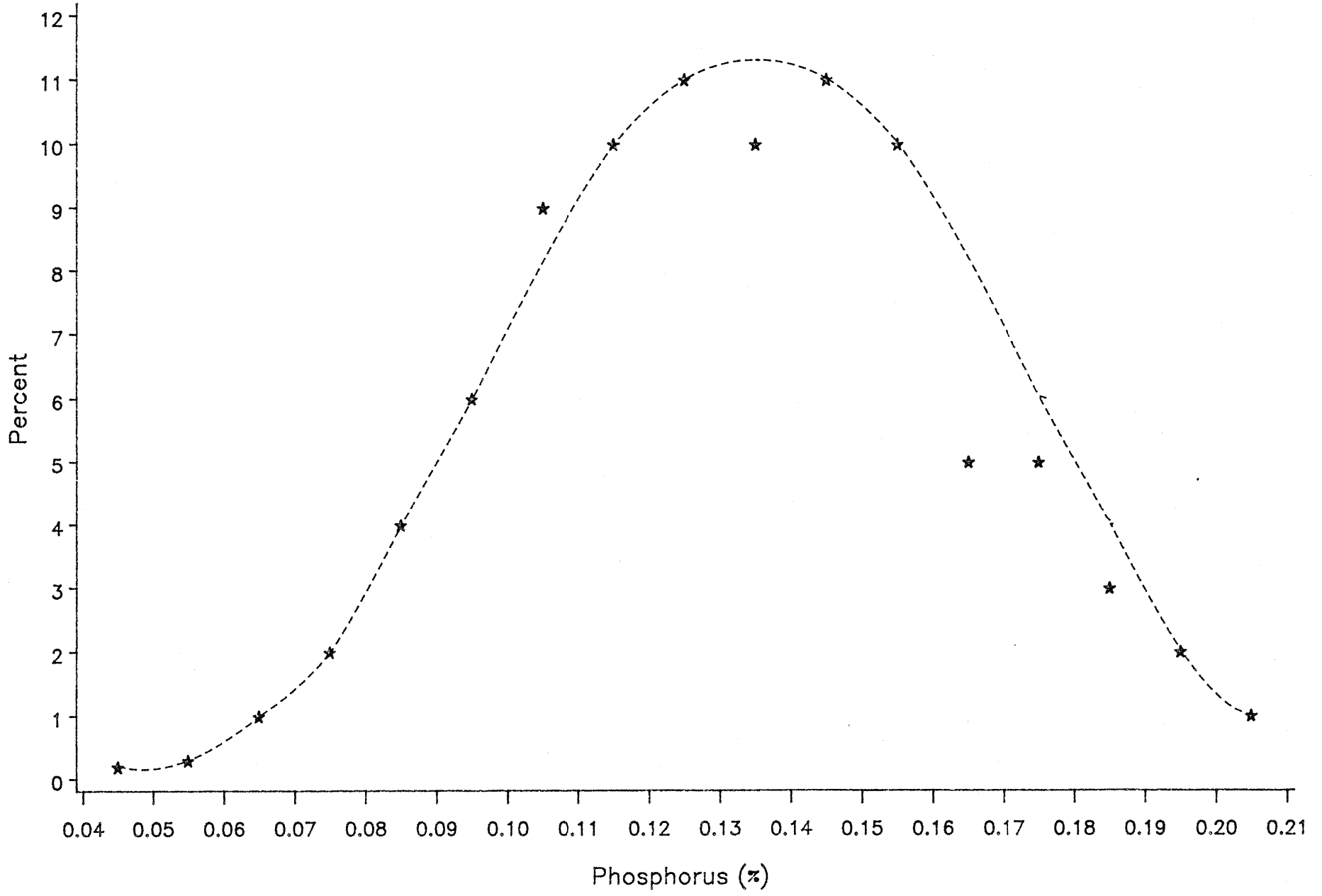
Samples must therefore be collected so that the appropriate action is taken. Managers want to avoid two traps;-

1. Applying fertiliser when it is really not necessary
2. Not applying fertiliser when it is really needed.

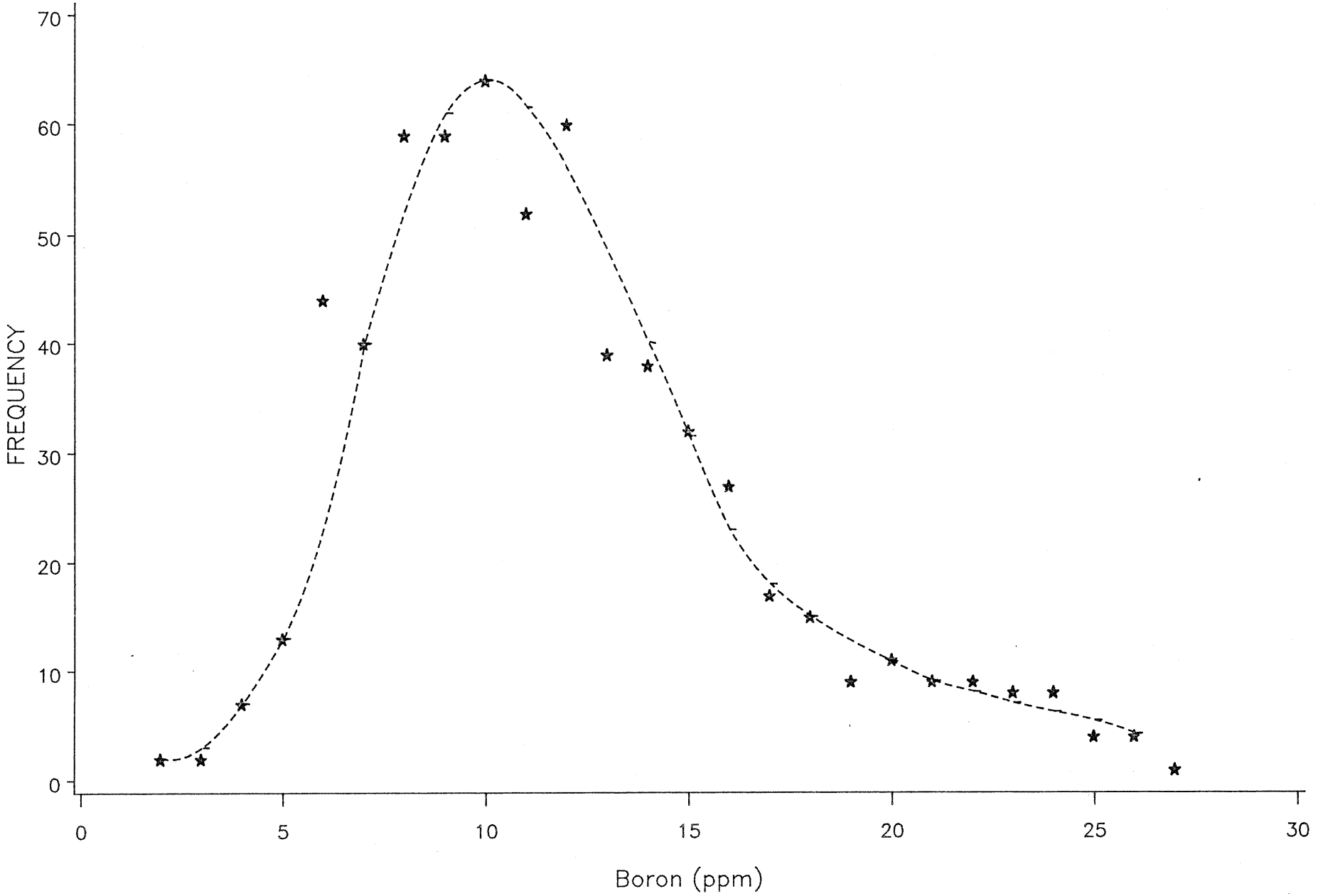
Fig 1a


FREQUENCY DISTRIBUTION OF RESULTS FROM RECOMMENDATIONS RECEIVED
FREQUENCY
300
250
200
150
100
50
0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Nitrogen (%)

FREQUENCY DISTRIBUTION OF RESULTS FROM RECOMMENDATIONS RECEIVED



FREQUENCY DISTRIBUTION OF RESULTS FROM RECOMMENDATIONS RECEIVED



The first error is probably the more serious since it involves a waste of money. The second error involves a lost opportunity.
Both errors can occur if the sampling error in the foliage sample is large enough. For example if the sample had a confidence interval of 0.04% P then at a true compartment concentration of 0.13% fertiliser would be applied mistakenly 16% of the time. Likewise with the same sampling error and a true compartment concentration of 0.10% fertiliser would not be applied 31% of the time when it should be.

OPTIMAL SAMPLING INTENSITY

In 1981 Kevin Calvert conducted a survey of Thames Districts forests. The forests sampled included Maramarua, Whangapoua and Tairua and were therefore very mixed as to soil type and nutrient concentration. The results of the survey were put out in one of the last Branch Reports

Calvert K.T. and Hunter I.R. 1981
Nutritional Survey of Thames District Forests
Production Forestry Division Soils and Site Productivity Report 138

Trees were sampled in clusters spaced throughout the compartment. From the variance between trees in that overall sampling we were able to construct the following table for the 95% confidence interval on the sample.

Table 1.

The number of trees that must be sampled to achieve a foliar P% estimate with a given 95% confidence interval.

Confidence interval 95%	Number of trees required per compartment	Number of clusters per compartment
.04%P	5	1
.03%	10	2
.02%	25	5
.01%	100	20

The first thing to notice about this table is that the number of trees required to get a small confidence interval is higher than normally used. One of our first pieces of advise to you which was based on the variation between trees in fertilised research plots gave a much lower estimate. We think this new higher estimate is caused because for the first time we have included the full variation in the estimate. You could say that:- variation in research plots = genetic variation between trees (only) but:- variation in a compartment = genetic variation + microsite variation + variation caused by past fertiliser topdressing.

We think that whenever sampling occurs in the presence of an ongoing fertiliser program this last form of variation will be present and significantly large. Perhaps by 1995 the use of modern guidance technology will have eliminated much of the variation but it appears to be very prevalent in todays compartments.

Obviously there is a cost in sampling and while it would be desirable to get that confidence interval as small as possible it might not be the most cost effective thing to do.

DETERMINING THE MOST COST EFFECTIVE SAMPLING STRATEGY

There can be no absolute answer to this problem. However an analysis can be made which is probably reliable as a guide. The analysis is based on a number of assumptions.

1. Any decision made now based on a foliage sample will probably be reviewed within 5 years when another sample is taken. Costs and profits need only be considered over a 5 year period.

2. A waste of real money (application of fertiliser when it is not needed) is slightly more important than a lost opportunity to fertilise.

3. The same principles would apply to fertilising with N,B, etc as to P on which this analysis is based.

4. The gain in volume due to fertilising and the lost opportunity due to not fertilising will be as detailed in :-

Hunter I.R and Kimberley M 1985
How much growth is lost by delaying P fertilising of a deficient stand?
FRI Forest Management and Resources Division Project Record No. 767.

The loss of growth at varying foliar P is given in Table 2.

Table 2.

Percentage growth lost by not fertilising at a certain foliar P

Foliar P%	Percent growth lost
0.06	69.5
0.08	32.5
0.10	15.2
0.12	7.1
0.14	3.3
0.16	1.6

5. The results of foliage samples are, statistically, normally distributed and Z tables can be used to apportion the results.

6. Fertiliser cost $200 per hectare and compounded for 5 years at 10% yields $322.

7. The compartment in question is capable of growing at 30m³ per hectare per year if well fertilised and the wood is worth $30/m³.

8. Foliage sampling costs $2.50 per ha for 5 trees per sampling unit, $6.25 for 25 to 50 trees and $40 for 100 trees (the numbers necessary to achieve 0.04%, 0.02% and 0.01% confidence intervals respectively). There is as there should be an approximate squaring of the cost for each halving of the confidence interval.

For each confidence interval and each true compartment concentration a risk analysis was performed. One example is given below:-

Confidence interval 0.04 % Compartment mean 0.09%P

Foliage sampling will give the "right" answer i.e. that the compartment has a foliar P less than 0.11% and is deficient 84% of the time. The benefit from fertilising at 0.09% P will be a 25% gain in growth worth $1125, at a fertilising cost of $325. But since this

will be achieved only 84% of the time the potential profit of $800 will be reduced to $672. Foliage sampling will give the "wrong" answer 16% of the time. A potential gain of $1125 will be lost 16% of the time leading to an overall opportunity cost of $180 per hectare.

There remain the two special cases of doing no foliage sampling at all and either 1. Fertilising nothing or 2. Fertilising everything regardless. In valuing these options we have assumed that the forest has the same distribution of observations as the frequency graph given in figure 1. If this were true 23% of the forest would be deficient. And clearly the right/wrong decisions would have a 23/67% division. Doing no foliage sampling would incur a weighted opportunity cost of $66 / hectare due to the deficient part of the forest failing to grow as expected. Fertilising everything regardless would lead to an actual loss of $134 per hectare because of all the wasted fertiliser.

The same assumption about the distribution of the results has been made in combining the values in one overall table i.e. if observations at 0.09%P constitute 6% of the overall observations then the profit/loss from activities at that concentration has received a 6% weighting. Results of the analysis are given in table 3.

Table 3.

The profit or loss resulting from foliage sampling with different degrees of sampling accuracy (in dollars).

Compartment mean foliar phosphorus	Expected frequency	Confidence interval achieved % .04	.02	.01
.05 - .07	3%	+71	+71	+70
.08	6%	+54 (-6)	+67	+65
.09	6%	+40 (-11)	+47 (-1)	+46
.10	9%	+22 (-19)	+26 (-10)	+27 (-1)
.11	10%	.	.	.
.12	11%	-11	-6	-5
.13	10%	-5	-1	-4
.14	11%	-3	-1	-4
.15	10%	0	-1	-4
.16 - .20	10%	0	-1	-4
Total		+$ 167	+ 201	+187
Total opportunity costs		- 36	- 11	- 1
Total including opp. cost		+ 131	+ 190	+186

Conclusions

This analysis shows that attempting to do without foliage sampling is not a sensible or profitable strategy. Losses of $66 and $134 per hectare were shown to arise if decisions about fertilising were taken without any information about the degree of deficiency. In practice the situation would not be quite as bleak as this. The probability that a compartment would be deficient is not quite as unpredictable as assumed in this study. Local knowledge and stand age can be used to refine the areas that require sampling. It seems however that this has not happened in foliage sampling to date because if it had the overall distribution would have been narrower and many more of the observations would have lain close to 0.11%. As a result many more decisions would have been made that required a tight confidence interval.

It is surprising the extent to which a small "grab sample" of 5 trees with a resultant confidence interval of 0.04% improves the profitability of running a deficient forest. That strategy is certainly better than either of the informationless strategies. However a substantial improvement in profitability occurs when the sampling intensity is increased to 25 trees. There is really no improvement in going up the next step to 100 trees.

Thus we conclude that managers should aim for a sampling intensity of at least 25 trees per sampling unit.

A SUGGESTED STRATEGY FOR SAMPLING DURING THE LIFE OF THE STAND

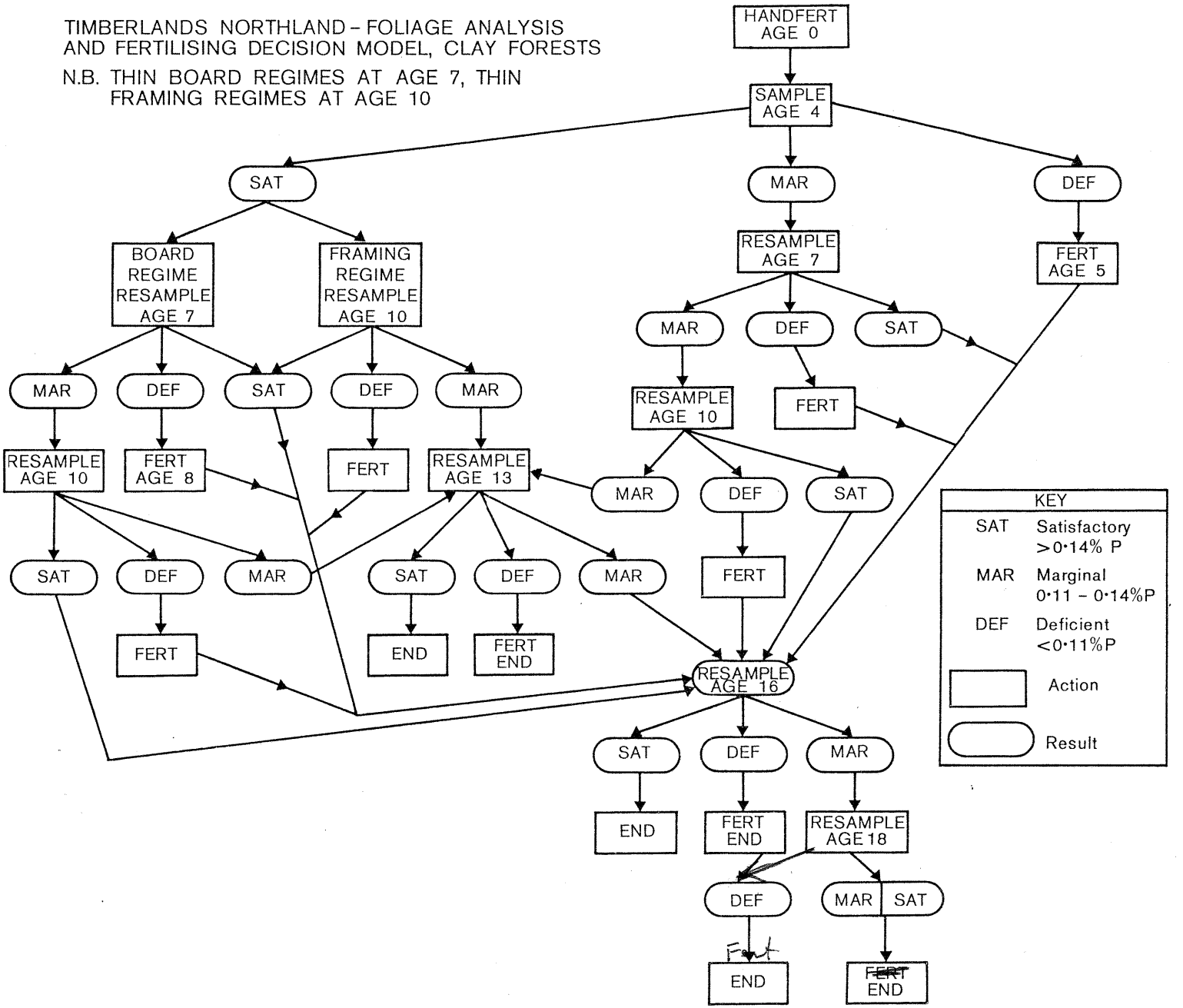
Timberlands Staff in Northland have developed a suggested strategy for sampling during the life of the stand. This strategy builds on the knowledge of the stands nutritional history to target foliage sampling at the stands most in need. If implemented it would almost certainly mean that more of the stands would be close to the intervention level than has been the case to date. The case for improved sampling is therefore further strengthened. The strategy is presented in figure 2.

To be fully useful it must be backed by a system which "remembers" the past nutritional history of the stand. Options would seem to be:-

1. The FRI Soils database which records analyses performed
2. The modified form of the stand record system produced by FRI
3. In-house card record systems.
4. A specific computer system.

TIMBERLANDS NORTHLAND - FOLIAGE ANALYSIS AND FERTILISING DECISION MODEL, CLAY FORESTS

N.B. THIN BOARD REGIMES AT AGE 7, THIN FRAMING REGIMES AT AGE 10



WHAT MATERIAL TO SAMPLE

1. Why upper crown secondaries in autumn?

Our whole foliage sampling system has been calibrated that way. We have thousands of analyses of such foliage from fertiliser trials where the response is known. Therefore when we advise action at a certain concentration that advise is always based on the fact that a "profitable" growth response has occured in a trial with foliage that had that concentration.

The "signal-to-noise" ratio in foliage sampling is small. Using phosphorus as an example, we saw how we could live with a confidence interval of 0.02%.

At any one time:-

The P concentration declines by 0.03% from the leader, through primaries to secondaries to minor branchlets.

The P concentration declines by 0.02% between first and second year foliage, by 0.01% between 2 and 3 year foliage and a further 0.01% between 3 and 4 year foliage.

The P concentration declines by at least 0.02% in the same age class and type of foliage down the length of the crown.

The P concentration varies by 0.05% between November and March in the same class of foliage. This occurs because young and immature foliage has much higher P concentrations for a brief time. The change is much greater for some other elements.

In summary:- the fluctuations in foliar P with time and crown position are huge relative to the small signal on which we trigger fertilising. This explains why we are so insistent on the time of sampling and the position.

There is one minor reservation. When a tree becomes grossly deficient in an element these gradients and changes tend to flatten out. That trend is noticeable in Figure 3 where the fluctuations in foliar P in the very deficient Site A trees are much less than sites B & C. This explains why you will sometimes see us taking a confirmatory sample at any time of the year. However the whole point of a sampling program is to prevent gross deficiency from occuring. So this facility of detecting a grossly deficient stand would actually represent a failure of forest management.

2. What alternatives are there?

2a. Litter sampling

In 1985 we published the results of a comparison of radiata pine foliage and litter as diagnostic tools. We felt that "with further calibration for the areas in which foliage sampling programmes operate it should prove a useful alternative to foliage sampling of tall trees." So far there has been no further calibration. The relationship between litter and foliage for N,P and B was not particularly strong and in the limited verification study reported in the paper there was quite a scatter of points around the line (Figure 4). The result from litter sampling would at the moment be inferior to a projection based on past knowledge of the stand's nutrition. It would be useful as an indication only of the nutritional status of an otherwise unknown very tall stand which would be very expensive or difficult to foliage sample.

2b. Weed sampling

We calibrated some weeds on a limited number of sites in 1987. However weeds have the same problem as litter:- the correlation between weeds and foliage is not particularly strong (Table 4 and

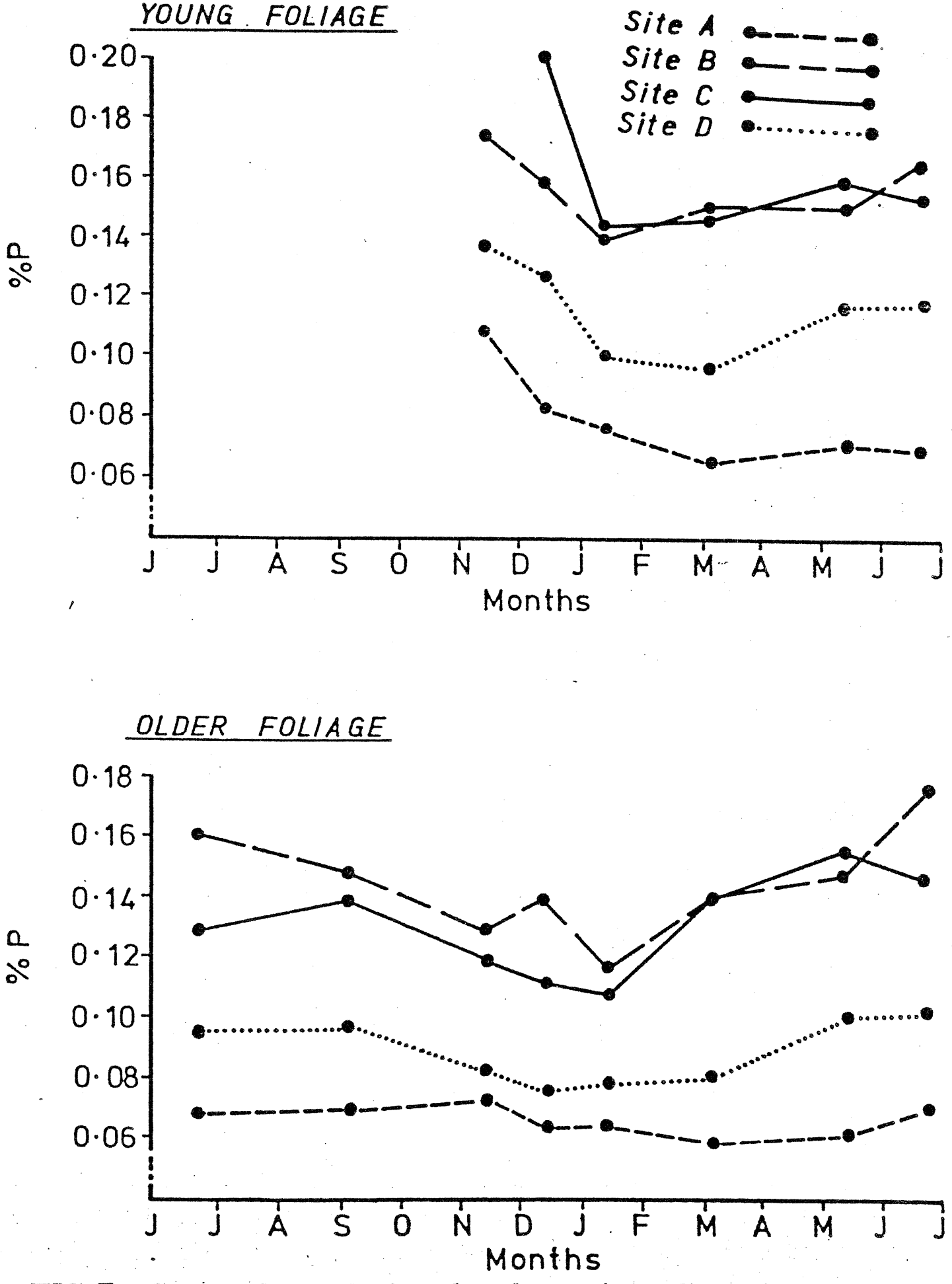


FIG 3—Seasonal trends for phosphorus in radiata pine foliage.

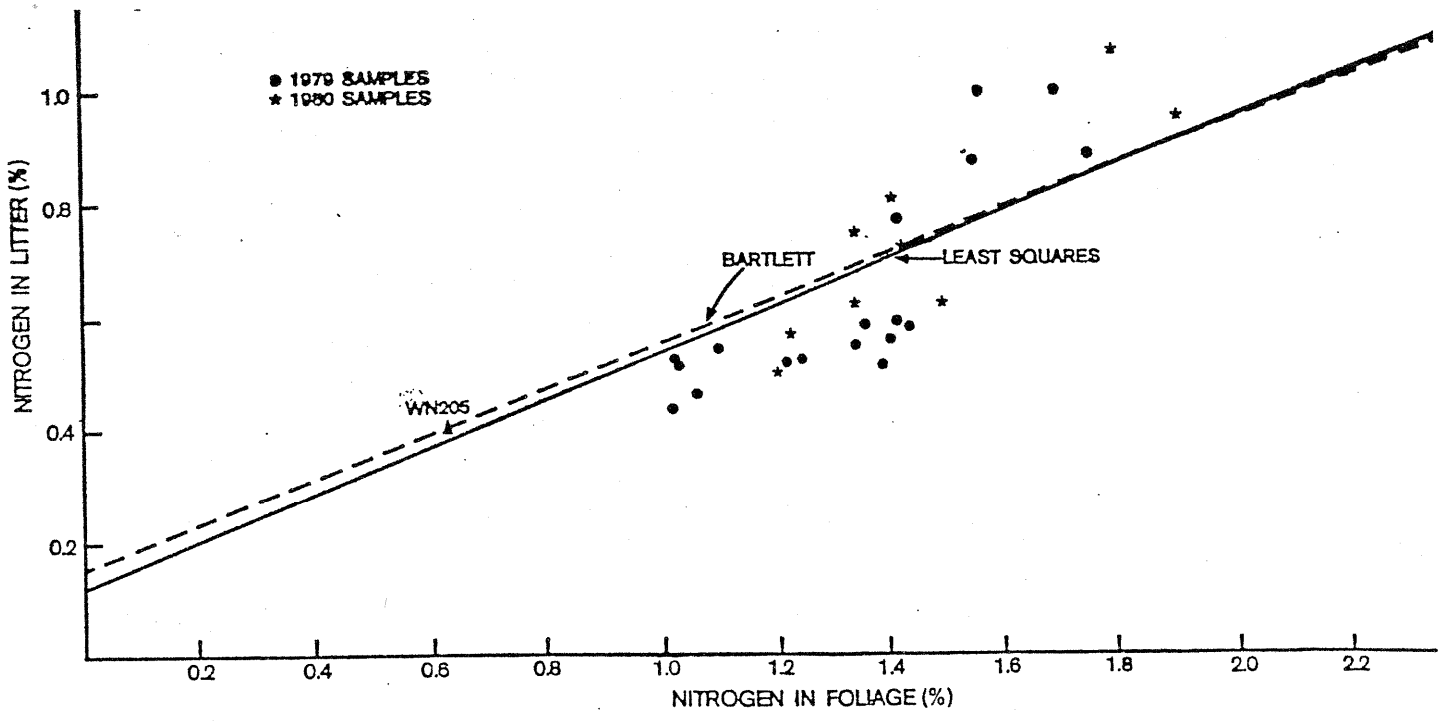


FIG 4-1—Independent verification of relationship between foliage and recent litter nitrogen. Regressions from text. Verification data from fertiliser trials described by Hunter & Graham (1982) and from the severely chlorotic site (WN205) referred to by Hunter & Hoy (1983).

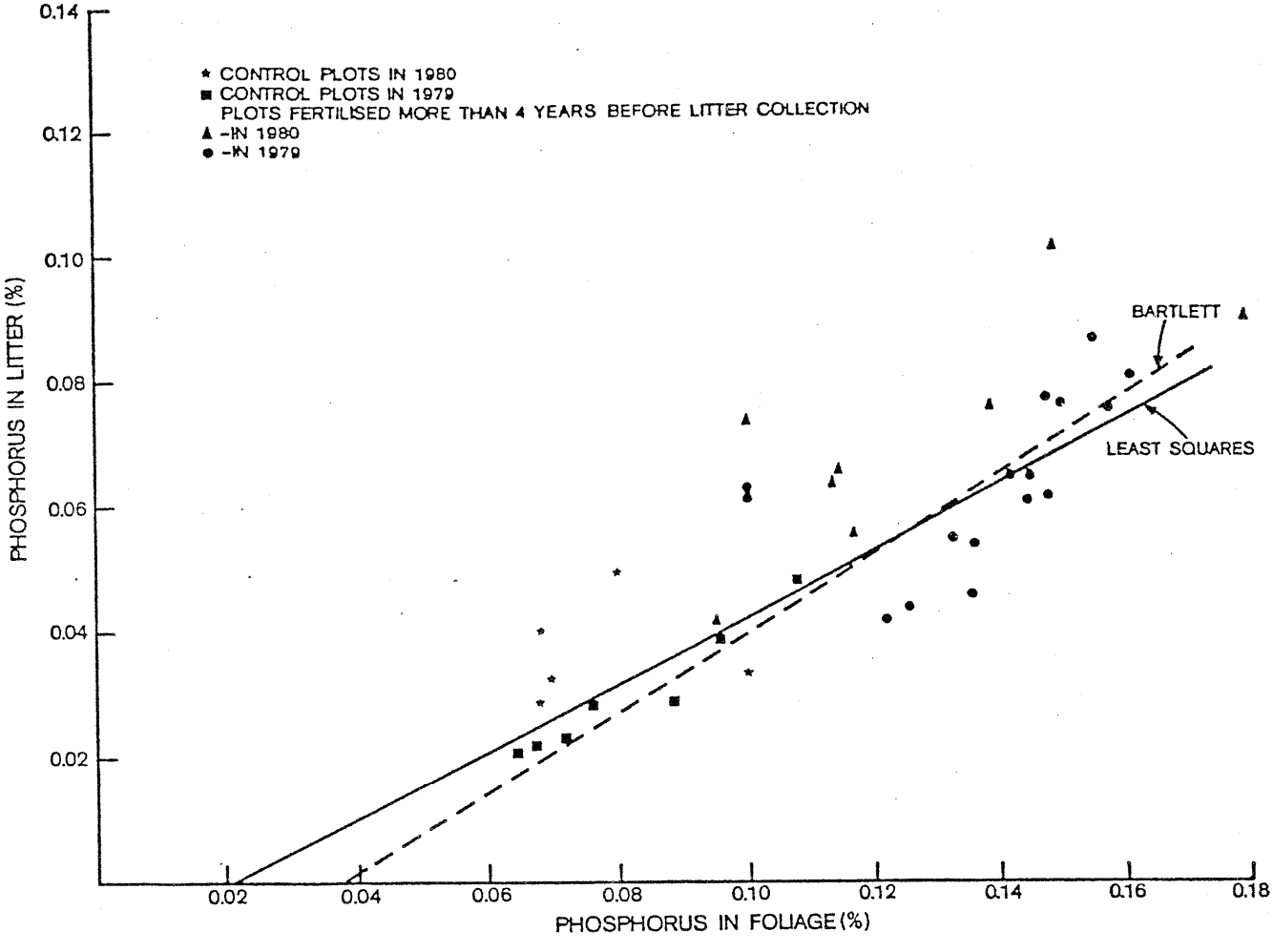


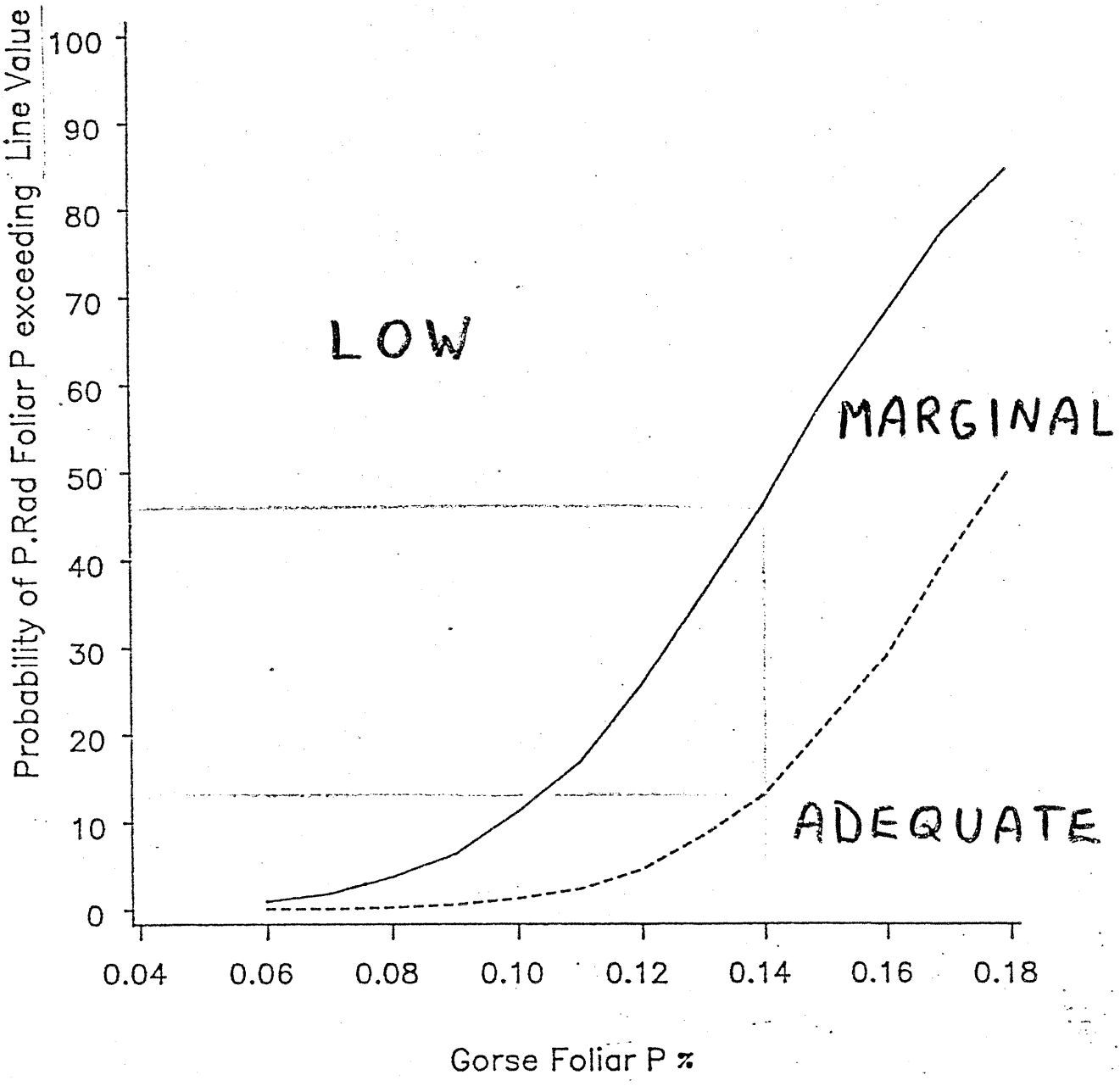
FIG 4-2—Independent verification of relationship between foliage and recent litter phosphorus. Regressions from text. Verification data from fertiliser trials described by Hunter & Graham (1982).

figure 5). Weeds have an advantage on bare ground where foliage is unavailable but the foliage sample is superior when available.

2c. Soil sampling

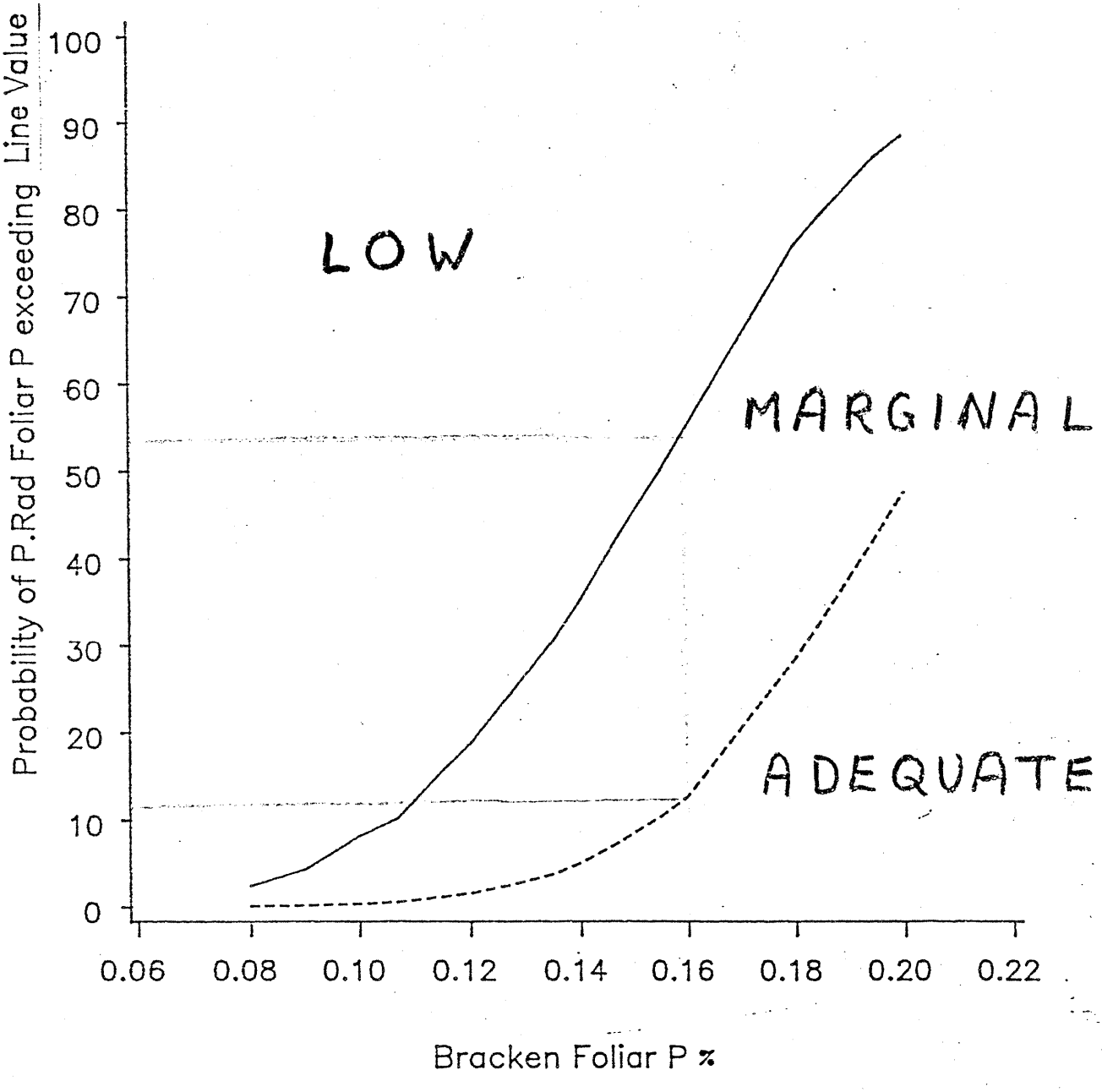
Foliage sampling is rather like driving a car looking in the rear mirror only. It tells you how easy it has been for the stand to gain nutrients. It does not tell you how easy it will be for the stand to obtain a particular nutrient unless the future is very similar to the past. Many things break that continuity:- stand development, thinning, drought. In theory a soil sample giving available nutrients should be the better predictor. In practice however the foliage sample proves to be currently the better. This is because the foliage sample, analysed for total nutrient content, is an accurate estimate of the nutrient status of the tree. A soil sample has to be processed by an artificial extraction procedure before available nutrients can be determined. These extraction procedures are currently so harsh and so little related to actual soil conditions that the answers they give are often not well related to tree nutrition. New instruments and new procedures may improve this situation and in the long term soil tests may well be the way to go.

GORSE AS PREDICTOR OF RADIATA FOLIAR P



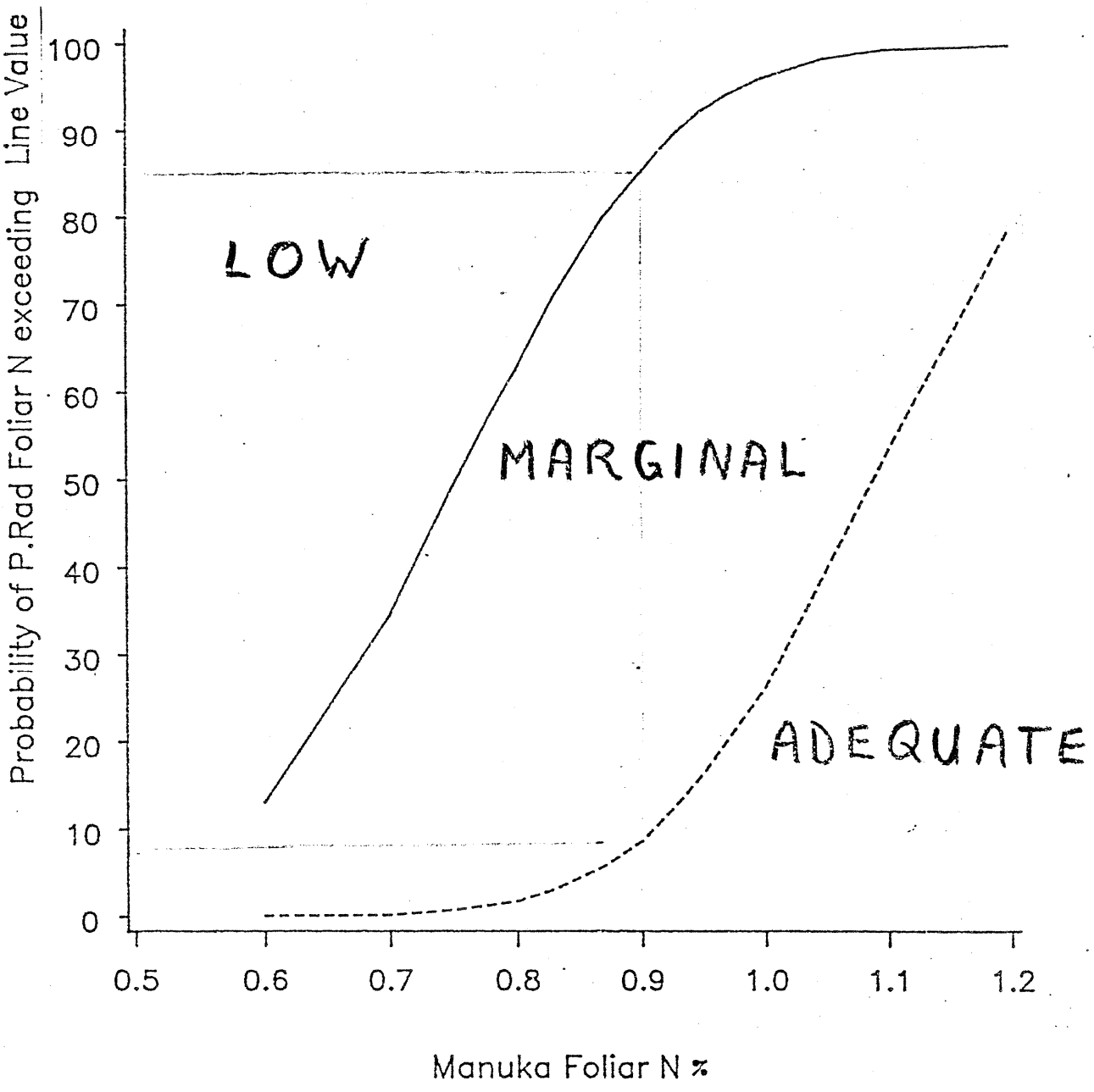
RADIATA FOLIAR P = 0.12% _____ ***RADIATA FOLIAR P = 0.14%*** _ _ _

BRACKEN AS PREDICTOR OF RADIATA FOLIAR P



RADIATA FOLIAR P = 0.12% _____ ***RADIATA FOLIAR P = 0.14%*** ___

MANUKA AS PREDICTOR OF RADIATA FOLIAR N



RADIATA FOLIAR N = 1.2% _____ ***RADIATA FOLIAR N = 1.5%*** ___

VARIANCE EXPLAINED (%)

	Bracken	Gorse	Manuka
N	-	-	45
P	48	38	22
K	42	24	28
Ca	4	54	-
Mg	37	-	10
B	26	13	1
Fe	7	16	21
Mn	-	-	-
Zn	30	-	-
Cu	-	-	41
S	45	-	37
Al	29	43	78
Na	75	19	11
Cl	50	52	-

APPENDIX 1

Alternative analysis prepared by Mark Kimberly

Assumptions:

1. At harvesting, wood will be valued at $\$50/m^3$.
2. Cost of fertilizing = \$200/ha.
3. Cost of foliage sampling: \$1/ha, \$5/ha, \$20/ha for 0.1, 0.5, 2 trees/ha respectively.
4. Fertilizer will remain active for only 5 years.
5. Accuracy of sampling as in Calvert & Hunter 1981 (see table 1).
6. Loss of growth as in Hunter & Kimberley 1985; max. growth of 30 $m^3/ha/yr$.
7. 10% discount rate.

This analysis considers a 50 ha compartment aged 10 years to be harvested at 25 years. Foliage will be sampled and fertilizer applied if foliar P < 0.11%. Note that in five years time, wood will be valued at $50/(1.1)^{10} = \$19.3/m^3$ Suppose true level of foliar P is 0.09% giving a growth loss of 6.67 m^3/ha. If a single cluster is sampled, probability compartment will be fertilized is 0.84 (table 1).

(a) If stand is fertilized,

$$\text{increase in NPV due to fertilizing} = \frac{6.67 \times 5 \times 19.3}{(1.1)^5} - 200 - 1 = \$198.7/ha$$

(b) If stand is not fertilized,

'increase' in NPV = -\$1/ha

Therefore, expected increase in

NPV = 0.84 x 198.7 - 0.16 x 1 = \$166.9/ha.

Results of similar calculations for a variety of foliar P levels and sampling intensities are shown in table 2.

Table 1. Probability stand will be fertilized for a variety of Foliar P levels and sampling intensities.

	Sampling intensity (trees/ha)		
Foliar P	0.1	0.5	2.
.06	0.99	1.00	1.00
.07	0.98	1.00	1.00
.08	0.93	1.00	1.00
.09	0.84	0.99	1.00
.10	0.69	0.87	0.99
.11	0.50	0.50	0.50
.12	0.31	0.13	0.01
.13	0.16	0.01	0.00
.14	0.07	0.00	0.00
.15	0.02	0.00	0.00
.16	0.01	0.00	0.00

Table 2. Expected improvement in NPV due to fertilizing, ($/ha).

Foliar P	Loss in growth	Don't fertilize	Sampling intensity (trees/ha)			Fertilize regardless
	(m^3/ha/yr)		0.1	0.5	2.0	
.07	14.3	0	638.8	649.9	634.9	656.8
.08	9.7	0	357.7	379.3	364.5	381.2
.09	6.7	0	166.9	192.3	179.9	199.7
.10	4.6	0	49.6	58.8	52.4	73.2
.11	3.1	0	-7.5	-11.5	-26.5	-13.0
.12	2.1	0	-23.3	-14.4	-20.7	-72.4
.13	1.5	0	-19.0	-6.1	-20.0	-112.5
.14	1.0	0	-10.8	-6.1	-20.0	-140.1
.15	0.7	0	-4.2	-6.0	-20.0	-159.3
.16	0.5	0	-2.0	-6.0	-20.0	-171.3
Weighted average (using expected frequencies)		0	55.9	63.0	50.3	-9.2