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NUTRIENT STRATEGIES FOR THE ESTABLISHMENT OF RADIATA PINE PLANTATIONS IN NEW ZEALAND

by

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EXECUTIVE SUMMARY

Deficiencies in nitrogen (N), phosphorus (P), potassium (K), boron (B) and magnesium (Mg) are commonly found in plantations of radiata pine in New Zealand. Although single element deficiencies exist, multi-element deficiencies are widespread. This paper describes the philosophy behind current research into fertiliser strategies designed to both maximise the response and to ensure longevity of the response for plantations established on nutrient poor soils.

INTRODUCTION

Nutrient dynamics in radiata pine plantations

Much of New Zealand's radiata pine production forestry plantations, with the exception of those established on old farmland, usually suffer from one or more nutrient deficiencies (Will, 1978; Mead and Gadgil, 1978). The deficiency symptoms can range from slight through to acute, covering both the macro elements such as nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) and the minor or trace elements, mainly boron (B), but with instances of copper (Cu) and zinc (Zn).

For the establishment and early growth of radiata pine on infertile soils, phosphorus is the classic growth limiting element. From as early as age 2 other nutrient deficiencies can assert themselves, and the forest manager must be continually aware of the need for possible corrective action, based on either field experience, or through early warning by foliar nutrient analysis.

Patterns of nutrient uptake by radiata pine

Until canopy closure, which occurs at ages form 4 to 7 years, the soil is the major nutrient reserve. To about age 2, although the demands are quite specific, the absolute requirements are quite small (Madgwick and Knight, 1977). From age 2 the demand for soil nutrients increases markedly. A typical nutrient demand curve for radiata pine is shown in Figure 1 (data from Madgwick and Knight, 1977) and the effect of lack of soil supply on foliar nutrient concentrations is shown in Figure 2 (data from Hunter and Skinner, 1986).

Agriculture and forestry: fertiliser mis-matching

For low fertility soils nutrient corrections need to be made from the time the seedling is planted, and the added nutrients need to remain available through to at least canopy closure. This period covers several years, and the major issue is the inability of most fertiliser grade materials, which are manufactured in a soluble form, to remain "available" in the longer term. Manufactured fertilisers were developed to cater for cropping or pastoral needs; that is, to be readily soluble and to meet agronomic demands for high nutrient availability over relatively short periods. In forestry, the demand for nutrients by a single crop of radiata pine is however measured in years, with the bulk of nutrients being absorbed early in the rotation in the period leading up to canopy closure. This applies particularly to the more commonly used fertiliser nutrients such as P, K and B where availability is high, immediately after application. The situation with N is more complex involving a biological component, with a "reversion" to more stable, and less available, organic forms in forest soils.

The theme of this paper is the rationale behind the development of nutrition strategies designed to meet the long term needs of radiata pine as a production crop.

PHOSPHORUS

Background to P fertilising

Many soils of the Auckland and Northland regions of New Zealand, as well as Nelson/Marlborough and Westland are acutely deficient in "available" P. Little or no growth is possible unless P fertiliser is applied at the time the plantation is established. Applications of superphosphate, or diammonium phosphate where N is limiting, have been the standard fertiliser recommendation. Applied as a slit application by the base of the seedling (to minimise stimulating "weed" competition), the applied P is usually effective for less than 2 years. Broadcast dressings of P are then required to maintain adequate P nutrition. Repeat applications of P may be likely over the duration of the rotation. A summary diagram for this effect early in the rotation is shown in Figure 3 (Hunter and Skinner, 1986; FRI, unpubl. data). The problem is a basic mis-match between nutrient availability and tree demand. At establishment, the demand, although low, is essential, and met by the soluble P application. Rapidly, however, the applied P is either leached from the rooting zone (sandy soils) or chemically precipitated (clays, iron and aluminium compounds); in both states P availability to the tree is very much reduced. The localised positioning of the nutrient means that roots rapidly grow out beyond the P source. The amount of nutrient applied in the first application, although sufficient to satisfy demand for the immediate post-planting period, is far too low to meet the crops' ongoing needs leading up to canopy closure. The issue of quantity and availability is met by a second P application, usually applied at about age 3. The need for further applications will depend on the both the nature and severity of the soil's infertility.

Alternatives to soluble P fertilisers

Soil P reserves are derived from primary P minerals (such as apatite), through weathering reactions. The released P is held as secondary minerals and available after dissolution for plant uptake. The phosphate moiety from soluble P fertilisers, such as the super- and triple- superphosphates, is, for all but sandy soils, rapidly adsorbed and then more slowly chemically precipitated, via the clay and sesquioxide (Fe and Al) components.

This ensures that the initially high levels of plant available P (through the fertiliser application) rapidly reduce. For many pasture soils, the problem of availability is often offset, after very large applications of P have significantly saturated the soils capacity to hold P. In forestry, these luxury applications of P are never applied.

An alternative to reducing the soils sorptive capacity for P (through large P applications) is to apply P in a relatively inert (poorly soluble) form. This ensures that the applied P is not captured as secondary reaction products; it is slowly made available, enabling the roots to compete (along side the soil components) for an "available" form.

Phosphate rock (PR) at time-of-planting

FRI trials with PR were established in the early 1980's as a nationwide series from Northland to Westland. These trials were installed to test the viability of PR as an alternative to the use of soluble P fertilisers commonly used. As well as the PR treatment, a mix of PR and soluble P (superphosphate) was included as a substitute for partial acidulation of PR (PAPR) as an alternative to PR. The rates of P applied were high; from 110 to 140 kg P/ha (depending of P source). These high rates were to ensure the treatment did not fail through inadequate P quantities. A summary illustrative diagram for the effect of PR and PAPR on foliar P for the first 10 years is shown in Figure 4 (FRI, unpubl. data). These data confirm that both PR and PAPR are alternatives to the use of the super- and triple-phosphates for plantation establishment.

Subsequent trials have examined the rates of P issue on a variety of soil types; early results indicate that a scaling of P according to soil type is likely, with rates varying from about 50 kg P/ha for the sandy podzols (Northland), to 100-150 kg P/ha on infertile, and highly P fixing, clay soils.

POTASSIUM

Potassium deficiency is a major problem on the podzolised soils of Northland, Nelson and Westland. Deficiency symptoms rarely occur until plantations are at least 3 years or older. The decline in foliar K from seedling establishment at several sites on podzolised soils is shown in Figure 5 (FRI, unpubl. data). By age 5 foliar K levels had declined to about 0.3%, which is marginal for radiata pine (Will, 1985). Applications of K at time-of-planting have no impact on the time of onset of K deficiency (Skinner, FRI, unpubl. data). Indirect likely estimates of productivity loss through K deficiency (from age 4 onwards) are available from the results of one field trial only, where, after correction of N and P deficiencies, K was added as part of an "extra" treatment with Cu and Zn. The growth response to the N, P and K mix additions are shown in Figure 6 (FRI unpubl data). Increases in basal area of up to 6 m2/ha were achieved and associated with an improvement in K nutrition (Figure 7) (FRI unpubl data) from marginal to deficient (0.3%) to adequate (>0.5%), (Will, 1985). However, within 3 years foliar K had declined to about the same levels in the "not refertilised" treatments. Unlike P, K is mobile within the soil matrix, and fertiliser compounds are readily soluble. Any attempt to maintain forest K nutrition will have to be based on applying the optimum quantity of K at the appropriate time. Trials are currently in progress to assess the rates by timing requirements.

NITROGEN

Biological N fixation has made a major contribution to the success of plantation forestry for sand dune stabilization in New Zealand (Gadgil, 1976). Estimates for N fixation over the duration of the rotation have been put at about 800 kg/ha (Dyck *et al.*, 1988). For all other soil types where soil N fertility is low, chemical N, usually as urea, or in combination with P as di-ammonium phosphate, is routinely used to maintain the N nutrition of radiata pine plantations (Will, 1985). The decline in foliar N concentrations during the establishment phase for radiata pine is shown in Figure 8, summarised from a range of establishment trials (Hunter and Skinner, 1986). Normal forestry practice has been to fertilise with an NP based prescription at planting, and to broadcast N, (usually in combination with P), at about age 4. Further applications of both N and P are usually required throughout the rotation.

By encouraging biologically fixed N as an alternative to the use of bagged N on other soils types, it is likely that the sand dune forestry success story can be emulated; this, coupled with recent work on the West Coast of the South Island to examine the experimental establishment of Lotus (Maku lotus), on impoverished "pakihi" or gley podzols (FitzGerald, pers. comm.) led to pilot studies with legumes on the infertile podzolised soils of Northland.

The experimental design used was a 4 * 24 factorial involving 4 levels of North Carolina rock phosphate, 2 species of legume, in combination with lime, K, S and control. The trial covered a well cultivated "control" plot from an earlier experiment. Due to the highly impoverished nature of the soil, and the excellent cultivation achieved, vegetation control was optimal and uniform. The site was hand-raked before the trial was established. Early results are presented in Table 1. Because of the extremely uniform nature of the site, small changes in soil can be related to the effect of fertilisers or legumes.

Early interpretation shows that lotus has grown much better than clover; "available" P (Bray-2 extract) has increased steadily by the addition of rock phosphate, but that lotus has used more of the P than clover (reflected by biomass differences); soil N concentrations have increased more under lotus than white clover (the small differences represent increases of about 100 kg N/ha); available K (Bray-2 extract) has ben markedly increased by the lotus - reflected by the relatively high K content of lotus.

This work demonstrates that legumes can be established on impoverished clayey soils to improve soil N fertility prior to establishing radiata pine. The effect of legume/fertiliser mixes for the establishment of radiata pine is under test.

BORON

Boron is the commonest micro-element deficiency in radiata pine. Since soil B exists in solution as boric acid, it is easily leached from the rooting zone (McLaren and Cameron, 1990). Although only trace amounts are required in soil solution, the range between deficiency and toxicity is narrow (Stone, 1990), and care has to be exercised when applying B in the soluble salt form, usually as Na borate. Early work with the correction of B deficiency concentrated on the use of Na borate fertiliser. Results were encouraging, (Figure 9, Hunter, Will and Skinner, in press) but the longevity of the response was limited. High application rates could not be used to improve the longevity of the response because of toxicity. Boron is highly immobile within tree tissue, and nutrient retranslocation is not available as a mechanism for B movement to the apical meristem under conditions of low root uptake of B.

Trials established in the early 1980's with colemanite (calcium borate) and ulexite (sodium calcium borate) as alternative B sources for radiata pine have shown that foliar B levels can be maintained at satisfactory levels (Figure 10, Hunter, Will and Skinner, in press). The longevity of the applied mineral is, as yet unknown, but, in combination with the release of B from decomposing litter, the prevention of B deficiency for a number of rotations seems likely.

MAGNESIUM

Magnesium deficiency is a common occurrence in the Central North Island, particularly under conditions of intensive silviculture where medium to high pruning is practised to achieve high value logs. The loss of foliar Mg in slash places severe demands on internal nutrient re-cycling. Demand by the tree often exceeds supply and deficiency occurs usually in spring when growth accelerates. In many cases the deficiency is short lived, as litter decomposes releasing Mg for root uptake. In other circumstances Mg deficiency is more serious, and appears to be restricted to those sites previously under pasture. Lowered reserves of soil Mg, through removal in hay and animal production appears to be one reason for the problem; competition between tree and pasture for available Mg is another aspect. Early trials with epsom salts (magnesium sulphate) and dolomite at 100 kg Mg/ha show that for severely Mg deficient trees, recovery is slow (Hunter *et al.*). It appears that the capacity to take up Mg, once the system has come under stress, is reduced. Current research is aimed at understanding the physiology of Mg uptake in relation to the problem of establishing radiata pine after pasture. Early data suggests that deep ripping, to incorporate Mg deeper in the soil profile, may be an ameliorative measure.

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Table 1 – The effect of P fertiliser on legume yields, and N, P and K soil analyses

P (kg/ha)	25	50	100	200
Herbage (kg/ha)				
Lotus	1040	1840	2756	3368
WC	78	110	200	162
Bray-2 soil extracts				
Phosphorus				
Lotus	1.9	3.3	10.6	16.2
WC	1.8	5.1	12.4	22.9
Potassium				
Lotus	0.54	0.57	0.63	0.59
WC	0.30	0.32	0.29	0.29
Soil nitrogen				
Lotus	0.25	0.23	0.29	0.29
WC	0.20	0.23	0.25	0.24

FIGURE 1

Nutrient uptake (averaged for N, P and K) for the early growth of radiata pine

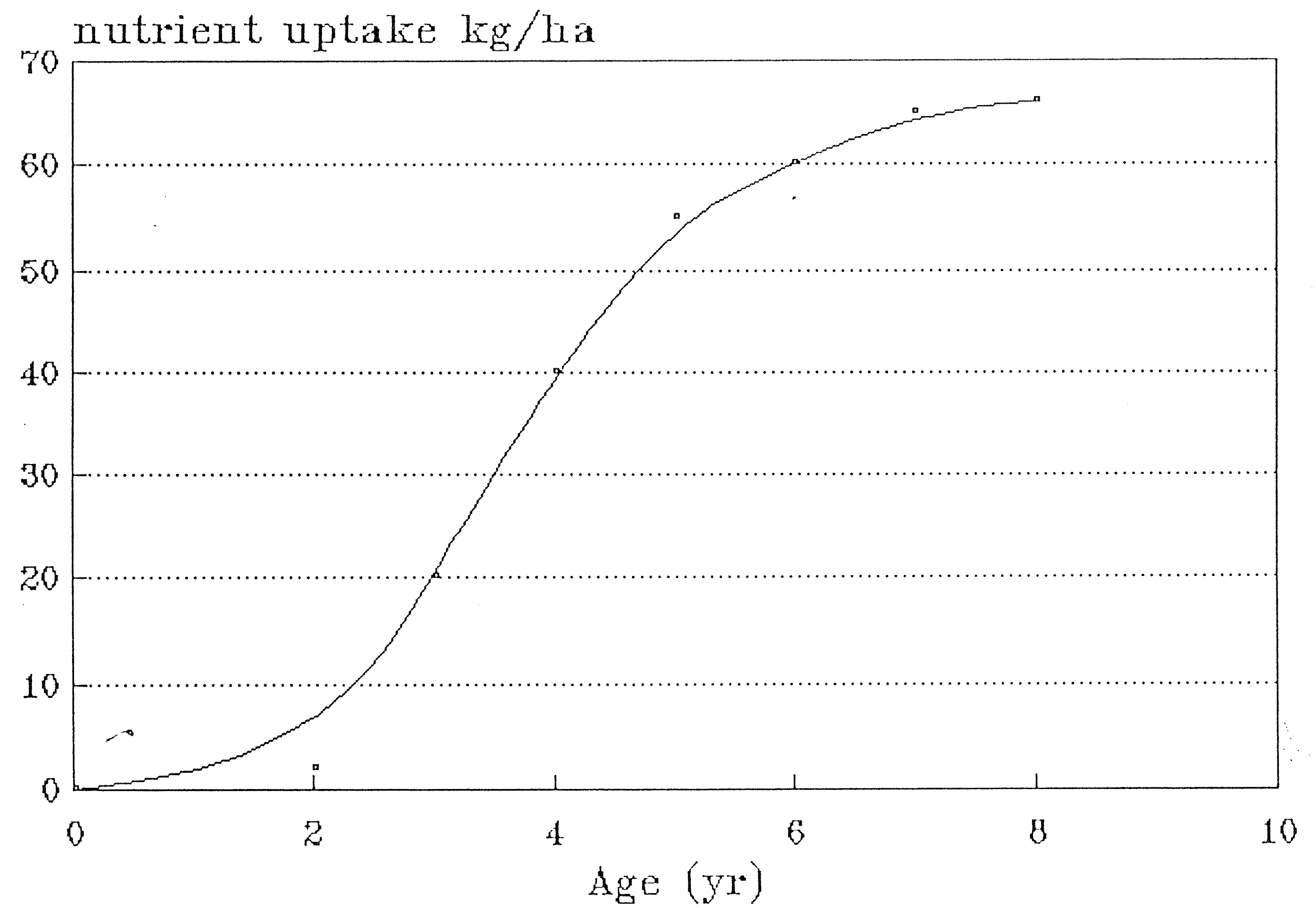

nutrient uptake kg/ha
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Age (yr)

FIGURE 2

The effect of site difference (soil fertility(on change in foliar nutrient concentrations

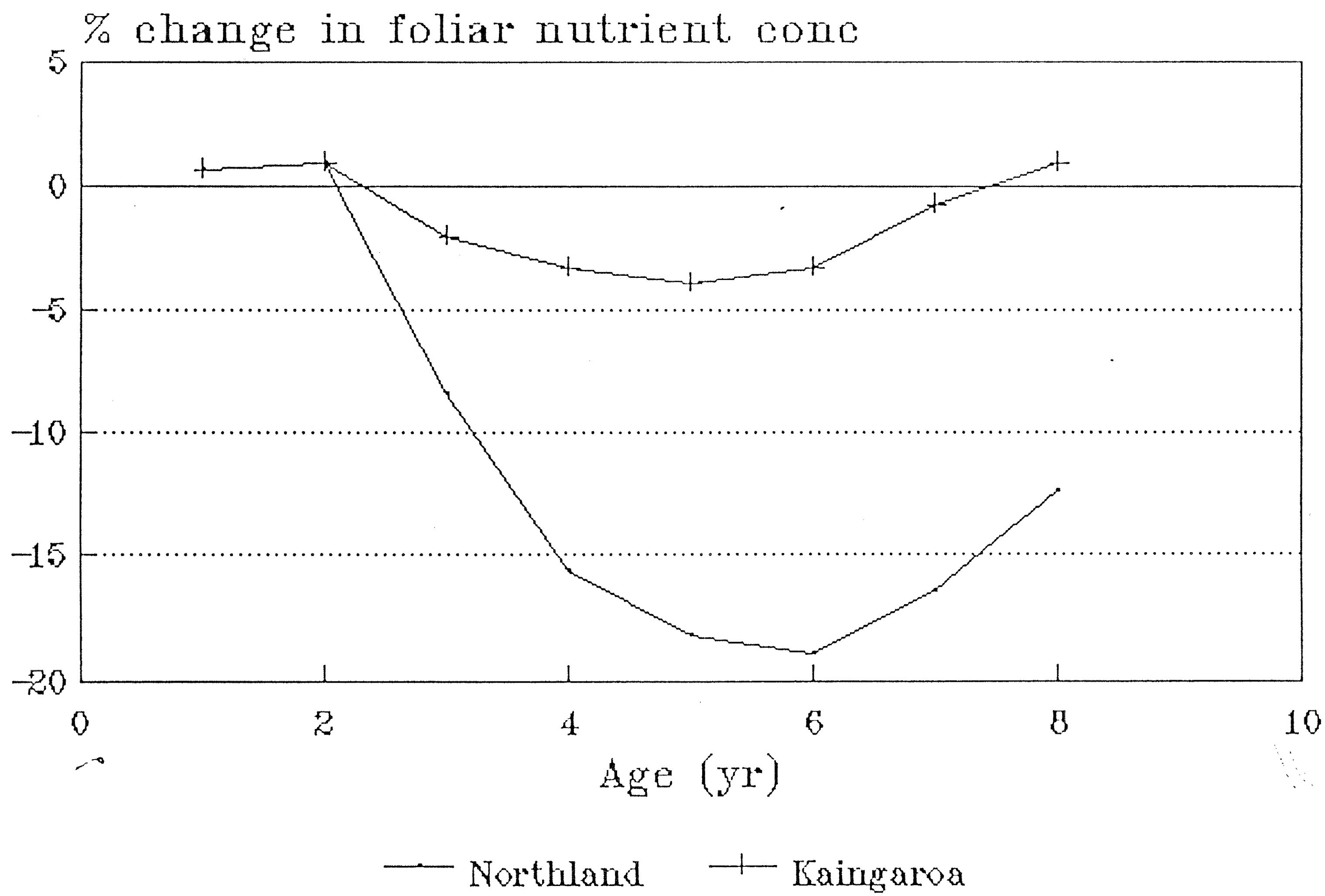

% change in foliar nutrient conc
5
0
-5
-10
-15
-20
0
2
4
6
8
10
Age (yr)
Northland
Kaingaroa

FIGURE 3

The effect of P fertilisation on foliar P concentrations

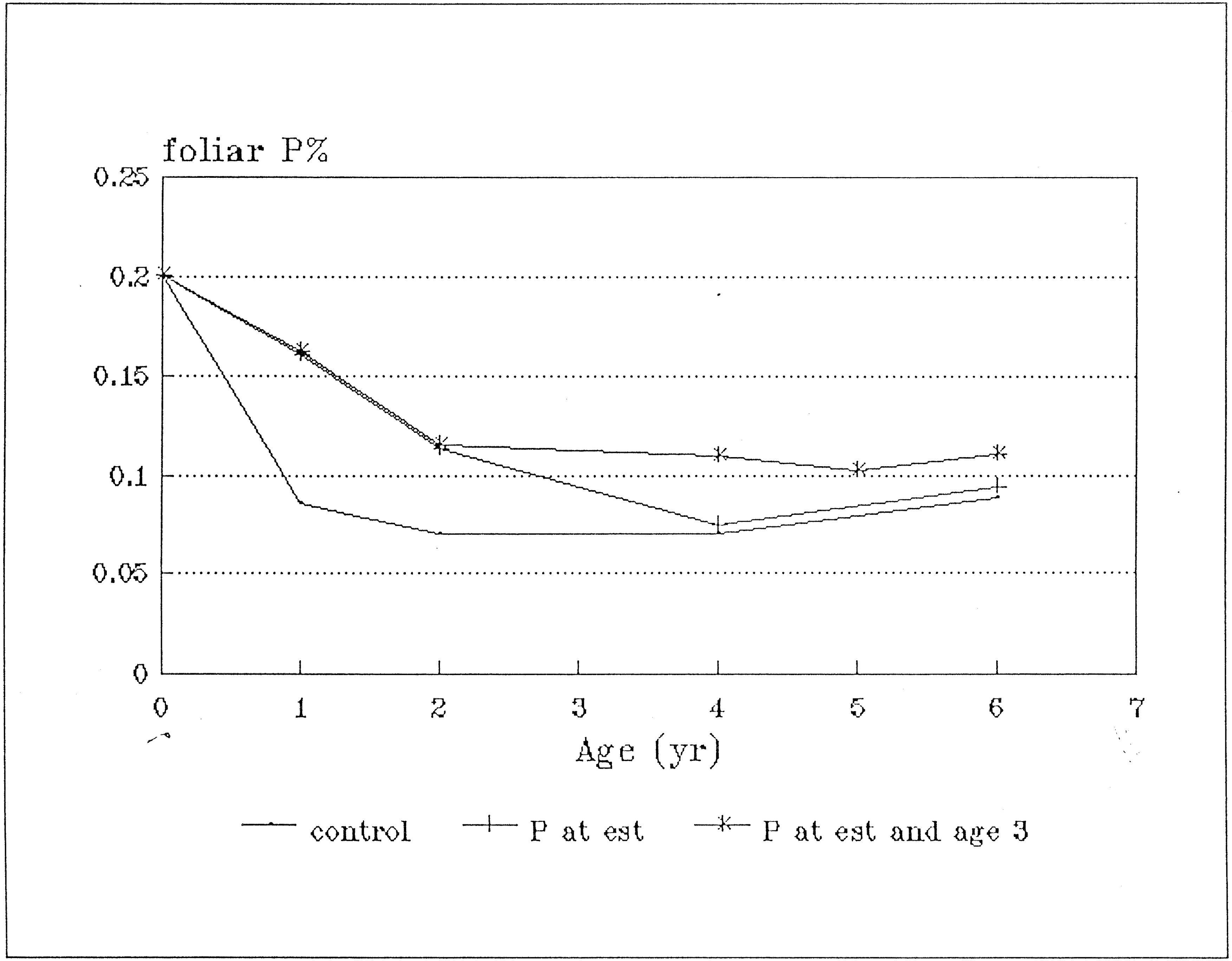

foliar P%
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
Age (yr)
control
P at est
P at est and age 3

FIGURE 4

The effect of phosphate rock (PR) and a PAPR equivalent
on the maintenance of foliar P

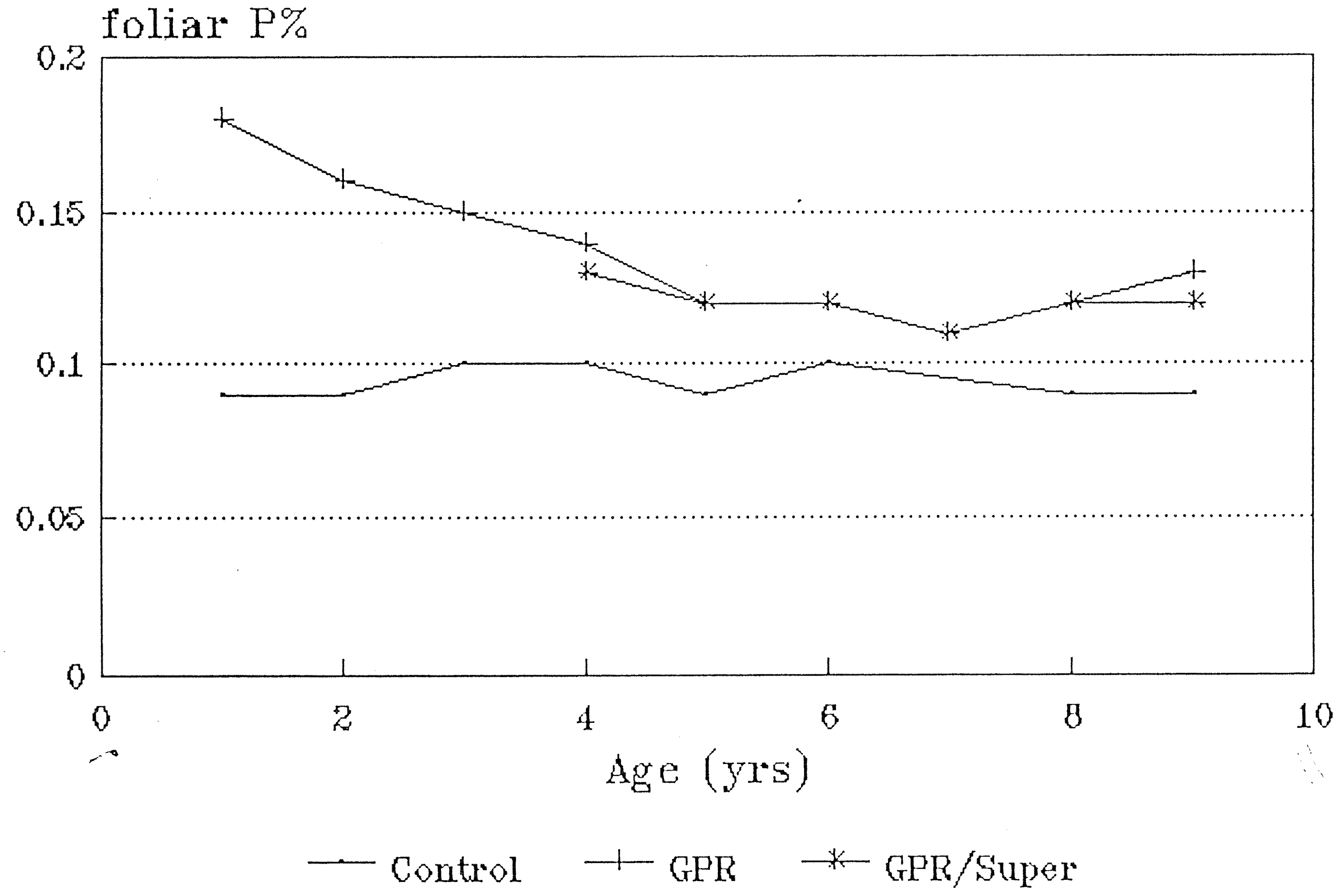
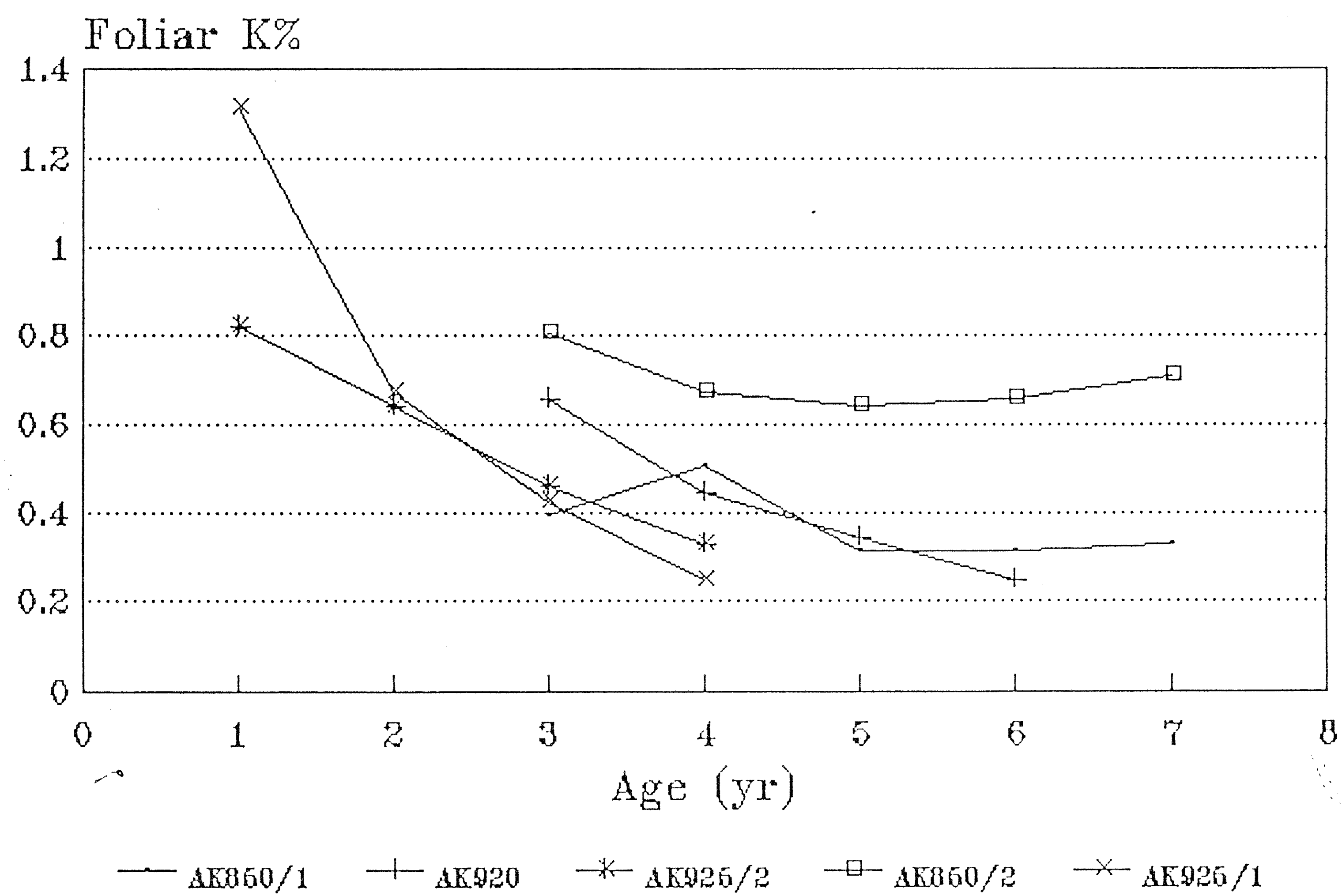

foliar P%
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
Age (yrs)
Control
GPR
GPR/Super

FIGURE 5

Patterns of K decline from establishment on impoverished soils



Foliar K%
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Age (yr)
AK850/1
AK920
AK925/2
AK850/2
AK925/1

FIGURE 6

The role of K in basal area gains to refertilising at age 4

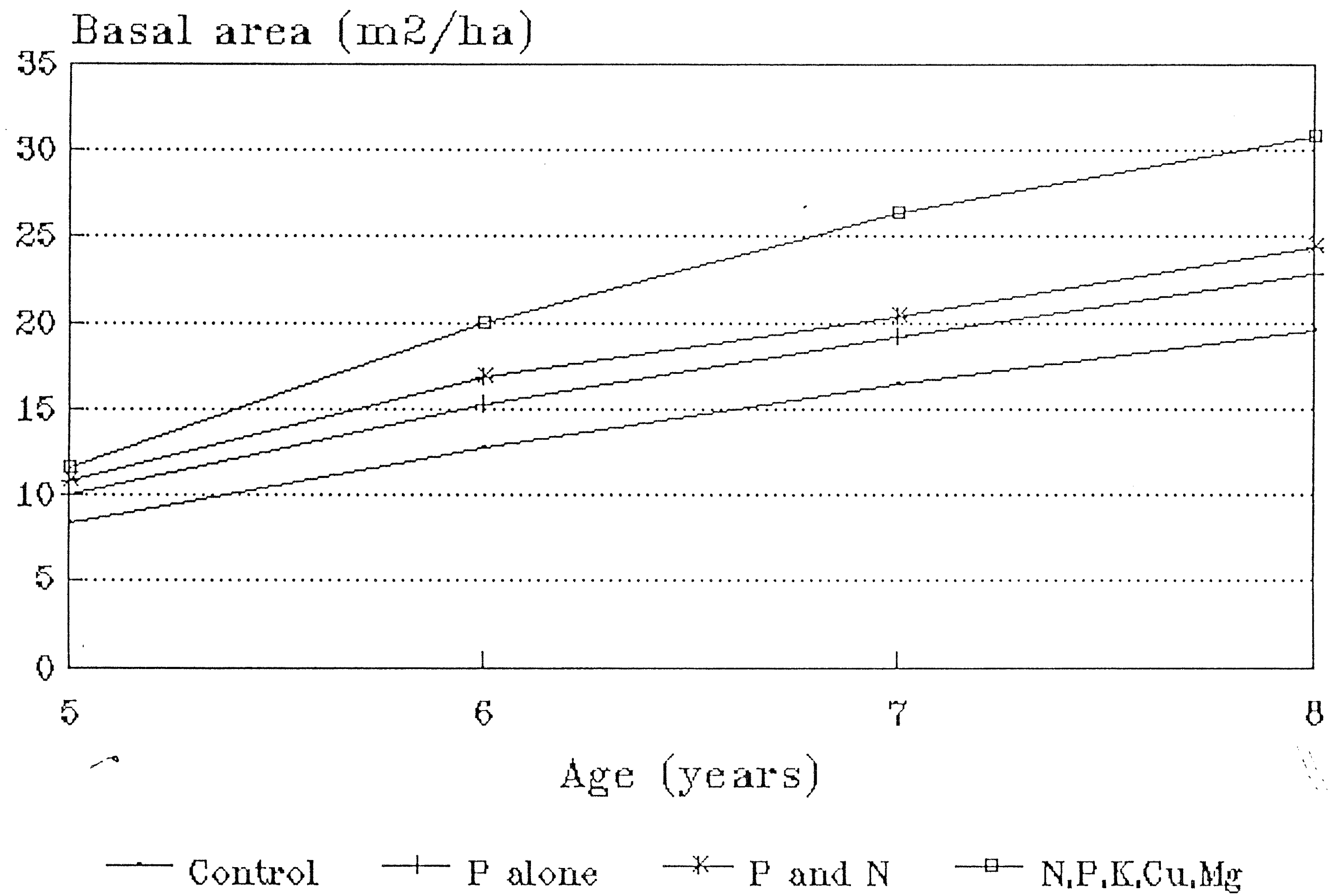

Basal area (m2/ha)
35
30
25
20
15
10
5
0
5
6
7
8
Age (years)
Control
P alone
P and N
N,P,K,Cu,Mg

FIGURE 7

The effect of refertilising at age 4 on foliar K concentrations

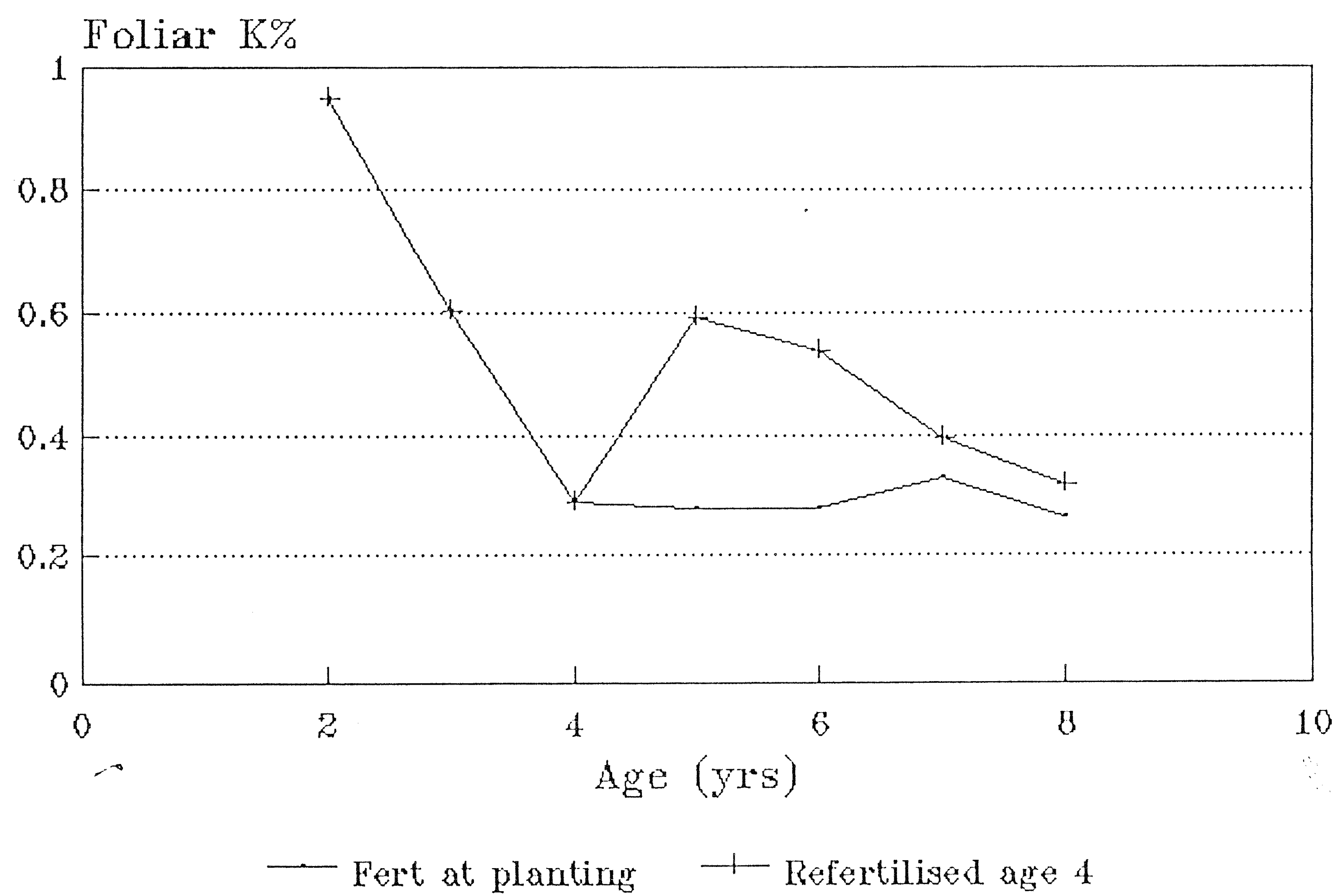

Foliar K%
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Age (yrs)
Fert at planting
Refertilised age 4

FIGURE 8

Patterns of N decline on N impoverished soils

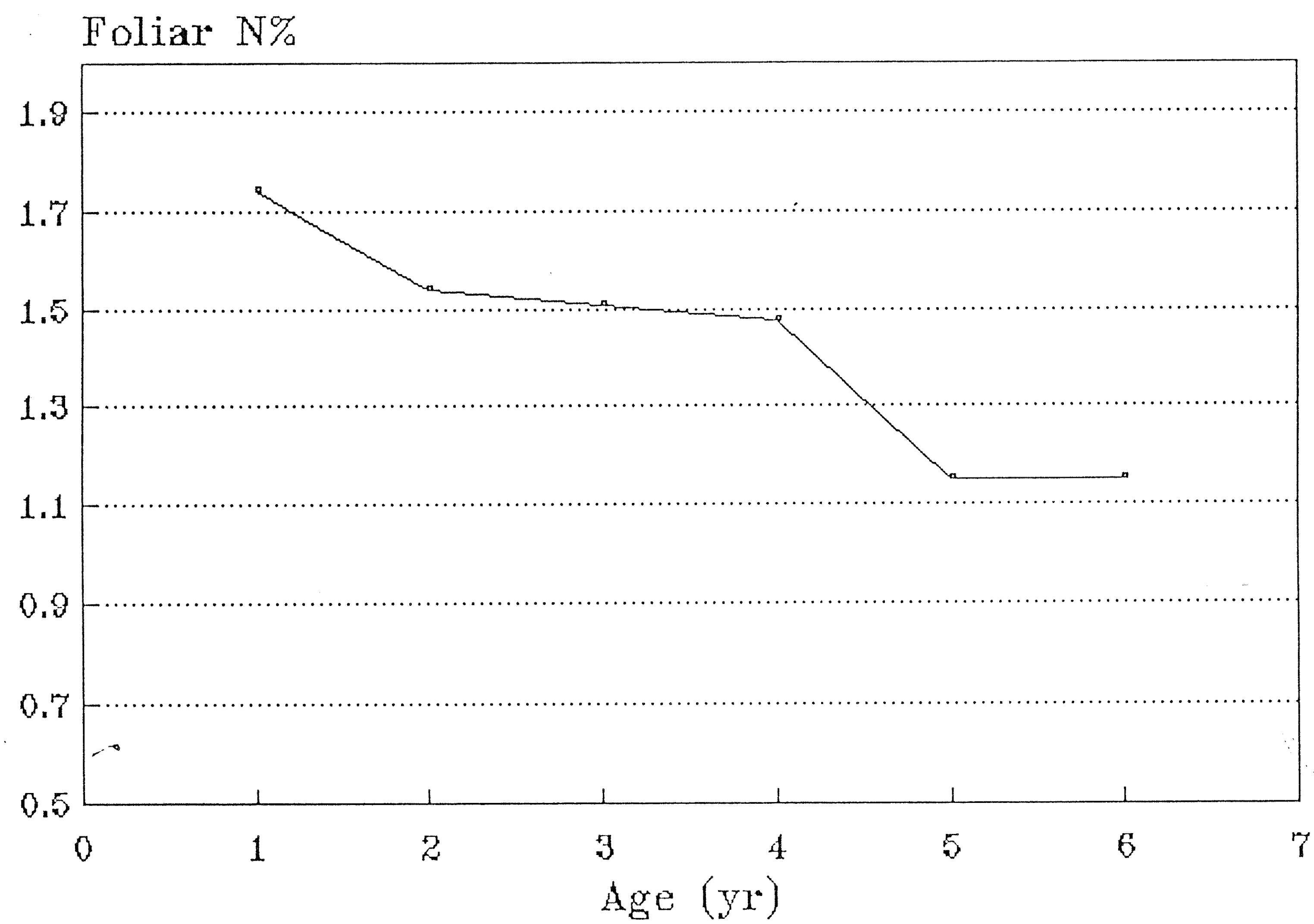

Foliar N%
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0
1
2
3
4
5
6
7
Age (yr)

FIGURE 9

The effect of various rates of B application on foliar B concentrations

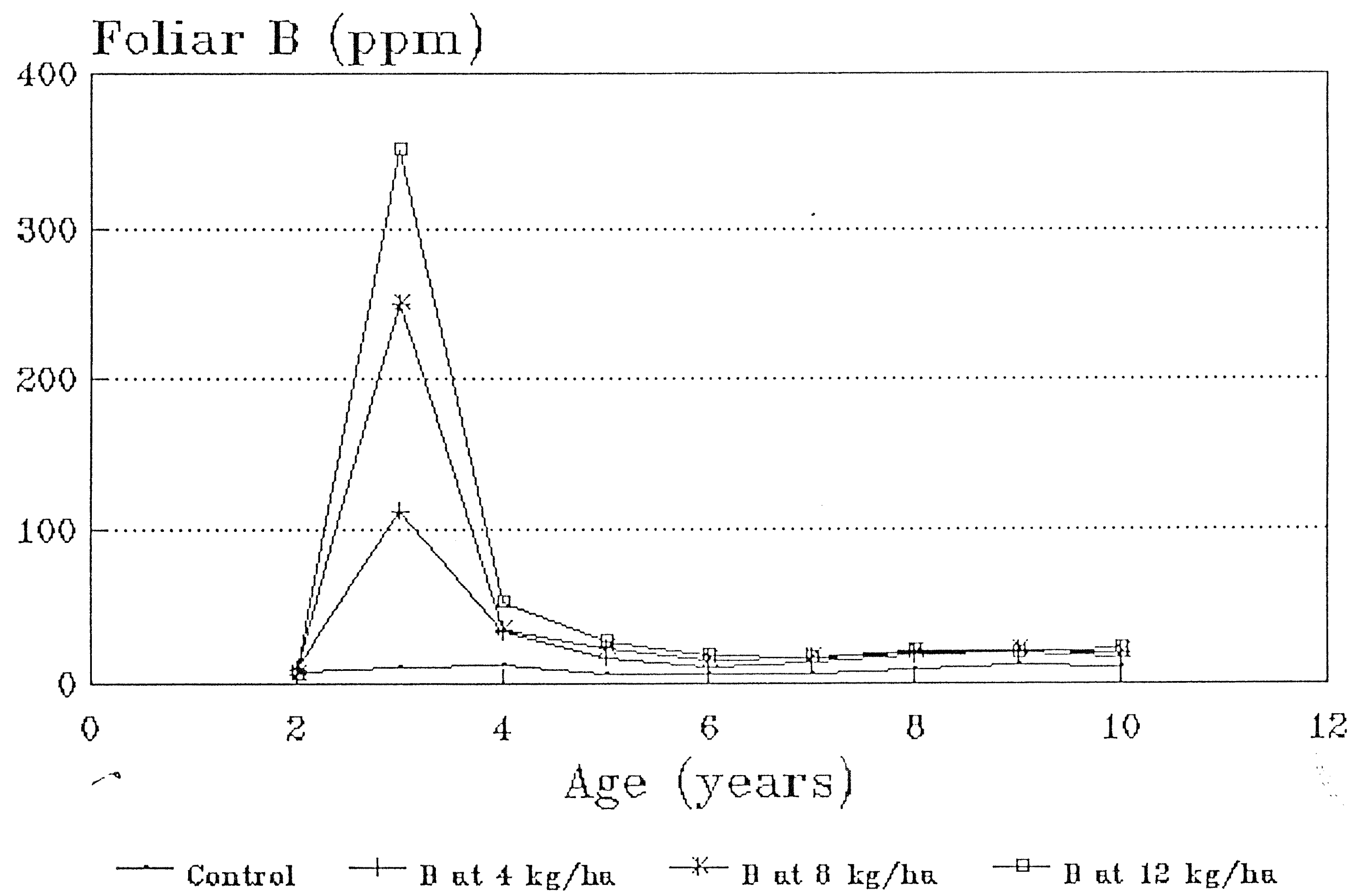
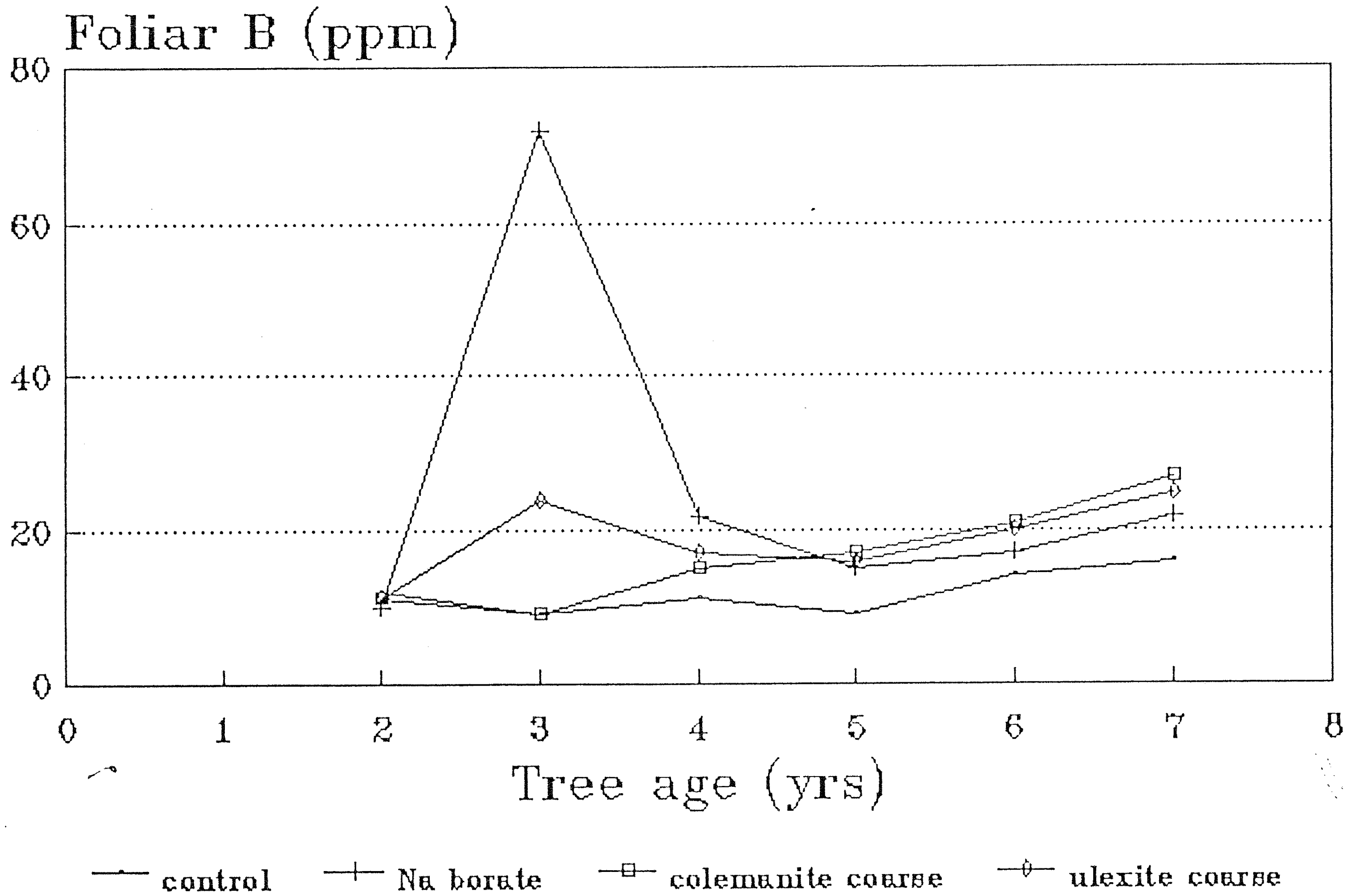

Foliar B (ppm)
400
300
200
100
0
0
2
4
6
8
10
12
Age (years)
Control
B at 4 kg/ha
B at 8 kg/ha
B at 12 kg/ha

FIGURE 10

The effect of B source on foliar B concentrations



Foliar B (ppm)
80
60
40
20
0
0
1
2
3
4
5
6
7
8
Tree age (yrs)
control
Na borate
colemanite coarse
ulexite coarse