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J. O'Donnell

17th March.....1980

To Naru,

Thanks for your grant and accommodation and help whilst in Darwin.

John O'Donnell

NUTRITION OF *PINUS CARIBAEA* VAR. *HONDURENSIS* BARR. AND GOLF. PROVENANCES ON RED EARTHS.

BY

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Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science (Forestry) with Honours at the Australian National University.

NOVEMBER, 1977.

ACKNOWLEDGEMENTS

I wish to extend my sincere appreciation to my supervisor, Dr. B.N. Gardiner for his interest and guidance throughout the study.

I am also indebted to the following:

NARU, for provision of a grant for this year of research and housing facilities whilst in Darwin.

CSIRO Division of Forest Research for allowing me the use of their facilities.

Mr D. Cameron, Mr. G. Craciun, Mr. S. Rance, Mr. J. Maggs, and Mr. A. White for guidance during the trial.

A.N.U. Forestry Department for provision of facilities.

Dr. D.G. Nikles and Dr. D.I. Bevege of Queensland Department of Forestry for helpful discussions.

Mr. R. McMurtrie and Mr. A. Dunn of CSIRO for statistical guidance.

Mr. K. Day for letting me use his paper on red earths.

Mr. F. Darlington, Mrs P. Abonyi, and Mrs P. Whittle for occasional help in chemical analysis.

Miss Y. Allison for the excellent typing of this thesis.

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ABSTRACT

Results are presented of the Darwin pot trial, designed as a factorial, testing three soils, three provenances of *P. caribaea* var. *hondurensis* and sixteen fertiliser treatments involving the use of P, N, S and T (trace element mixture).

The analysis of variance revealed that P, S and T treatments had significant effects on total dry weight. P was the most important nutrient for plant growth. The S x N, P x N x S, P x T, T x S, N x T x S, P x S and P x T x S fertiliser interactions were also significant. The PNS treatment was the optimum treatment averaged over all soils and provenances. Seedlings of the Queensland provenance had the largest dry weight (averaged over fertiliser regimes) on all soils, with the Alamicamban provenance having the least dry weight. Seedlings on the PBO-10 cm soil had the largest dry weight (averaged over all fertiliser regimes and provenances) and the PB10-25 cm soil had the least. This indicated the importance of the topsoil of red earths for the growth of *P. caribaea*. The greater production of the PBO-10 cm soil relative to the Three Ways soil also indicated that the Point Blaze site

should be planted with a field trial.

Mycorrhizal addition resulted in an increase in total dry weight production in most cases tested. The influence of mycorrhizae on the growth of *P. caribaea* should be investigated further.

The soil x fertiliser and provenance x fertiliser interactions were both significant at the 0.001 probability level for total dry weight production. This emphasises the need for further studies into the genotype x environment interactions with *P. caribaea* provenances.

The Ainslie trial confirmed that large increases in growth can be obtained with *P. caribaea* with the addition of phosphorus.

INTRODUCTION

Pinus caribaea is becoming increasingly important in tropical forestry. This is so since, according to Slee and Nikles (1968), the species combines all the major attributes of a successful exotic species outlined by Jacobs (1964). On suitable sites the species can produce similar growth to *P. radiata* and produces strong timber for constructional purposes (Lamb, 1973). Another reason why *P. caribaea* is becoming important in tropical forestry is the lack of general utility of native conifers (Zobel, 1972). An example of this is *callitris* in the Northern Territory. Also, since the eucalypt forests in the Northern Territory have low volumes and high internal defect, and since the Darwin market must import most of its timber requirements, it is apparent that an exotic species such as *P. caribaea* is needed for the Northern Territory.

In the Northern Territory *P. caribaea* has done well on the deeper red loam soils (Craciun, 1977a). The possible reasons why *P. caribaea* grows well on red earths are discussed in the review of red earths.

The Point Blaze site is on a red earth in the Northern Territory. The site has a slightly lower eucalypt stocking in terms of basal area and number of stems than the Three Ways site. However, the eucalypt growth on the site is good compared with other red earth sites on the mainland. Thus, the reason for the pot trial is to serve as a preliminary study of the growth of *P. caribaea* on this soil to help decide whether a field trial is feasible. The Three Ways soil was included so that the PB0-10 cm soil could be compared to a soil where *P. caribaea* is already growing in the field.

There are large differences between the growth of *P. caribaea* var. *hondurensis* provenances in International Provenance trials on red soils. Thus, it was decided to include two of the faster growing provenances from this trial, the Mount Pine Ridge and the Alamicamban provenances. A Queensland seed source (originally from Mount Pine Ridge) was also selected.

Thus, this trial considered the genotype x environment interaction. Bevege and Simpson (1973) consider this interaction needs to be taken into account when species/provenance/family selections are made for establishing commercial plantations in particular locations with well-defined climatic and edaphic regimes.

This interaction was investigated in a pot trial. These trials have the advantages of allowing the complicated designs needed to consider the genotype x environment interaction. Pot trials also have less variable soil and climatic conditions and results are obtainable in a shorter time than with field trials.

A pot trial was also conducted on a more fertile, Mount Ainslie (A.C.T.) red earth. This was conducted to study the influence of only nitrogen and phosphorus on growth, since these two plant nutrients have been most important in the growth of Pinus in Australia.

CHAPTER I.

AIMS OF THE PROJECT

There were four major aims of this project. These are considered in turn below.

1.1 Deficiencies in Current Knowledge

Little attention has been devoted to the nutrition of *P. caribaea*, especially to the different provenances. Thus, one aspect of the project was to study growth rate, distribution of growth between different parts of the seedling and nutrient uptake with four provenances on four red earths under various fertiliser regimes.

1.2 Genotype x Environment Interaction

Forestry is rapidly becoming more intensive in the U.S.A. to help overcome the high land costs (Pritchett and Goddard, 1967). The same pattern is occurring in Australia, and thus genotype x environment interactions which could be used to economic advantage will help reduce the problem of high land costs. Bevege and Simpson (1973) have demonstrated *P. caribaea* provenance x environment interactions in a factorial pot trial testing for interactions between two soil types, two endophytes, three provenances and nine fertilisers. One aim of the Darwin experiment was to demonstrate similar interactions on red earths under different environmental conditions.

1.3 Growth with Fertilisers

Pinus caribaea, as demonstrated in the nutrition review of that species is an extremely efficient species that can grow on nutritionally poor soils, and also respond to fertilisers. Many of the Forest Services of the less well developed countries do not fertilise their plantations. Thus, a major aim of this trial was to demonstrate that *P. caribaea* is responsive to fertilisers.

In Australia, soil nutrient deficiencies often limit growth, and thus fertilisation is necessary. It is important to find the best fertiliser regime to apply to a given species on a given soil type. This is especially so in the Northern Territory, since fertiliser application at planting should produce enough growth to allow the young tree to survive through its first dry season. By using the correct fertilisers survival chances will be increased. Thus, a major aim of the Darwin trial was to find the optimum fertiliser regime for seedlings on each of the three red earths.

Bevege and Simpson (1973) have demonstrated that three different provenances of *P. caribaea* exhibit different deficiencies and sensitivities. These two factors were also looked for with the three provenances used in this trial since if a provenance was sensitive to a particular nutrient, money and effort would be lost. Similarly, if a provenance showed a deficiency in a particular nutrient, more fertiliser should be applied to that provenance.

Burley, Awan and Frias (1971) and Humphreys (1972) have noted that phosphorus x nitrogen interactions occur with *P. caribaea*. Travers (1965), Beck (1970) and Waring (1973) have demonstrated this interaction with *Pinus radiata*. This interaction was studied on four different red earths to see whether the interaction occurred with *P. caribaea* on these soils or whether deficiency of other nutrients limited the interaction.

1.4 Response of *P. caribaea* on Different Red Earths

The Point Blaze topsoil was studied with the aim of establishing the optimum fertiliser regime on this soil, since this information would be useful in determining the fertiliser regime(s) to be used for a field trial. One minor aim of including the Three Ways soil was to examine the trace element response since there is a possible zinc deficiency on this soil.

The Ainslie soil was included to compare growth responses of the infertile Darwin soils with a soil of higher fertility.

CHAPTER 2.

PINUS CARIBAEA : TAXONOMY, NATIVE RANGE, AS AN EXOTIC, ADVANTAGES AND DISADVANTAGES.

2.1 General Introduction

P. caribaea is becoming increasingly important as a plantation species. There are obvious reasons for this, as outlined by Slee and Nikles (1968). They suggest that *P. caribaea* combines all the major attributes of successful exotic species as given by Jacobs (1964). These include having the ability to colonise bare ground without shelter, having a multi-nodal branching habit and indefinite shoots, having strong apical dominance, having adequate available seed supplies, having the ability to be grown in the forest nursery in one season, having resistance to fire, and finally having the capability of rapid early growth.

Zobel (1972) considers another reason why pines such as *Pinus caribaea* are becoming important in the tropics and subtropics is the lack of general utility of native conifers. This applies to Queensland with *Araucaria cunninghamii* and in the Northern Territory with *Callitris intratropica*.

2.2 Taxonomy

2.2.1 Varieties

Barrett and Golfari (1962) studied *P. caribaea* morphologically and ecologically over its whole natural range. They observed differences within the species in its manner of growth, size, shape of seeds and ecological requirements. From these differences they divided the species into three varieties corresponding to three geographically distinct zones of origin. The three varieties are *Pinus caribaea* var. *caribaea* Barr. and Golf. which is localised in Cuba, *Pinus caribaea* M. var. *bahamensis* Barr. and Golf. from the Bahamas Islands, and *Pinus caribaea* var. *hondurensis* Barr. and Golf. localised in Central America. Greaves and Kemp (1977) note that *P. caribaea* var. *caribaea* is the slowest growing and *P. caribaea* var. *hondurensis* is the fastest growing in international trials to date.

2.2.2 Provenances

Provenance in forestry refers to the population of trees which are growing at a particular place of origin (Callaham, 1964). According to Greaves and Kemp (1977), sixteen provenances of *P. caribaea* var. *hondurensis* are being studied in the International Provenance trials throughout the world and already large differences in growth between the provenances have been demonstrated.

2.3 Native Range

P. caribaea has a large and discontinuous distribution (map 1) (Lamb, 1973). The present geographical range of the species lies between 12° 13' N latitude near Bluefields on the east coast of Nicaragua and 27° 25' N latitude in the Grand Bahama and Great Abago (Lamb, 1973). The range for *P. caribaea* var. *hondurensis* is from 12-18^{O} N (Salazar and Albertin, 1973). The longitudinal range of the species is from 71^{O} 40' to 89^{O} 25' W.

Considering only *P. caribaea* var. *hondurensis*, the altitudinal range is from sea level to 1000 metres in Belize (formerly known as British Honduras) and to somewhat lower altitudes in Honduras and Nicaragua (Lamb, 1973). Throughout its range *P. caribaea* grows in a summer rainfall, winter dry season which is free from frost and is warm and humid for most of the year. On the mainland in Belize the climate is more variable and less equable except on the coast. The range in temperature in inland districts is from 5^{O}C to 37^{O}C. In coastal districts the temperature rarely falls below 15.6^{O}C or rises above 32.3^{O}C (Lamb, 1973).

On the mainland, *P. caribaea* var. *hondurensis* grows on different soils to the other two varieties. In Belize the pine either grows on the relatively flat coast, which has alluvial sandy soils which are leached, acid and very infertile, or on soils in the mountains which are granitic, well drained and deep (McWilliam, 1955). Lamb (1973) comments that on the inland sites, *P. caribaea* var. *hondurensis* can be found on a wide range of parent materials, including granites, schists and shales. These soils are acid, (pH 5-5.5), loam to sandy loam and well drained.

According to Lamb, the distribution is not entirely defined by soil type or climate and varies along its borders, where the pine is in competition with hardwoods, according to the incidence of hurricanes, fires and human interference.

2.4 *PINUS CARIBAEA* in the Northern Territory

2.4.1 Climatic Differences from the Native Range

P. caribaea has been successfully introduced into the Northern Territory under a monsoonal rainfall of 1300 to 1500 mm per year. This is a similar rainfall to that of Mount Pine Ridge, but markedly less than Brus Lagoon which receives 2600 mm (Lamb, 1973) (map 1). Most inland stands of the Honduras Republic and Nicaragua have rainfall levels similar to the Northern Territory. The differences in rainfall patterns between the native range and the Northern Territory appear to be:

(i) the dry season in the Northern Territory extends for five to six months. These conditions are more severe than in the natural habitat of the species.

(ii) the rainfall distribution in the pines' native range is also markedly seasonal. However, it often has a tendency to be bimodal in distribution.

(iii) the wet season in the Northern Territory is wetter than the wet season in Belize (Cameron and Craciun,

1972).

Slight differences between the Northern Territory and the native range of *P. caribaea* also occur with respect to the temperature. Golfari (1963) gives the annual mean temperature for *P. caribaea* in its native range as 24.5° to 26°C. The annual mean temperature in the Darwin region is 26.7°C. The difference in the mean temperature between the hottest and coldest month in the natural range of *P. caribaea* is 6°C (Golfari, 1963). In the Northern Territory it is only 4°C.

Thus the Northern Territory has longer dry season, wetter wet season and higher temperatures. It can only be described as a harsher environment for growth of *Pinus caribaea*.

2.4.2 Performance

By 1972, after two years growth in trial plots on red earths and sandy colluvial soils, height increments for *P. caribaea* averaged one metre per year (Cameron and Craciun, 1972). Height increments of almost two metres a year have been obtained by some provenances in an International Provenance trial at Three Ways, Melville Island at age 3 1/2 years (map 2) (Craciun, 1977a).

It was originally expected that provenances from lower altitudes and the driest climates would be best suited to

Northern Territory conditions (Craciun, 1977b). However, provenances from wetter environments have demonstrated superior adaptability on the better central Melville Island sites. Craciun (1977b) suggests the long dry season is misleading when selecting the ideal provenance, since the deep red loam soils possess a very good moisture storage with a good upward capillary movement from the 7 to 10 metre deep water table. He suggests that the extreme wet periods and intense rainfall which occur during the peak wet months, constitute at least as difficult a period for the pines as the extended dry season.

2.4.3 Importance and Potential of, and Problems with the Species *P. caribaea*

The best way to demonstrate the importance of *P. caribaea* is to look at the alternatives available. *Callitris* is extremely slow growing and non-responsive to fertiliser application. It has a mean annual volume increment of $4m^3\ ha^{-1}$ (Craciun, 1977a). This combined with the fact that indigenous forests have low volumes and high internal defect makes it obvious that an exotic species is needed for the Northern Territory (Craciun, 1977a). Establishment of *P. caribaea* is very important, since the Northern Territory must now import virtually all its timber requirements.

Most land suited to the establishment of softwood plantations occurs on aboriginal reserves. In the future this might be used to advantage, since forestry plantations on these reserves would created needed employment for aboriginals.

Also, by growing *P. caribaea* provenances in the Northern Territory, the genes of different provenances are conserved. This is important, since according to Kemp (1974) some of the provenances are in danger of extinction due to extensive and frequent logging.

However, many factors are limiting the potential of *P. caribaea* in the Territory. These include poor soil types, the occurrence of only small patches of good quality land, nutritional problems and termites. One factor that may save forestry in the Northern Territory, and one I will not dwell on, relates to seed. Seed production in Malaysia is difficult due to environmental and nutritional problems. Seed production could bring money and employment to the Northern Territory, and the large haulage costs with wood production will be reduced.

2.5 Advantages of *P. caribaea*

P. caribaea has many favourable characteristics. The species has advantages through the whole forestry rotation from establishment until the wood is marketed.

Advantages at establishment include: the seed is more easily obtained in quantity than that of most other lowland tropical pines, is easily germinated, and the rapid early growth reduces establishment costs (Lamb, 1973). The species has the ability to grow on hot, dry infertile sites, is easy to handle in the nursery, and in Malaysia competes with lalang (*Imperata cylindrica*) (Freezaillah, 1966). The species also adapts as an exotic over a wide range of latitudes and edaphic situations (Slee and Nikles, 1968). *P. caribaea* has advantages in tree form with continual production of side branches reducing weakness associated with large branches (Lamb, 1973). It has a self-pruning habit and generally light, horizontal branches (Haynes, 1973). It also has great resistance to fire. On suitable sites it can achieve a mean annual increment of 21 to 28 m^3ha^{-1} up to the thirtieth year, which is comparable to *P. radiata* in Australia and New Zealand. Form of the species can be rapidly improved by vigorous selection. Finally, the species produces a strong timber for constructional purposes (Lamb, 1973).

2.6 Disadvantages of *P. Caribaea*

Lamb (1973) considers many disadvantages of growing *P. caribaea*. It does not produce seed in any quantity when grown in a climate where the winter atmosphere is moist, is less tolerant of frost and waterlogging than *P. elliottii*, does not survive well as open rooted planting stock, stem form is usually variable on fertile moist sites and termites can be a problem. Finally, the species does not produce as good a pulp as temperate pines.

NUTRITION OF *PINUS CARIBAEA*

3.1 Response of *P. caribaea* to Fertilisation

3.1.1 Factors and Cautions Relating to Fertilisation

Lamb (1973) considered the factors enumerated by Maki (1966) and applied these to *P. caribaea*. He suggests that it is essential to know that soil aeration and texture permit sufficient rooting depth and moisture retention so that the trees can make use of the added nutrients. Fertilisation can increase the risk of disease in pine plantations if it upsets the optimum balance of nutrients. Also, lack of humus and colloids in some deep sandy soils may prevent the retention of artificial fertilisers for periods long enough to permit absorption by trees.

3.1.2 Response to Phosphorus

P. caribaea appears to be more responsive to phosphorus than to any other nutrient. This has been demonstrated in two glasshouse trials. Bevege and Simpson (1973) conducted an omission trial testing for deficiencies of phosphorus, nitrogen, potassium, calcium, magnesium and trace elements on ridge and swamp soils at Kennedy in Queensland. At 18 months the heights for the "minus phosphorus" treatments were similar to the controls (nil fertiliser application).

Platteborze (1972) obtained a 155% increase in mean height when phosphorus was applied to the surface soil at Rantau Panjang plantation in Malaysia. There was no obvious response to any of the twelve other elements tested.

Lim and Sundralingham (1974) established a field trial using six year old *P. caribaea* on a Durian soil. The soil was fertilised with phosphorus, nitrogen and boron. Results after three years showed a highly significant growth response to phosphorus which was further enhanced by the addition of nitrogen. The reason they suggest for the large response to phosphorus is enhanced development of ectomycorrhizal pine roots.

Site index influences the response to phosphorus. At Byfield, in Queensland, fifteen year old *P. caribaea* responded strongly to rock phosphate applied at 250, 500 and 750 $kgha^{-1}$ where the site indices were 22.8 and 25.8 metres, responded less where the site index was 28.9 and not at all where the indices were between 31.9 and 41.0 (Anon., 1970, 1972). On the less fertile sites the 500 $kgha^{-1}$ dressing was economically worthwhile and the response to the 750 $kgha^{-1}$ dressing was probably economically worthwhile.

Platteborze, Chong Sen and Sundralingham (1971) studied ten 0.104 hectare plots of *P. caribaea* at different sites in

Malaysia. They observed a significant correlation between available phosphorus in the soil and growth rate, the relationship being hyperbolic in form. They did not find a significant correlation with nitrogen or potassium.

3.1.3 Response to Nitrogen

Waring (1969) argues that nitrogen and phosphorus should be added together, since not only are large production gains possible in the current rotation, but as the equilibrium point of the soil organic matter is raised, the present trend towards a reduction in fertility can be reversed. The application of nitrogen on lowland tropical sites with a pronounced dry season is considered to be potentially harmful. Nitrogen application sometimes increases growth during the wet season, when abundant water supplies are available, but thereafter leads to reduced growth or even mortality the following dry season (Ojo and Jackson, 1973).

Bevege and Simpson (1973a) noted all three varieties of *P. caribaea,* and also *P. elliottii,* responded to nitrogen in the presence of superphosphate on a podzol at Gregory, Queensland. However on a low humic gley at Beerburrum, varieties *hondurensis, caribaea,* and hybrids between varieties of *P. caribaea* and *P. elliottii* did not respond to nitrogen fertilisation in the presence of superphosphate. Bevege and Simpson (1973a) consider the differential response is due to the low initial nitrogen status of the Gregory soil.

Richards and From (1965) studied the effect of ammonium nitrate and lime on the early growth of *P. caribaea* in a glasshouse trial. High soil nitrate depressed the yield of roots and shoots in the early stages of the trial, but this effect was outgrown between 20 and 31 weeks, except for the lime and NH_4NO_3 treatment which still depressed growth at 31 weeks after sowing. Richards (1961) also noted this reduction in early yield with high levels of available nitrogen with *P. taeda*. However, this depressive effect was also overcome with time.

3.1.4 <u>Interactions</u>

(i) <u>Nitrogen x Phosphorus</u>

Humphreys (1972) observed a field factorial trial on a ferruginous latosol in Fiji. Phosphorus, urea, trace elements and magnesium sulphate had been applied. There was a marked nitrogen x phosphorus interaction for *P. caribaea*. Burley, Awan and Frias (1971) also observed the nitrogen x phosphorus interaction with *P. caribaea* var. *caribaea* in Cuba thirty seven months after fertilisers were applied at 50 $kgha^{-1}$ for each fertiliser. These nitrogen x phosphorus interactions with *P. caribaea* are in conformity with the genus *Pinus*, since Travers (1965) and Beck (1970) have obtained interactions with *P. radiata* and Richards (1959) established this interaction with *P. taeda*.

(ii) Nitrogen x Sulphur

The nitrogen x sulphur interaction occurs with *P. caribaea* in glasshouse trials on red earths in the Northern Territory when phosphorus has been applied as a basal dressing and was therefore not limiting growth (Cameron, pers. comm.). Bevege (1973) notes that the possibility exists of a nitrogen x sulphur interaction in Fiji, since sulphur content is low in some areas, particularly where nitrogen is low.

3.2 Foliar Nutrient Levels and Requirements

Bevege (1977) has compared productivity and foliar levels of 18-20 year old *P. elliottii* (P.E.E.) and *P. caribaea* (P.C.H.) on a range of sites at Toolara, Queensland. He noted that foliar nutrient levels are generally lower with P.C.H. than P.E.E. on the same site. This suggests either P.C.H. is less demanding nutritionally than P.E.E., or that the continuous growth of P.C.H. requires transport of nutrients from mature to developing foliage. The foliar levels of nitrogen ranged from 0.57% to 1.28% for P.E.E. and 0.57% to 1.05% for P.C.H. Foliar levels for phosphorus ranged from 0.051% to 0.124% for P.E.E. and 0.041% to 0.086% for P.C.H. Foliar levels for calcium, magnesium, copper, zinc, boron, manganese, and sulphate - sulphur were generally lower in P.C.H. on all sites. However, for potassium, P.C.H. has higher concentrations than P.E.E. in five out of six cases.

Humphreys (1972) also compared the foliar concentrations of *P. elliottii* and *P. caribaea* in the field. This was done in the Nausori Highlands in Fiji with trees four years old. *P. caribaea* had lower foliar concentrations of nitrogen, phosphorus and potassium, slightly higher concentrations for calcium, and higher concentrations for magnesium. The results for potassium and magnesium are opposite to those obtained by Bevege (1977).

Iyambo (1973) has carried out a chemical analysis of *P. caribaea* trees on a basaltic soil in Nigeria. He analysed the roots, stems and needles for nitrogen, phosphorus, potassium, sodium, megnesium and calcium. The contents of the needles were higher than the stems and roots in every case. The level of nitrogen in the foliage was 0.74% which is similar to levels found by Bevege (1977). However, Iyambo (1973) observed extremely high phosphorus values in the foliage of 0.41%. He commented that this high level of phosphorus would improve nitrogen uptake.

Bonneau (1973) has divided species into three groups in terms of optimum foliar composition.

(i) conifers with needles low in mineral elements such as *Pinus elliottii, P. pinaster* and *P. taeda.* 1.2-1.5% N, 0.10-0.11% P.

(ii) conifers with medium-rich needles such as *Pinus radiata, Picea abies* and several deciduous species.

(iii) Some conferous and deciduous species whose foliar system is rich in mineral elements.

> 2.0% N, 0.24% P.

Neglecting the case of Iyambo (1973), *P. caribaea* obviously fits into group (i) with *Pinus elliottii, P. pinaster* and *P. taeda.*

Pinus caribaea tends to be more tolerant of low phosphorus conditions than *P. elliottü,* and thus the critical level is lower (Bevege, 1973). The critical foliar level for *P. caribaea* is in the range 0.065 - 0.070% on most sites (Anon, 1975). The levels for *P. elliottii* and *P. taeda* are 0.081 and 0.098% respectively.

Freezaillah (1966) states that *P. caribaea* is not demanding on the nutrient status of the soil. Indeed, good growth of the order of $14m^3ha^{-1}$ can be obtained on relatively poor soils if rooting depth is sufficient.

Further evidence for the low nutritional requirements of this species, apart from the low levels of nutrients in the foliage considered earlier, has been given by Mullin (pers. comm.). In Rhodesia the species has been planted on infertile, shallow, gravelly soils derived from granite. The growth has been excellent, with trees averaging 11 metres by six years. Indeed the poorer sites have been chosen since *P. caribaea* outgrows every other pine on these sites.

3.3 Influence of Soil Nutrient Status on Development of Vertical Roots

Freezaillah (1966) has stressed the importance of rooting depth for *P. caribaea*. He studied rooting patterns (depth of rooting in particular) on three different soil types in Malaysia. Freezaillah and Sandrasegaran (1969) have observed that nutrient status of the soil influences depth of rooting of *P. caribaea*. They studied seven different soil types in Malaysia and found the verticial roots of *P. caribaea* developed deepest in soils richest in phosphorus. Sites with higher phosphorus status also had a larger root volume.

3.4 Mycorrhizae

Raets (1962) used two different nursery soils having similar chemical composition and physical properties.

On the La Mucuy (Mexico) soil the pines grew successfully, yet on the Merida soil they did not. He thus used nursery plants transplated into the two soils and also a third soil composed of the Merida soil with a small amount of the La Mucuy soil. He observed significant differences as to height growth, weight increment, mycorrhizal development and colour of the plants, in favour of the La Mucuy soil and the mixture. He concluded that the differences between the soils were due to mycorrhizae.

An inverse relationship has been found between total nitrogen content of the seedling roots and mycorrhizal percentage (Fowells and Krauss, 1959 and Dumbroff, 1968). Richards and Wilson (1963) observed this trend with *Pinus caribaea* in a glasshouse trial. Mycorrhizal development was reduced by increasing the level of soil nitrate, either by adding ammonium nitrate or by liming. However Anthony (1971) did not observe this trend with *P. caribaea* in a pot trial in Malaysia.

High levels of nutrition affect the development of mycorrhizae on *P. caribaea*. Richards and Wilson (1963) have observed that with the addition of sodium dihydrogen phosphate the percentage of nitrogen in the roots was lowered, and mycorrhizal development increased. Anthony (1971) observed that his "good" fertiliser treatments had better mycorrhizal development, and that "poor" seedlings had sparsely developed mycorrhizae.

3.5 Influence of Nutrition on Dieback

Dieback occurs with *P. caribaea* in the lowland tropical countries and particularly in Malaysia (Slee, 1977). Affected stems exhibit an absence of foliage on some shoots where the needles fail to penetrate the fascicle sheath. The needleless lengths may extend for several metres, and the affected stems frequently dieback and malformation in the form of forks or basket whorls results.

Slee considers the symptoms so widespread as to indicate major climatic controls as the cause of dieback. However, he considers the effect may be modified by edaphic conditions or rainfall patterns.

Many authors have suggested nutritional factors as a cause of dieback with *P. radiata* and *P. caribaea* (Proctor, 1967; Gentle, 1970; and Waring, 1971). Waring (1971) studied disorders of *P. caribaea* throughout Malaysia. The trees had normal form on several degraded sites, but in Western Malaysian plantations, on cleared high sites particularly, multiple leaders, crooked stems, foxtails and leading shoots were common. He suggested this could be due to deficiencies in major elements or trace elements such as boron. Proctor (1967), Gentle (1970) and Snowdon (1973) all observed correlations between boron deficiency and dieback in *P. radiata*.

3.6 Conclusions

P. caribaea seems to be an extremely efficient species. Information on this subject is sparse, but I will tie relevant information together.

(i) Bevege (1977) has shown that the species is either less demanding nutritionally than *P. elliottii* or that the growth of *Pinus caribaea* throughout the year involves transport of nutrients from mature developing foliage.

(ii) *Pinus caribaea* compares favourably to *P. radiata* in terms of wood production (Van Altena, 1971).

(iii) it can grow faster than most species on poor soils (Mullin, pers. comm.).

CHAPTER 4.

GENOTYPE X NUTRITION

4.1 Increasing Forest Productivity

There are only two main factors that limit forest productivity. These are quality of the environment and the genetic potential of the trees (Davey, 1967). In Australia, soil nutrient deficiencies often limit growth of pine plantations (Forrest and Ovington, 1971). It is thus necessary to fertilise deficient plantations. It is also important to find provenances that respond to these fertilisers.

4.2 Reasons for Differing Abilities of Genotypes to Respond to Fertilisation

4.2.1 Differences in Uptake

Nutrients move from the soil across the root boundary to the interior of the root and eventually to the upper portion of the tree (Voigt, 1967). Genetic, environmental and physiological components are all involved in this ion uptake process. The genetic component will be considered in this review.

Differences between genotypes in terms of uptake are influenced by many factors. These include lateral roots (Russell and Sanderson, 1967; Bowen and Rovira, 1970); thickness of root and amount of root hair (Nye, 1966); root size (Giertych and Fober, 1967); area of root absorbing surfaces (Nye and Foster, 1958; Forrest, 1969); root cation exchange capacity (McLean, Adams and Franklin, 1956; Snaydon and Bradshaw, 1961); differences in ability to lower the free energy of phosphorus (Nye and Foster, 1958); carrier systems (Noggle and Fried, 1960; Snaydon and Bradshaw, 1962; Voigt, 1967) and growth influence on uptake (Van den Driessche and Wareing, 1966).

4.2.2. Differences in Efficiency of Translocation and Utilisation

Specht and Groves (1966) have noted the success of indigenous heath species on phosphorus deficient soils may be due to their enhanced ability to efficiently redistribute phosphorus and other elements already within the plant. Foy and Barber (1958), Schauble and Barber (1958) and Clark (1975) have all considered the efficiency of translocation of magnesium in different maize *(Zea mays L)* inbreds. Clark (1975) concludes that magnesium was not being as efficiently translocated to the leaves in Oh 40 B as in other inbreds, and that the controlling mechanism appeared to be in the root.

Variation in efficiency of nitrogen utilisation has been noted by Vose (1962), Walker and Hatcher (1965) and

Giertych and Fober (1967). Giertych and Fober (1967) studied twenty Polish provenances of *Picea abies* and found the better growing provenances were more economical nitrogen users. Vose (1962) considered the relative efficiency of three strains of ryegrass with regard to nitrogen utilisation. He noted that strain A was more efficient, being able to accumulate the greatest amount of dry matter with the nutrients available.

Rees and Hassouna (1964) have shown differences in the efficiency of phosphorus, potassium and iron utilisation between inbred and hybrid F1 rye families. Shea, Gerloff and Gabelman (1968) have also observed differences in efficiency of potassium utilisation in strains of snapbeans *(Phaseolus vulgaris)*.

4.2.3 Conclusions

As a consequence of the above factors, namely differences in uptake, translocation and utilisation, different provenances and other genotypes growing in the same environment exhibit different concentrations of nutrients in the foliage. This phenomenon has been observed at the species level (Beaton et al., 1965; and Van den Driessche and Wareing, 1966), at the variety level (Munns, Johnson and Jacobson, 1963), at the provenance level (Steinbeck, 1966; Giertych and Fober, 1967; and

Van den Driessche, 1973), at the clonal level (Curlin, 1967) and finally for control pollinated progenies (Jahromi, Goddard and Smith, 1976).

Also, as a consequence of variations in uptake, translocation and utilisation, genotypes vary in susceptibility to nutrient deficiencies. Millikan (1953), Fielding and Bowen (1961), Wall and Andrus (1962), Epstein and Jeffries (1964) and Bevege and Simpson (1973) have all noted variations in susceptibility to deficiencies between genotypes.

Finally, differences in uptake, translocation and utilisation result in plants having different requirements for nutrients. This allows the genotype x environment interaction to occur. This is considered below.

4.3 Genotype x Environment Interaction

The variation between genotypes in their response to different environmental conditions is called the genotype x environment interaction (Shelbourne, 1972). Interaction exists if genotype A performs better than genotype B in one environment, but B outperforms A in another environment (Wright, 1973).

4.3.1. Interactions in Terms of Yield

(i) Genotype x Nitrogen Interaction

Curlin (1967) propagated 22 *Populus deltoides* clones from cuttings and grew these under fertilised and unfertilised conditions. He obtained a strong clone x nitrogen fertiliser interaction in terms of height, diameter and volume growth.

(ii) Genotype x Phosphorus Interaction

Goddard, Zobel and Hollis (1976) obtained this interaction with *Pinus elliottii* in a glasshouse trial. They conducted the study to gain some insight into mechanisms by which some families take greater advantage of added phosphorus than others. They suggest that there are inherent factors that influence the transport and utilisation of phosphorus, and size and extent of absorptive root surfaces. They suggest these factors could be responsible for differing responses to phosphorus fertilisers in the field.

(iii) Genotype x Nitrogen x Phosphorus Interaction

Posey (1964) has observed that even individual trees within a species may react differentially to a given fertiliser. Using *Pinus taeda* as the test species, he observed that the "average" tree receiving nitrogen or a nitrogen-phosphorus regime, responded with an increase in growth, decrease in specific gravity and decrease in tracheid length. However, of the 120 trees sampled from plots receiving nitrogen, 30 trees failed to follow the average tree pattern of response.

Jahromi et al. (1976), using control pollinated *Pinus elliottii* on a phosphorus deficient soil under four fertilisation treaments (nil fertiliser, phosphorus only, nitrogen only and nitrogen and phosphorus together) observed a genotype x fertiliser interaction. However, the effects of the fertiliser treatments were stronger than the genetic effects on this soil.

Bevege (1977) has studied the species/variety x fertiliser interaction with the three varieties of *Pinus caribaea* and *Pinus elliottii* on a lateritic podzolic and a ground water podzol at Bingera, Queensland. *P. caribaea* responded best in terms of height, to the nitrogen x phosphorus fertiliser regime at age 2 1/2 years on both soil types.

(iv) *P. caribaea* Provenence x Fertiliser Interaction

Bevege and Simpson (1973) have conducted a pot trial designed as a factorial testing three provenances of *P. caribaea*, mycorrhizal inoculation with *Boletus* or *Rhizopogon* and an omission layout of nutrients involving nine fertilizer treatments on granite derived ridge and swamp soils from Cardwell, Queensland. They obtained a soil x provenance x nutrition interaction significant at the 0.01 probability level and a provenance x nutrition interaction significant at the 0.05 level. They interpreted this interaction as indicating that different provenances exhibit different deficiencies and sensitivities and react differently on different soils. Nikles (pers. comm.) also studied the *P. caribaea* provenance x environment interaction, but in the field. He studied a Cardwell ridge soil and a Kennedy swamp soil, using four fertiliser regimes. Over all sites, fertilisers, and provenances, he obtained a provenance x fertiliser interaction significant at the 0.01 probability level in terms of current height increment.

4.3.2 Interactions in Terms of Nutrient Concentration in the Foliage

Jahromi et al. (1976), apart from observing a slash pine cross *(Pinus elliottii)* x fertiliser interaction in terms of height, top dry weight and needle dry weight in a 16 month long pot trial, also observed this interaction in total accumulation of nitrogen and phosphorus in the whole seedlings and in the distribution of these elements into the plant portions. Also, Walker and Hatcher (1965) obtained a progeny x fertiliser interaction with *Pinus elliottii* for nitrogen and phosphorus concentration in the needles.

4.3.3 Genotype x Mycorrhizae Interaction

There is evidence that differences in seedling vigour may be brought about by inoculating with different mycorrhizal inoculum (Bowen and Theodorou, 1967; Theodorou and Bowen, 1971; Lamb and Richards, 1971; and Bevege and Simpson, 1973). Lamb and Richards (1971) inoculated *P. elliottii* and *P. radiata* with eight species of mycorrhizae in a glasshouse trial. The eight species of mycorrhizae differed in their effectiveness with respect to nutrient uptake and yield of the plant, and the species differed in effectiveness with the two pines. Bevege (1977), in a pot trial testing three provenances of *P. caribaea* with two endophytes on two soils from Cardwell (ridge and swamp), observed a significant provenance x endophyte interaction in terms of shoot dry weight and a significant soil x provenance x endophyte interaction in the same unit of measure as well as root to shoot ratio.

4.3.4 Genotype x Soil Interaction

Both Bevege and Simpson (1973) and Nikles (pers. comm.) have obtained provenance x site interactions, in terms of height increment, with *P. caribaea* provenances. The former used a pot trial, whereas the latter used a field trial. However, they both used swamp and ridge soils in their studies. Zobel and Roberds (1970) mention a glasshouse experiment using two control pollinated seed lots of *Pinus taeda*. The two crosses showed strong differences when grown on sandy versus clayey soils. They consider this points to the potential of obtaining greater production by putting both the soil and fertiliser - responsive select trees in the proper environment.

4.4 Selection of Genotypes

4.4.1 Reasons for Selection

Trials evaluating the genotype x environment interaction allow a better consideration of the trees to be evaluated for breeding programmes (Bevege and Simpson, 1973). These trials also ensure that management decisions about what to plant, where to plant it, and how to grow it are made with a sound appreciation of the tree/site variables and interactions involved.

Forrest and Ovington (1971) consider there should be selection, as parents of future tree crops, of trees of high growth rates and efficient utilisation of the available nutrients on the deficient soils of Australia. Selection of provenances along these lines before selection of individual trees will give *P. caribaea* tree breeders in the future an opportunity to improve form and growth with provenances that have already been shown to respond to fertilisers.

4.4.2 Choice of Genotypes

In regard to nutritional responses, the ideal genotype is one capable of sustaining growth at a low fertiliser level which also responds to high substrate nutrient levels (Jahromi et al., 1976). Indeed, Nikles (pers. comm.), with *P. caribaea* International Provenance trials, has studied provenances at high and low levels of nutrition. If forest fertilisation practices change in the near future, and this could happen as food crops receive high priority, then he will have provenances at hand immediately that grow well without fertilisers.

4.4.3 Benefits and Constraints of Genotype Selection for Nutrient Response

Selection of trees which respond to fertilisation could markedly increase the economic efficiency of fertilisation, as well as increase the already considerable value of tree improvement programmes (Davey, 1967). Selection of provenances, for response to fertilisers before individual tree selection, would undoubtedly increase the value of tree improvement programmes.

However, there are constraints. Selection of trees responsive to fertiliser and not trees that grow well at low levels could be a dangerous practice. This is so since labour and ground preparation machinery are expensive, interest rates are high, and fertilisers and machinery represent very high energy costs (Bevege, 1977). Most of the genotype x nutrition interactions have been with young trees (Zobel and Roberds, 1970). They question whether these interactions will be observed at harvest time. They suggest care needs to be taken that response alone is not the sole criterion. Total performance, with or without fertilisers, is of ultimate importance.

CHAPTER 5.

RED EARTHS

5.1 Distribution, Physical and Chemical Properties

Red earths are widely distributed over the greater part of the continent north of an arc running from south-east N.S.W., through Oodnadatta in South Australia to near Geraldton in Western Australia (Stace, Hubble, Brewer, Northcote, Sleeman, Mulcahy and Hallsworth, 1968).

Red earths have gradational profiles that are not calcareous throughout and B horizons have an earthy fabric and are whole coloured red (Northcote, Hubble, Isbell and Thompson, 1975). They have weak profile differentiation with gradual or diffuse horizon boundaries except for the darker A1 horizon. They have deep profiles ranging from 0.9 metres to 6.0 metres, with clay content increasing with depth (Stace *et al.*, 1968).

Red earth soils occur widely throughout the Northern Territory in the rainfall range 657 mm to 1625 mm (Day and van-Cuylenburg, 1977). Day and van-Cuylenburg have divided the red earths of this range into four groups based on profile morphology. These are loamy, sandy, lateritic and duplex red earths. All these groups are deep soils (greater than 150 cms), with the exception of the lateritic group.

The fertility status of red earths is low (Stace et al., 1968; Northcote et al., 1975; Day and van-Cuylenburg, 1977). Both phosphorus and nitrogen values are low (Isbell and Smith, 1976; Day and van-Cuylenburg, 1977). Total contents of zinc and copper are also low (Day and van-Cuylenburg, 1977).

5.2 Growth of *P. Caribaea* on Red Earths

5.2.1 Influence of Texture

P. caribaea appears to be very adaptable to different soil types, since it will succeed on both loamy and sandy soils (Poynton, 1975). Viera (1967) has demonstrated that it can grow on infertile sands in Guyana. Platteborze (1971) reported on the most desirable textures for pine plantations in West Malaysia. Very suitable soils have textures heavier than sandy loams, suitable soils have sandy loam textures and marginal soils have sandy or loamy sand textures. Bevege (1977) has shown at Toolara, in Queensland, that *P. caribaea* grows best on loamy soils.

Although red earths have low chemical fertility, Isbell and Smith (1976) note that many of their properties are agronomically favourable. Day and van-Cuylenburg (1977) studied the textures of the A and B horizons of the four groups of red earths. Using Platteborze's (1971) classification, the loamy red earth topsoil appears especially suitable for pine plantations, and the topsoil of the sandy group suitable. All the B horizons of the four groups have textures heavier than or equal to sandy loams, which Platteborze states is very suitable for pine plantations. It is obvious that red earths possess the physical characteristics to support growth of *P. caribaea*.

5.2.2 Influence of Drainage

Hunt (1960) (quoted from Humphreys, 1972) has noted that in the native range of *P. caribaea*, the variety grows best on well drained, well watered locations. Platteborze (1972) placed great importance on soil internal drainage for his soil classification in Malaysia. Very suitable soils (class A) are well drained whereas unsuitable soils (class C) are excessively drained or have imperfect drainage.

Slager and Schulz (1969) also considered drainage in their soil classification for *Pinus caribaea* in Surinam. Freezaillah and Sandrasegaran (1969) observed with free draining soils in Malaysia the depth of rooting varied between 2.2 and 3.3 metres. High water tables, soil compaction and low nutrient status inhibited development of vertically growing roots.

Red earths are well drained. This is to be expected since these soils are red, indicating that iron is not as hydrated as with yellow soils. Isbell and Smith (1976) have noted this with Queensland red earths, and Cameron and Craciun (1972) and Day and van-Cuylenburg (1977) have observed this with Northern Territory red earths.

5.2.3 Influence of Depth

Platteborze (1972) placed great importance on soil depth in his soil suitability scheme for *P. caribaea*. Soils deeper than 0.9 metres are very suitable for this species. Effective soil depths between 0.6 and 0.9 metres are only marginal for pine development. Freezaillah (1966) also considers the importance of soil depth for *P. caribaea*. He has observed that the variety will produce large wood volumes even on marginal soils, provided the soils are sufficiently deep.

Red earths are usually deep soils and Isbell and Smith (1976) observed the North Queensland red earths ranged from 3 to 6 metres in depth, while in the Northern Territory Day and van-Cuylenburg (1977) have noted that three of the four groups are deeper than 1.5 metres. Thus these red earths are deeper than the 0.9 metres which Platteborze (1972) notes is very suitable for this species. Red earths also have very low stone contents (Day and van-Cuylenburg, 1977).

5.2.4 Influence of Fertility.

Platteborze (1972), in his soil suitability classification for *P. caribaea*, did not mention soil nutrient deficiencies since they could be corrected by fertilisers. In the review of *P. caribaea* nutrition it has been explained that this species is a very low nutrient demander so the low fertility of red earths referred to earlier would not necessarily hinder the growth of *P. caribaea* to the degree it would hinder other species.

5.2.5 Influence of Sesquioxide levels

Hunt (1960) notes that *P. caribaea* in Belize grows best on pink-red colluvial type soils derived from granite, slate and quartzite. Humphreys (1972) adds that this provenance grows best on a soil at least partly derived from igneous rocks and reasonably high in sesquioxides. Indeed, red earths are dominated by sesquioxides (Stace et al., 1968).

5.2.6 Influence of Moisture Retention

Day and van-Cuylenburg (1971) studied the moisture retention of the four groups of red earths in the Northern Territory. The sandy and lateritic red earths retained less than the loamy red earth group, and the duplex group retained least. Considering the deep nature of these soils and the strong annual recharge, there is a large supply of plant available moisture for deeper rooting species such as *P. caribaea*.

5.3 Limitations of Red Earths

(i) Low nutrient levels.

(ii) Phosphorus fixation (This will be discussed in my experimental work).

(iii) Limited occurrence. Areas of good quality red earths only occur in small patches, allowing only small scale plantation projects.

(iv) High erosion susceptibility. This is especially so with the less coherent, sandy, lateritic and texture contrast red earths. (Day and van-Cuylenburg, 1977).

(v) Limited water entry. Many of the loamy red earths become hardset and crusted during dry periods, hence limiting water entry (Day and van-Cuylenburg, 1977).

5.4 Nutrition of *P. Caribaea* on Red Earths

P. caribaea has been tested on two main soil types in the Northern Territory, both in the field and in glass-house trials. These are red earths and sandy colluvial soils. The soil type with the best potential for a plantation scheme is the red earth, since *P. caribaea* has responded well to fertilisers in both glasshouse and field trials using this soil type.

The first main trial with *P. caribaea* was a glasshouse omission trial on a red earth from Three Ways. Phosphorus was the most important nutrient but nitrogen and sulphur were also important. Other glasshouse trials on red earths have followed. There have been consistent responses to phosphorus, sulphur and nitrogen and their interactions. This is different from southern plantations where the main response is to phosphorus, nitrogen and potassium.

However, in field trials on red earths the main consistent responses have been to phosphorus and nitrogen and their interaction. There has been no growth response to sulphur in the field.

5.5 The Growth of *P. Caribaea* on Red Soils Derived from Laterite

Nikles (1970) noted species x site interactions involving red earths at Beerwah, Queensland, with *P. caribaea* producing a superior economic yield compared to *P. taeda* on red earth residual soils. The reverse pattern occurred on humic soils.

Craciun (1977a) has considered the growth of different provenances of *P. caribaea* in an International Provenance trial at Three Ways, Melville Island on a red earth. The Alamicamban provenance is slightly superior to the Mount Pine Ridge and Queensland select provenances in terms of height growth. Two other authors have also observed that the Alamicamban provenance is doing well on red soils. Kaumi (1977), in Uganda, noted that the Alamicamban provenance was superior in growth to the Mount Pine Ridge provenance at age 3.4 years on a lateritic red soil of shallow depth over murram and ironstone. Vivekanaden (1977) observed this same trend on a red lateritic clay loam in Sri Lanka.

D A R W I N   T R I A L

CHAPTER 6.

INTRODUCTION

The trial was a $2^4 \times 3 \times 3$ factorial testing for interactions between sixteen fertiliser regimes, three provenances and three red earths.

6.1 Provenances

The three provenances used were the "Queensland" provenance, the Mount Pine Ridge provenance and the Alamicamban provenance.

6.1.1 Site Details of the Three Provenances

These are shown in table 6.1. The Queensland provenance was routine-collected seed obtained from a trial plot at Whitfield Creek, Queensland, established between 1952 and 1956. The seed for this trial plot was originally obtained from the Mount Pine Ridge site. This trial plot received no site preparation or fertilisation. The Mount Pine Ridge area carries a poorly stocked stand of pine, growing on grassy broken ridges covering an area of 595 square kilometres (McWilliam, 1955) (map 1). The soils are leached and low in organic matter, which is generally confined to the upper few centimetres (Lückhoff, 1964). The Mount Pine Ridge (M.P.R.) provenance in this trial was seed collected by a commercial seed firm. Daganayasi (1974)

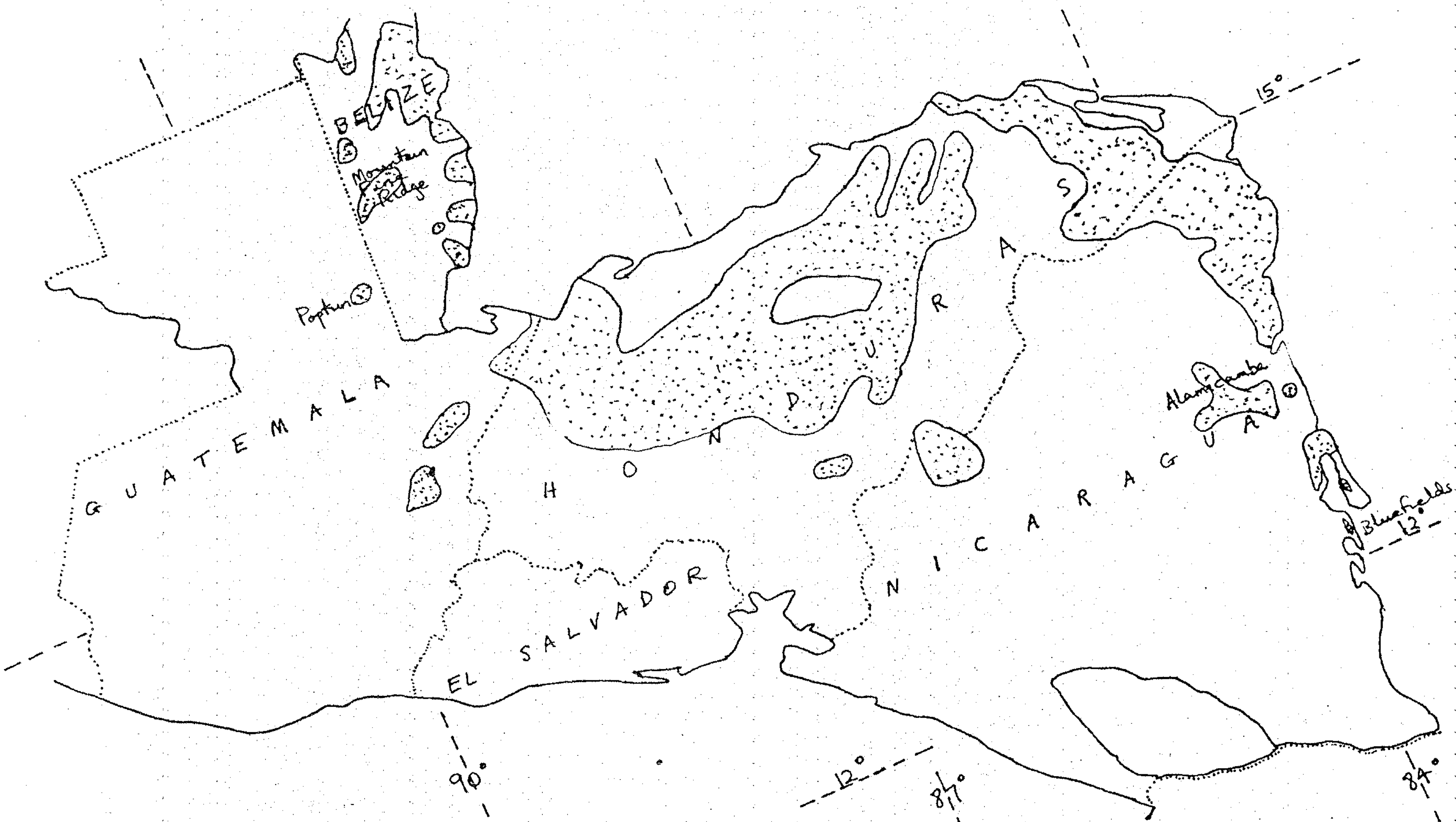
TABLE 6.1

SITE DETAILS OF THE THREE PROVENANCES USED

	QUEENSLAND	M.P.R.	ALAMICAMBA
Country of Origin	"Queensland" ex M.P.R.	Belize	Nicaragua
Latitude	$18^{o}12'S$	$17^{o}00'N$	$13^{o}34'N$
Longitude	$145^{o}55'E$	$89^{o}00'W$	$84^{o}17'W$
Altitude	6 m	400 m	25 m
Precipitation	2145 mm	1600 mm	2900 mm
Dry Season	5 months	2 months	1 month
Parent Material	Granite Alluvium	Granite	Alluvium
Soil Texture	Sandy Loam	Sandy Loam	Gravelly Loam
Drainiage	Fair - Good	Good	Good
pH	-	-	5.0
Collector of Seed	Qld. Dept. For.	Timmers and Leyer	Seed Section, CFI

MAP 1

THE NATURAL DISTRIBUTION OF PROVENANCES OF *P. CARIBAEA* VAR. *HONDURENSIS* (MAP FROM HAYNES, 1973)



notes that commercial seed collections in Belize are made without any tree selection at all. The Alamicamban provenance lies approximately in the centre of a large coastal savannah in Nicaragua (Haynes, 1973) (map 1). The seed for this trial was collected by the Commonwealth Forestry Institute, so this seed may be of better quality than the M.P.R. provenance.

6.1.2 Seed Weight and Nutrient Reserves

The Queensland and M.P.R. provenances have similar seed weight, with the Alamicamban provenance having a much smaller seed weight. In general, the Queensland provenance has the largest amount of each nutrient and the Alamicamban provenance the least (table 6.2).

6.1.3 Choice of Provenances

All three provenances have shown fast growth rates in the International Provenance trial at Three Ways. This was an important factor in the choice of provenances, since the Darwin trial was only of a short term nature. Also, Bevege and Simpson (1973) have used the M.P.R. and Alamicamban provenances in a similar trial in Queensland. This allowed the results of the Darwin trial to be compared with another trial under different environmental conditions.

6.2 Soils

The PBO-10 cm soil had the highest concentration

TABLE 6.2

Seed weight and nutrient contents (3 replicates)

Variables	PROVENANCES		
	QU (mg/seed)	M.P.R. (mg/seed)	ALA (mg/seed)
Seed weight	21.0	21.4	13.3
P/Seed	0.223	0.197	0.120
N	1.076	1.022	0.645
Zn	0.005	0.002	0.003
Fe	0.006	0.003	0.009
Mn	0.004	0.004	0.002
K	0.162	0.155	0.099
Ca	0.026	0.013	0.014
Mg	0.081	0.023	0.051

of total soil phosphorus and the Three Ways soil the least. The PBO-10 cm soil also had the highest concentration of total soil nitrogen and the PB10-25 cm soil the least. In general, the total and exchangeable cations were highest on the PBO-10 cm soil, and least on the Three Ways soil. The pH values for the three soils were similar. The PBO-10 cm and Three Ways soils had sandy clay loam textures, whereas the PB10-25 cm soil had a sandy clay texture. The Three Ways soil had the largest amount of organic matter and the PB10-25 cm soil had the least (table 6.3).

6.3 Comparison of the Three Ways and Point Blaze Sites

The Point Blaze site is on the mainland approximately 160 kilometres south-west of Darwin (map 2). The fact that it is on the mainland offers a distinct advantage over Three Ways on Melville Island (map 2), where logs will have to be moved by log truck and barge to get to the Darwin market. Both areas have a *Eucalyptus miniata - E. tetradonta* association. The Three Ways site has a slightly higher eucalypt stocking in terms of basal area and number of stems per hectare (photos 1 and 2).

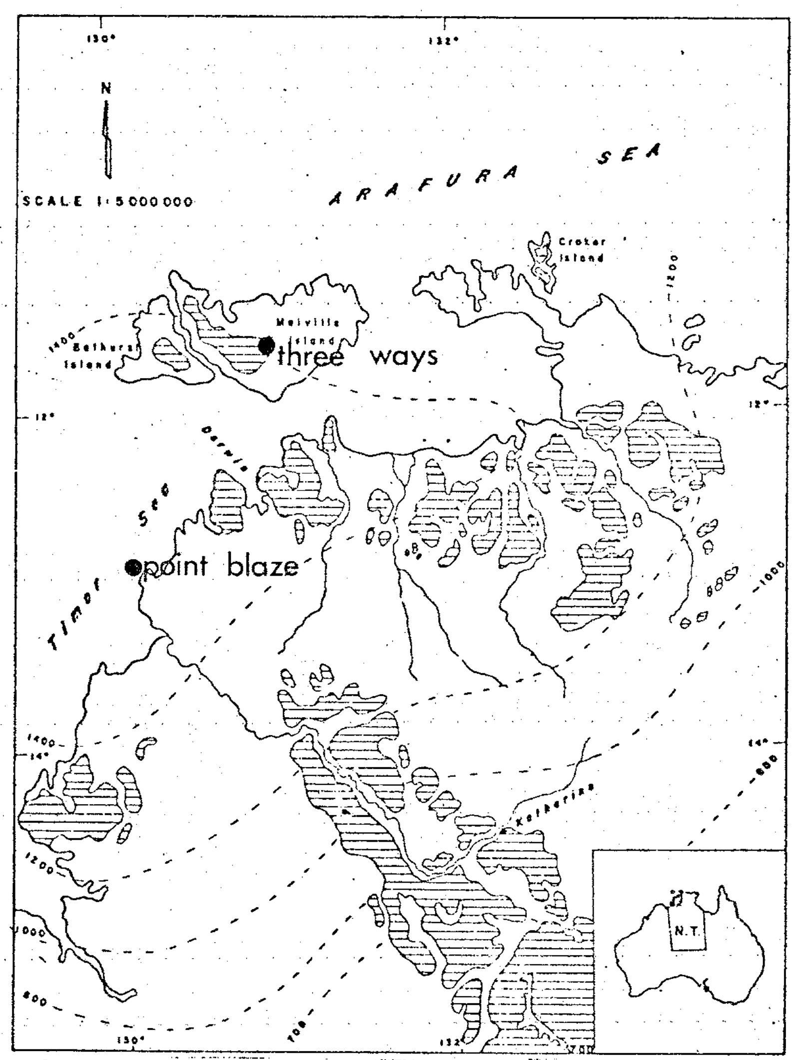
TABLE 6.3

Chemical and Physical Properties of three red earths

Soil Property	PBO-10	PB10-25	3W
Chemical Compositions			
Total P (2 replicates p.p.m)	130	110	90
N	920	460	830
K	280	290	100
Ca	1,000	430	100
Mg	630	580	400
Na	120	140	130
Fe	27,000	33,000	51,000
Zn	9	10	10
Cu	9	12	10
Mn	124	132	82
Exchangeable Cations (meq/100g) (2 replicates)			
Ca	4.5	1.9	0.7
Mg	2.6	1.8	1.4
K	0.2	0.1	0.3
Na	0.1	0.2	0.4
pH	5.8	5.8	6.0
Physical Properties			
Texture (2 replications)	Sandy Clay Loam	Sandy Clay	Sandy Clay Loam
Organic Matter (%), (3 replications)	5.2	2.5	5.8
Moisture Retention (%) (1/3 bar) (3 replications)	19.5	18.1	17.0

MAP 2.

OCCURRENCE OF THE TWO SOIL COLLECTION SITES IN THE NORTHERN TERRITORY.



PHOTOS 1 AND 2

Vegetation of the two sites of soil collection

PHOTO 1

Three Ways Site

PHOTO 2

Point Blaze Site.

CHAPTER 7.

MATERIALS AND METHODS

7.1 Design

The design was a $2^4 \times 3 \times 3$ factorial with two replications, testing for interactions between sixteen fertiliser regimes, three provenances and three red earths. The three red earths were separated into blocks, with the treatments within each block completely randomised. There was no choice in this design since there was not enough soil to put the three provenances in different pots under the same treatment. The design was similar to past experiments carried out by C.S.I.R.O. Division of Forest Research, except that different provenances have not previously been included in the design.

7.2 Germination and Maintenance

Seed of the three provenances was sown into three separate seed germination trays. These contained a base of gravel, with ten centimetres of coarse sand over this. The seed was placed on this sand, pressed in lightly, covered with a two millimetre covering of perlite, and the trays were kept in a high shade shadehouse with 70% Sirlon cloth. The seedlings started emerging after six days, and when the hypocotyl was approximately two centimetres long, were pricked out into pots. Six seedlings were pricked out per pot in a circle with two replicates of each provenance opposite each other.

All three soils were watered daily with de-ionised water to 15% moisture content for two weeks until the water retention apparatus was set up, and then the soils were watered to field capacity, using a different counterweight for each soil.

The pots were removed from the shadehouse two weeks after fertilisation, to a bench with 50% shade cover. For the last month this shade was removed to maximise response to fertilisers. The pots were moved around within soil types since the outer pots tended to be hotter.

7.3 Location and Duration

The pot trial was conducted at the C.S.I.R.O. Division of Forest Research base in Darwin over a fifteen week period.

7.4 Treatments

7.4.1 Soils

Three red earths were collected from two sites in the Northern Territory, these being the Point Blaze site and the Three Ways site. The Point Blaze area is an untried site for *P. caribaea*. The red earth is a sandy clay loam. The forest type is tall open forest with *Eucalyptus tetradonta* and *E. miniata* as the dominant species. Soil was obtained from the 0 to 10 cm and 10 to 25 cm layers. In contrast to the Point Blaze site, the Three Ways site had a *P. caribaea* International Provenance trial and a local *P. caribaea* nutrition trial one hundred metres from the collection site. The red earth here was a sandy clay loam. The vegetation here is similar to the Point Blaze site with *E. nesophila* also present. The red earth was obtained from the 0 to 10 cm layer.

The three red earths were then sieved with an 0.65 cm sieve, sun-dried, homogenised and 3200 grams of this soil placed into 19 cm pots.

7.4.2 Fertilisers

The sixteen fertiliser regimes used are shown below (N = nitrogen, P = phosphorus, S = sulphur, T = trace element mixture).

0	T	PS	NPT
N	NP	PT	NST
P	NS	ST	PST
S	NT	NPS	NPST

Thus each fertiliser was applied to eight of the fertiliser regimes and not to the other eight regimes.

The fertilisers were applied when the seedlings were twelve to fourteen days old in the forms and weights (grams per pot) shown below:

N	as	NH_4NO_3	1.074	g/pot
P	as	$NaH_2PO_4.2H_20$	1.074	" "
S	as	$CaS0_4.2H_20$	0.716	" "
T	as	$MgCl_2.6H_20$	0.089	" "
		FeChelate	0.003	" "
		$ZnCl_2$	0.022	" "
		$MnCl_2.4H_20$	0.045	" "
		$CuCl_2.2H_20$	0.022	" "
		$Na_2B_40_7$	0.003	" "
		$Na_2Mo0_4.2H_20$	0.003	" "

Potassium was applied, as $KHC0_3$, as a basal fertiliser to all pots, with 0.358 grams per pot. Phosphorus was the first fertiliser to be applied, followed by sulphur, nitrogen and trace elements daily after phosphorus. All fertilisers were applied in liquid form except for sulphur, since $CaS0_4.2H_20$ has a low solubility in water. It was thus applied in powder form. Enough solution was prepared to do all three soils at the same time to ensure that the solution was uniform. All the solutions were applied evenly around the pot and watered in with de-ionised water.

Nitrogen application was split into three applications with 20% of the weight applied when fertilisation commenced, 40% six weeks later and the remaining 40% two weeks after this.

7.4.3 Provenances

The three provenances used in this experiment were:

S11383 Mount Pine Ridge

provenance grown at Whitfield Creek, Queensland.

S11687 Mount Pine Ridge

British Honduras.

S11710 Alamicamba, Nicaragua

7.4.4 Mycorrhizae

All 96 pots in the main trial received mycorrhizal inoculation one month after fertilisation with *Suillus* aff *granulatus* and *Rhizopogon roseolus* fruiting bodies. These fruiting bodies were mashed together, added to water and 50 ml applied to each pot. Twelve pots not included in the main trial did not receive mycorrhizal inoculations and included four pots for each soil, two replicates having no fertiliser, and two with NPST fertiliser. These pots were initially kept separate from the main trial, but were later included to ensure uniformity of conditions. These twelve pots were included so that any analysis of variance could be conducted using the same treatments with and without mycorrhizae, to assess the importance of mycorrhizae.

7.5 Measurements

Measurements were taken of the three provenances on the three soils at the time of fertilisation when the seedlings were twelve to fourteen days old. The measurement of root and shoot variables was conducted since morphological differences between the provenances at fertilisation could influence this trial. Measurements were carried out one, two and three months after fertilisation for each seedling in the trial. Measurements included height (from the cotyledons to needle-tips) and number of branches.

7.6 Harvest Procedure

Three months after fertilisation the three provenances in each pot were marked differently with tape to avoid mistakes. After washing the roots with tapwater and photographing, the two replicates of each provenance in each pot were bulked, then separated into shoots and roots, and placed in paper bags ready for drying.

7.7 Field Study

Twelve auger holes to 120 centimetres depth were dug over the ten kilometre width of the Point Blaze site. Two auger holes were dug on the Three Ways site. The International Provenance trial and a local nutrition trial at Three Ways were also studied.

7.8 Chemical Analysis

Plant material was dried at 85°C, ground, and put into paper bags ready for chemical analysis. Nitrogen and phosphorus were measured by the method of Williams and Twine (1967). Nitrogen and phosphorus determinations were made on the foliage, stems and roots of the Point Blaze 0 to 10 cm and Three Ways 0 to 10 cm red earth using 0.3 gram of plant material. Cations were measured by the method of Lambert

(1976), using dry ashing before digestion with 7 ml of 3N HCl.

Soil nitrogen and phosphorus were determined by the same method as foliar nitrogen and phosphorus, except that one gram of soil was used. Total soil cations were determined by the method of Piper (1950). Exchangeable cations (calcium, magnesium, potassium and sodium) were determined by the leaching method using ammonium acetate (pH 7.0). Organic matter was determined by the method of Walkley-Black (Hesse, 1971). pH was determined by shaking six grams of soil in thirty millilitres of water for half an hour, standing for half an hour and then measuring with a pH meter. Particle size analysis was by a modified method of Loveday (1974). Phosphorus adsorption capacity was determined by the Coleman, Thorup and Jackson (1960) method which was adapted for Northern Territory conditions. Water retention was determined using pressure plate apparatus.

7.9 Statistical Analysis

Analysis of variance was carried out on two computers using the programme GENSTAT at C.S.I.R.O., and ANOVA, a subprogramme of SSPS (Statistical Package for the Social Sciences). GENSTAT enabled both the analysis of variance and means to be calculated. GENSTAT was used to analyse the Darwin dry weight data. ANOVA was used to conduct an analysis of variance on the Darwin mycorrhizal data.

SPSS subprogramme REGRESSION was used for correlation analysis. This analysis was performed on the Darwin dry weight data over all soils, on the nitrogen-phosphorus chemical data and on the phosphorus/cation data.

CHAPTER 8.

RESULTS AND DISCUSSION

8.1 Provenance Effect

8.1.1 Growth

An analysis of variance was conducted on the growth data obtained three months after fertilisation (except for height which was at two and three months after fertilisation). The analysis showed a significant provenance effect for all variables except for the stem/foliage dry weight ratio (table 8.1).

There was a significant (0.001 probability level) difference between provenances in terms of total dry weight (table 8.1). The Queensland provenance had the largest total dry weight over the sixteen fertiliser treatments (0.63 g/seedling), and the Alamicamban provenance had the least (0.45g) (table 8.2). However, the Queensland provenance (0.50 g) was only marginally superior to the M.P.R. provenance (0.47 g) on the PB10-25 cm soil. This was probably due to the fact that a deficiency (or deficiencies) was limiting growth on this soil, and thus the differences between the provenances were smaller than on the other two soils (figures 8.1, 8.2 and 8.3). Also, the Queensland provenance responded less, in terms of total dry weight, to mycorrhizal inoculation on the PB10-25 cm soil than the M.P.R. provenance for the nil and NPST fertiliser treatments (figures 8.13 and 8.14).

VARIATES

Source of Variation	DF	FOLIAGE VR + Signif	ROOT	STEM	TOTAL	STEM/FOL	SHT/RT	FOL/TOT	DF	2ND HT	3RD HT	3RD ST.HT	3RD BR.
Soil	2								2				
Total	2	74.40	30.86	55.72	67.98	3.32	10.18	7.67	2	27.51	53.28	49.78	19.49
Fert	15	37.79***	20.41***	29.17***	33.34***	8.03***	2.52***	3.89***	15	22.31***	34.41***	20.61***	11.71***
Fert x Soil	30	4.58***	2.47**	3.63***	3.90***	1.93*	1.52	1.39	30	1.80*	3.08***	2.64**	1.54
Residual	48	1.38	1.84	1.37	1.63	1.09	1.31	1.19	48	1.66	1.62	1.79	1.36
Total	93	11.19	8.46	8.78	11.64	2.64	1.85	1.90	93	7.80	11.45	8.41	3.94
Prov	2	49.57***	13.30***	47.24***	43.60***	1.40	7.72***	4.46*	2	58.21***	49.21***	36.45***	4.69**
Soil x Prov	4	2.80*	2.59*	2.35	2.94*	0.55	1.88	1.48	4	2.71*	1.76	2.33	1.06
Prov x Fert	30	3.33***	1.48	2.43***	2.73***	0.91	1.78*	1.71*	30	1.45*	1.57*	1.34	1.01
Soil x Prov x Fert	60	1.13	1.05	0.88	1.12	0.77	0.82	1.05	60	0.76	0.73	0.84	1.06
Residual	96								367				
Total	192								463				

KEY

*** Significant at 0.001 probability level   VR = Variance ratio

** 0.01

* 0.05

TABLE 8.1 Analysis of variance for plant growth variables over 3 soil types, 16 fertiliser regimes and 3 provenances 3 months after fertilision.

TABLE 8.2

Effect of provenances and soils (averaged over sixteen fertiliser regimes) on total dry weight (g/seedling)

Prov. / Soil	QU	M.P.R.	ALA	MEAN
PBO-10	0.78	0.67	0.56	0.67
PB10-25	0.50	0.47	0.40	0.46
3W	0.62	0.46	0.38	0.49
MEAN	0.63	0.53	0.45	0.54

TABLE 8.3

Relative total dry weight as a function of provenance only (over all fertilisers) (%). (Alamicamban provenance = 100%)

Prov. / Soil	QU	M.P.R.	ALA
PB0-10	139	120	100
PB10-25	125	118	100
3W	163	121	100

This could possibly have been occurring with the other fertiliser regimes.

There appeared to be little difference in terms of relative response of the M.P.R. and Alamicamban provenances on the three soils, since the M.P.R. provenance produced 20%, 18% and 21% more total dry weight than the Alamicamban provenance on the PBO-10 cm, PB10-25 cm and Three Ways soils respectively (table 8.3). However, the Queensland provenance produced 39%, 25% and 63% more total dry weight than the Alamicamban provenance on the same three soils. This indicated that the response of the Queensland provenance to fertilisers was influenced more by soil factors than that of the M.P.R. provenance. Since both are derived from the Mount Pine Ridge area, either the original selection of seed trees or natural and artificial selection under Queensland conditions was influencing this result. The large response of the Queensland provenance relative to the M.P.R. provenance on the Three Ways soil exemplifies this fact.

The difference between the provenances were smaller on the two Point Blaze soils than on the Three Ways soil (table 8.3). This indicated that the Queensland and M.P.R. provenances responded better on the sandier Three Ways soil and that the Alamicamban provenance responded better on the two Point Blaze soils.

The three provenances responded differently to phosphorus in terms of total dry weight (figures 8.1, 8.2, and 8.3). Without phosphorus, there was little difference between the provenances. The Queensland provenance remained dominant due to a larger content of nutrients in the seed. However, with phosphorus application, there were larger differences between the provenances. This occurred to the greatest degree on the PB0-10 cm soil, and least on the PB10-25 soil.

The optimum fertiliser regime and degree of response (over the control) varied for each provenance on the three soils. There were no clear trends for each provenance (table 8.4). The minimum increase in total dry weight of the optimum treatment over the control was 90%. This emphasises the advantages of using fertilisers with *P. caribaea*. Since no sulphur response has been obtained in the field on red earths, the optimum fertiliser to use to cover all provenances would be PNT. The use of superphosphate as a source of phosphorus would also cover any sulphur deficiencies that might occur. Trace elements should be included since they have helped boost total dry weight in seven out of nine cases (table 8.4).

The provenance effect was more significant for needle-tip height two months after fertilisation than

FIGURE 8.1

EFFECT OF FERTILISERS ON THE TOTAL DRY WEIGHT OF THREE PROVENANCES ON THE PBO-10 cm SOIL

FIGURE 8.2

EFFECT OF FERTILISERS ON THE TOTAL DRY WEIGHT OF THREE PROVENANCES ON THE PBO10-25 cm SOIL

FIGURE 8.3

EFFECT OF FERTILISERS ON TOTAL DRY WEIGHT OF THREE PROVENANCES ON THE THREE WAYS SOIL

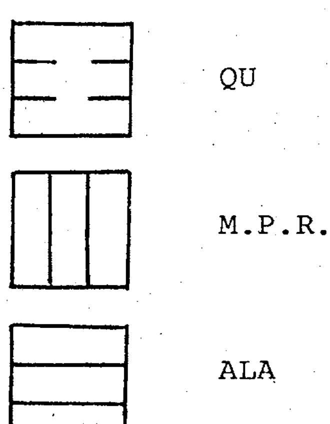
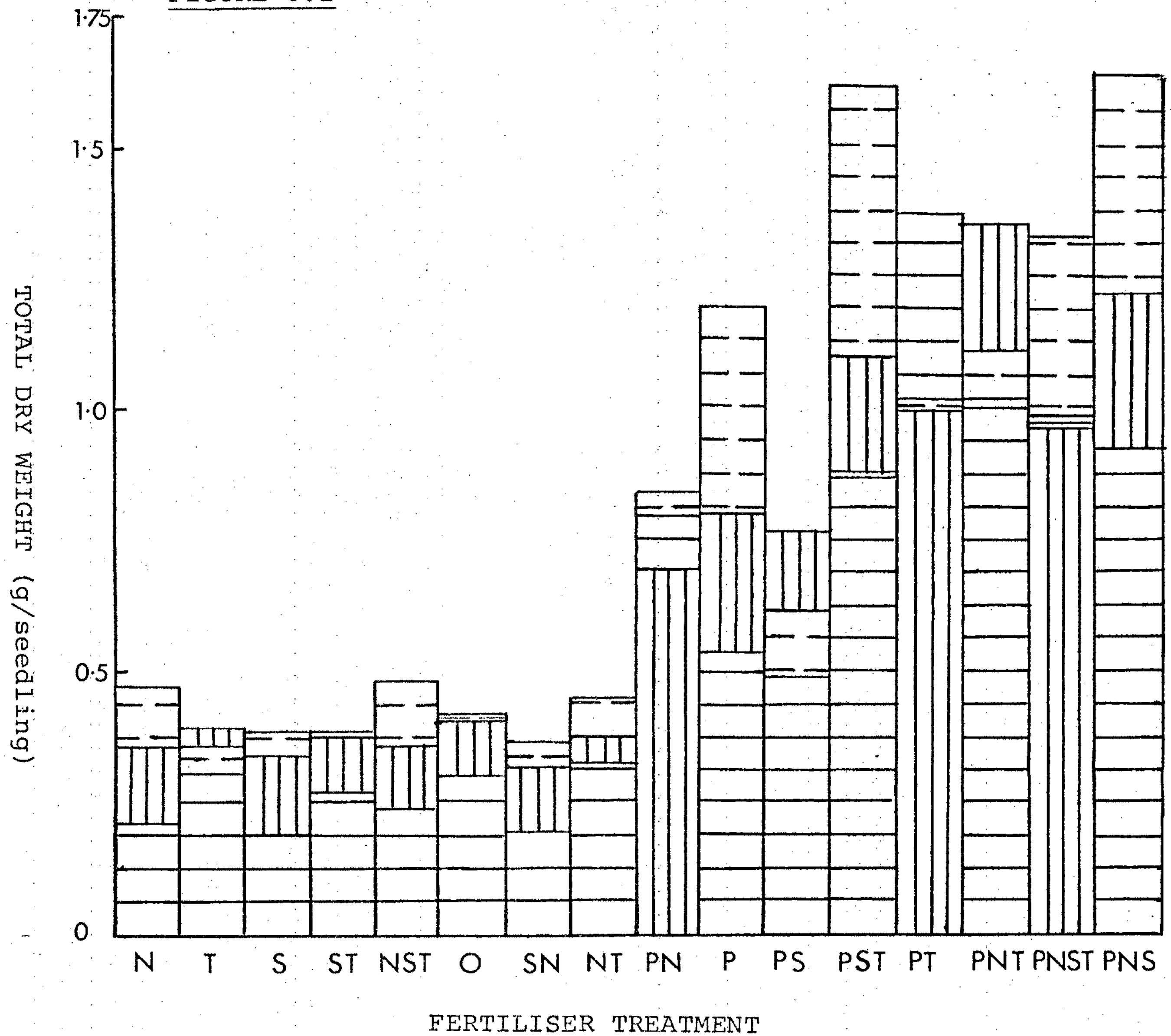


FIGURE 8.1



TOTAL DRY WEIGHT (g/seedling)
1·75
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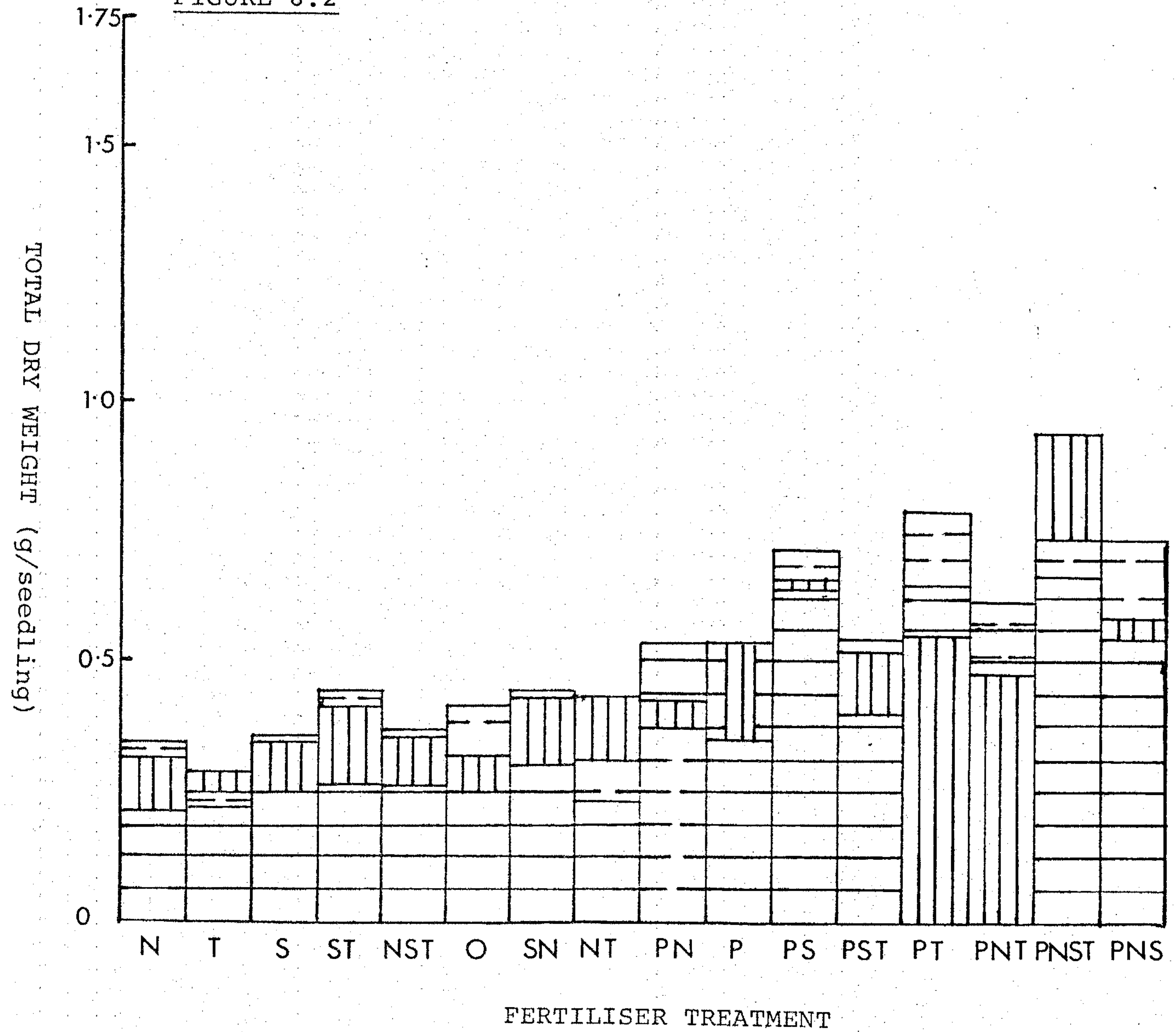
FERTILISER TREATMENT

FIGURE 8.2


TOTAL DRY WEIGHT (g/seedling)
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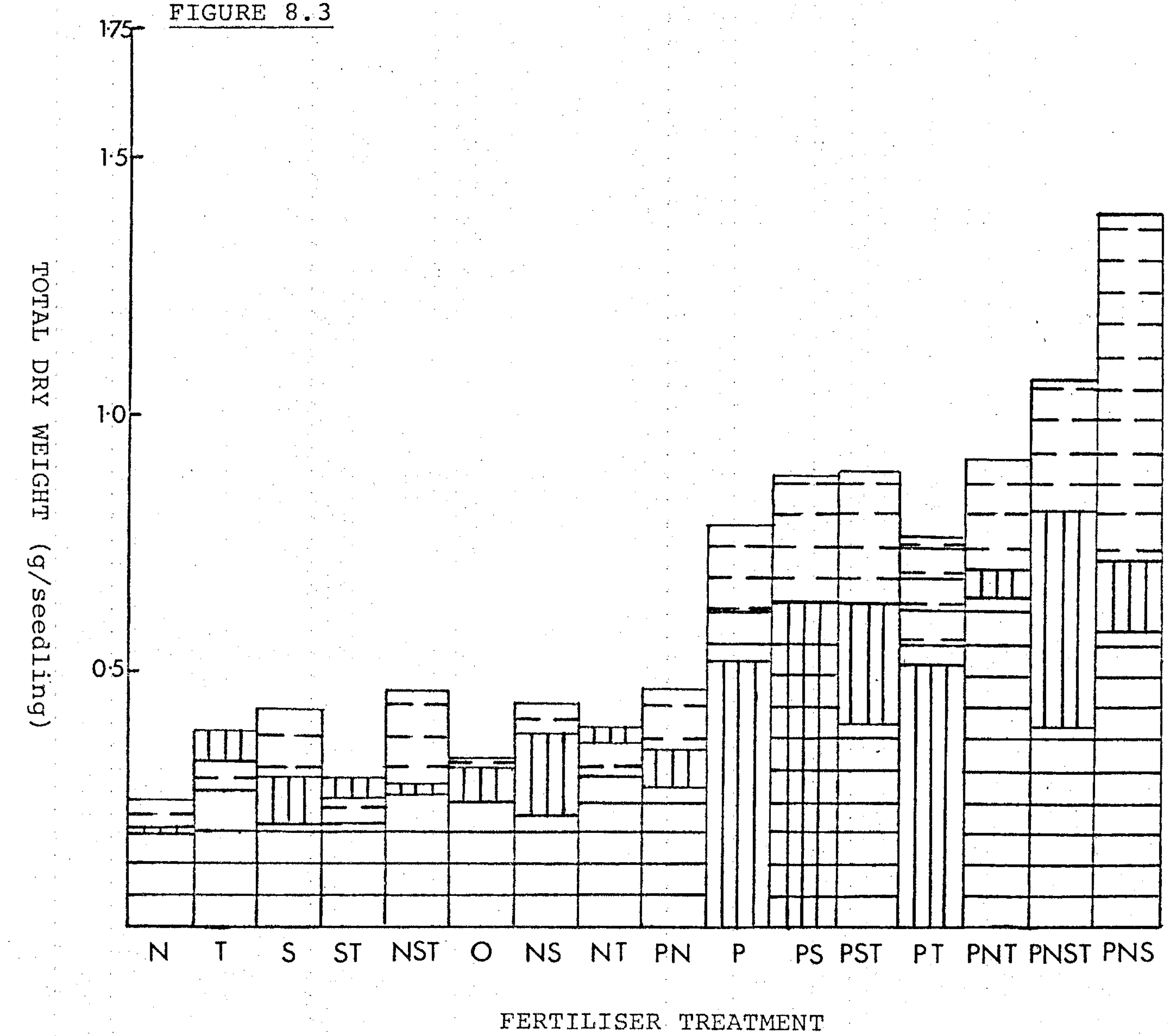
FERTILISER TREATMENT

FIGURE 8.3



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FERTILISER TREATMENT

TABLE 8.4

Percentage increase in total weight for the optimum fertiliser regime (control = 100%)

Soil and Provenance	Optimum Regime	Percentage Increase Over Control
PBO-10		
QU	PNS	291
M.P.R.	PNT	235
ALA	PT	355
3W		
QU	PNS	327
M.P.R.	PNST	159
ALA	PT	150
PB10-25		
QU	PT	90
M.P.R.	PNST	193
ALA	PNST	168

needle-tip height three months after fertilisation (table 8.1). This indicated that the difference between provenances was decreasing with time. Curlin (1967) considered differences in root proliferation could be a genetic factor influencing mineral uptake during the juvenile period. This could be so in this trial since there were differences between the provenances in development of the root system at the time of fertilisation (photo 3). Curlin considered if this was so, varietal differences might disappear several years after establishment.

There was a significant difference between provenances (0.001 level) in terms of root dry weight (table 8.1). However, this was not as significant as for foliage, stem and total dry weight. The percentage increase in root dry weight of the Queensland and M.P.R. provenances relative to the Alamicamban provenance (averaged over all fertiliser regimes) was less in every case than for total dry weight (tables 8.3 and 8.5). The Queensland provenance, with the largest total dry weight also had the largest shoot/root ratio (averaged over all fertiliser treatments and soils), and the Alamicamban provenance, with the smallest total dry weight, had the smallest shoot/root ratio (tables 8.2 and 8.6). This tended to reduce the difference between provenances in terms of root dry weight.

The Queensland provenance had the largest shoot/root ratio on the two Point Blaze soils, but not on the sandier Three Ways soil (table 8.6). Indeed, the shoot/root ratio

PHOTO 3

Root and shoot development of three provenances at time of fertilisater application.

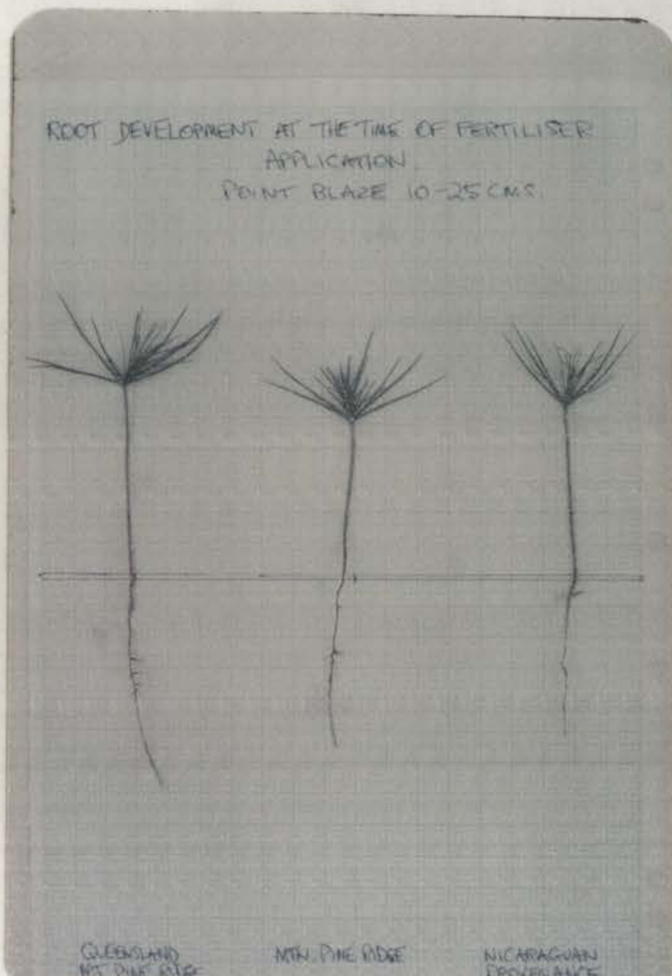


TABLE 8.5

Root dry weight (g/seedling) (averaged over sixteen fertiliser regimes) and relative root dry weight as a function of provenance only (included in brackets, Alamicamban provenance = 100%)

Soil \ Prov.	QU	M.P.R.	ALA
PBO-10	0.21(124)	0.20(118)	0.17(100)
PB10-25	0.15(115)	0.15(115)	0.13(100)
3W	0.18(150)	0.13(108)	0.12(100)

TABLE 8.6

Effect of provenances and soils (averaged over sixteen fertiliser regimes) on the shoot/root ratio.

Prov. / Soil	QU	M.P.R.	ALA	MEAN
PBO-10	2.8	2.5	2.5	2.6
PB10-25	2.5	2.3	2.1	2.3
3W	2.5	2.6	2.5	2.5
MEAN	2.6	2.5	2.4	2.5

TABLE 8.7

Effect of provenances and soils (averaged over sixteen fertiliser regimes) on the foliage/total dry weight ratio.

Prov. / Soil	QU	M.P.R.	ALA	MEAN
PBO-10	0.52	0.50	0.51	0.51
PB10-25	0.50	0.49	0.47	0.49
3W	0.50	0.51	0.49	0.50
MEAN	0.51	0.50	0.49	0.50

was similar for all provenances on the Three Ways soil (2.5 - 2.6). The shoot/root ratio was not significantly correlated with total dry weight (r = 0.11, Appendix 1). As noted in section 8.3.3 nitrogen was the most important influence on this ratio.

The provenance effect was only significant at the 0.05 level for the foliage/total dry weight ratio (table 8.1). This ratio was influenced more by nutrition than provenance effects since the fertiliser effect was significant at the 0.001 level (table 8.1). The Queensland provenance had the largest ratio (averaged over all soils and fertiliser treatments)(0.51) and the Alamicamban provenance had the smallest ratio (0.49) (table 8.7).

8.1.2 Concentration and Uptake of Phosphorus, Nitrogen and Cations

An analysis of variance was not conducted on this data since there was no replication of data. Only the PB0-10cm and Three Ways soils were examined.

The Queensland provenance had the greatest total phosphorus uptake (foliage, stems and roots) on both soils and the Alamicamban provenance had the least on both soils (table 8.8). However, the differences between provenances in terms of shoot (foliage and stem) phosphorus concentration were much smaller, ranging from 0.095% to 0.104% for the

TABLE 8.8

Phosphorus and nitrogen chemical analysis (averaged over all fertiliser regimes).

Soil and Provenance	Shoot P Concentration (%)	Shoot N Concentration (%)	Total P Uptake (mg/seedling)
3W			
QU	0.095	2.3	0.61
M.P.R.	0.103	2.4	0.49
ALA	0.100	2.1	0.45
MEAN	0.100	2.3	0.52
PBO-10			
QU	0.101	2.1	0.86
M.P.R.	0.104	2.3	0.75
ALA	0.100	2.3	0.62
MEAN	0.102	2.2	0.74

three provenances on the two soils (averaged over all fertiliser treatments) (table 8.8). The Queensland provenance was obviously utilising the larger amounts of phosphorus taken up. The M.P.R. provenance appeared to be slightly less efficient in phosphorus utilisation, since this provenance had a slightly higher phosphorus concentration than the other provenances on both soils (table 8.8). The Queensland provenance was substantially superior in terms of total dry weight, over the other provenances on the Three Ways soil (table 8.3). This provenance appeared to be utilising the phosphorus efficiently on this soil since the phosphorus concentration was considerably lower than the other two provenances (table 8.8).

The shoot nitrogen concentration ranged from 2.1% to 2.4% for the three provenances on the two soils (averaged over all fertiliser treatments) (table 8.8). This was due to the high nitrogen application and probably also to soil nitrogen mineralisation. The M.P.R. provenance had the highest nitrogen concentration on both soils. This could possibly be due to the lower efficiency of phosphorus utilisation.

Cation concentration and uptake were also measured for the three provenances on the PBO-10 cm and Three Ways soils, but for the "plus phosphorus" treatments only, since inadequate foliage material was available for the "minus phosphorus" treatments.

The Queensland provenance had the largest uptake of cations and the Alamicamban provenance the least on both soils (table 8.9). This was the same trend as for total dry weight on both soils (table 8.2). In contrast to cation uptake, there was little difference between the provenances in terms of cation concentration on both soils (table 8.9). It was possible that the provenances were taking up cations at a proportional rate to total dry weight production, since the concentration of cations was similar for all provenances, which had different dry weights.

8.2 Soil Effect

8.2.1 Growth

Due to the design of this experiment, the significance of the soil effect could not be calculated by analysis of variance. However, the difference between the soils was obvious in this trial. The seedlings on the PBO-10 cm soil had the largest total dry weight (0.67 g/seedling) and the PB10-25 cm soil had the smallest total dry weight (0.46 g) (averaged over all provenances and fertilisers) (table 8.2). The seedlings on the PBO-10 soil were the most responsive to fertiliser since this soil had larger quantities of phosphorus, nitrogen and cations, and consequently did not become as deficient in these nutrients as the Three Ways and PB10-25 cm soils. Texture could have been influencing the results, since as noted previously, the three provenances responded differently, in terms of total

TABLE 8.9

Cation uptake (mg/2 seedlings) and concentration (in brackets; Ca, Mg, K = %; Zn, Mn = p.p.m) averaged over all phosphorus treatments.

Soil and Provenance	Ca	Mg	K	Zn	Mn
3W					
QU	2.9(0.33)	1.7(0.20)	10.5(1.2)	0.04(43)	0.25(282)
M.P.R.	1.8(0.29)	1.3(0.21)	7.9(1.3)	0.03(45)	0.17(271)
ALA	1.7(0.32)	1.1(0.21)	6.2(1.2)	0.02(40)	0.13(265)
MEAN	2.1(0.31)	1.4(0.21)	8.2(1.2)	0.03(21)	0.51(417)
PBO-10					
QU	4.7(0.39)	2.7(0.23)	19.2(1.6)	0.03(21)	0.51(417)
M.P.R.	4.2(0.42)	2.2(0.24)	16.5(1.7)	0.02(22)	0.46(470)
ALA	3.8(0.42)	2.2(0.23)	14.3(1.6)	0.02(22)	0.41(454)
MEAN	4.2(0.41)	2.4(0.23)	16.7(1.6)	0.02(22)	0.46(447)

dry weight, on the three soils. Phosphorus fixation also was probably having an important influence on this trial. The phosphorus sorption was highest on the Three ways soil and least on the PBO-10 cm soil (figure 8.4). The same trend occurred for total iron concentration (table 6.3). Thus, iron was probably fixing some of the applied phosphorus, and this reduced the amount of phosphorus available to the seedlings.

Stransky and Wilson (1967) have reported that the shoot/root ratios of *Pinus echinata* and *P. taeda* increased with increasing clay content of the soil. This did not appear to be the case in this trial, since the PB10-25 cm soil, with a high (36%) clay content, had a lower shoot/root ratio over all provenances and fertiliers (2.3) than the Three Ways soil (2.5) with a 22% clay content (table 8.6).

The three soils appeared to have only a small influence on the foliage/total and stem/foliage dry weight ratios (Tables 8.7 and 8.10).

8.2.2 <u>Concentration and Uptake of Phosphorus, Nitrogen and Cations</u>

Seedlings on the PBO-10 cm soil had larger amounts of phosphorus (total uptake) than seedlings on the Three Ways soil (table 8.8). There appeared to be little difference between the two soils in terms of shoot phosphorus

FIGURE 8.4

THE PHOSPHORUS ADSORPTION OF FOUR RED EARTHS

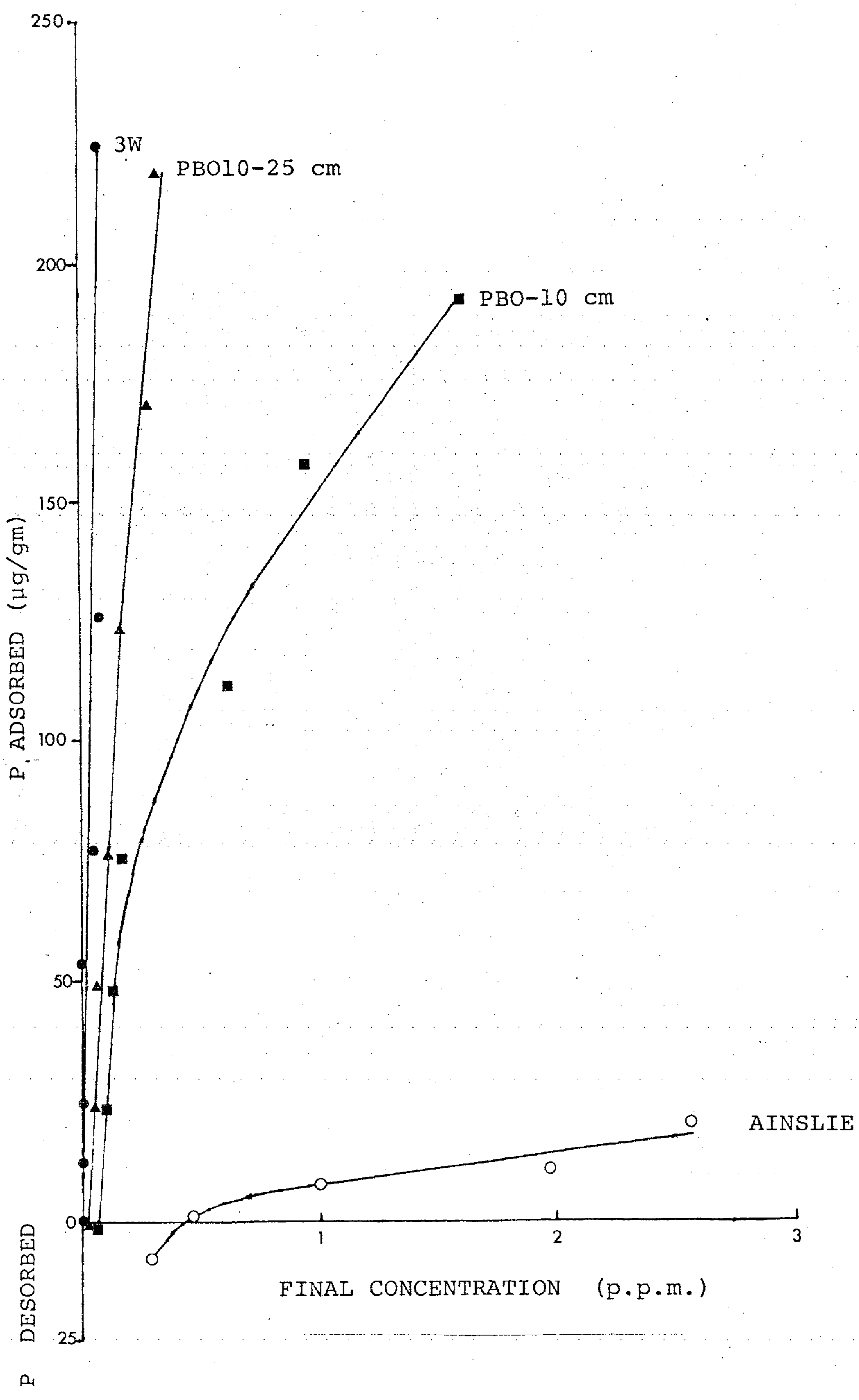


TABLE 8.10

Effect of provenances and soils (averaged over sixteen fertiliser regimes) on the stem/foliage dry weight ratio

Soil \ Prov.	QU	M.P.R.	ALA	MEAN
PBO-10	0.41	0.40	0.40	0.40
PB10-25	0.42	0.40	0.42	0.41
3W	0.44	0.41	0.44	0.43
MEAN	0.42	0.40	0.42	0.41

concentration (table 8.8).

There were also substantial differences between the two soils in terms of cation uptake. The amount of calcium, magnesium, potassium and manganese were all considerably higher in the seedlings on the PBO-10 cm soil (table 8.9). However, zinc uptake was less on the PBO-10 cm soil (0.02 mg/two seedlings) compared to the Three Ways soil (0.03mg). The total zinc levels in the two soils were similar, being 10 p.p.m. on the Three Ways soil and 9 p.p.m. on the PBO-10 cm soil (table 6.3). A soil factor was probably limiting zinc uptake, since the total dry weight production was greater on the PBO-10 cm soil compared to the Three Ways soil (table 8.2). The concentration of the cations (except zinc) were all higher in the seedlings on the PBO-10 cm soil than the Three Ways soil (table 8.9).

8.3. Fertiliser Effect

8.3.1 Morphological Differences Between the Three Provenances at Time of Fertilisation

Geary and de Barros (1973), using progeny of sixteen Belize select phenotypes of *P. caribaea* in a Puerto Rico nursery, noted that factors of seed environment influenced germination vigour, and that this produced size differences between progeny. It was thus important to study the differences in size between progenances at the time of fertilisation, since these differences could influence initial uptake and utilisation of the fertilisers applied.

Measurements of root length, number of laterals and shoot development were taken, but the variability among the six replicates was very high and thus the results were not used. However, the pattern that emerged on the three soils for the three provenances is shown in photo 3. The Queensland provenance had the largest shoot system, more laterals and a larger taproot than the two other provenances. The M.P.R. provenance had a slightly larger shoot system, more laterals, and a slightly longer taproot than the Alamicamban provenance. This effect was probably due to the Queensland provenance having the largest quantities of nutrients in the seed, with the Alamicamban provenance having the least (table 6.2). It was thus apparent that the Queensland provenance had an early advantage in uptake and utilisation of nutrients.

8.3.2 Response to Fertilisers Over Time

The height response to fertilisers over time was only considered on the PBO-10 and Three Ways soils. The figures only included "minus phosphorus" and "plus phosphorus" treatments (averaged over all fertiliser treatments). The results for nitrogen, sulphur and trace element were similarly treated (figures 8.5 and 8.6). Thus, these data

FIGURE 8.5

EFFECT OF PLUS AND MINUS APPLICATION OF FOUR FERTILISERS ON THREE PROVENANCES ON THE THREE WAYS SOIL

FIGURE 8.6

EFFECT OF PLUS AND MINUS APPLICATION OF FOUR FERTILISERS ON THREE PROVENANCES ON THE PBO-10 cm SOIL

———— QU

------------ M.P.R.

— — — ALA

0 minus application

1 plus application

FIGURE 8.5

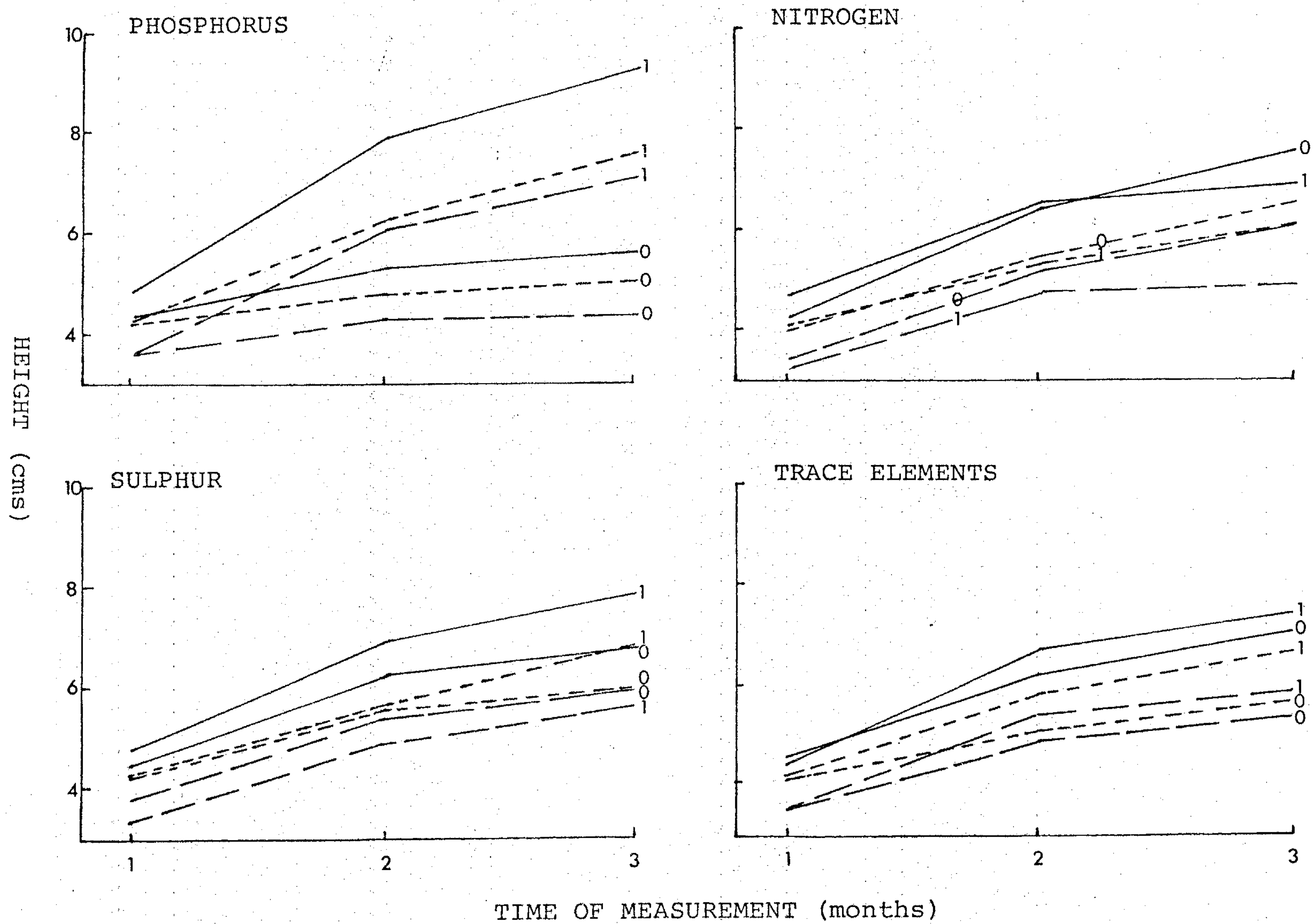
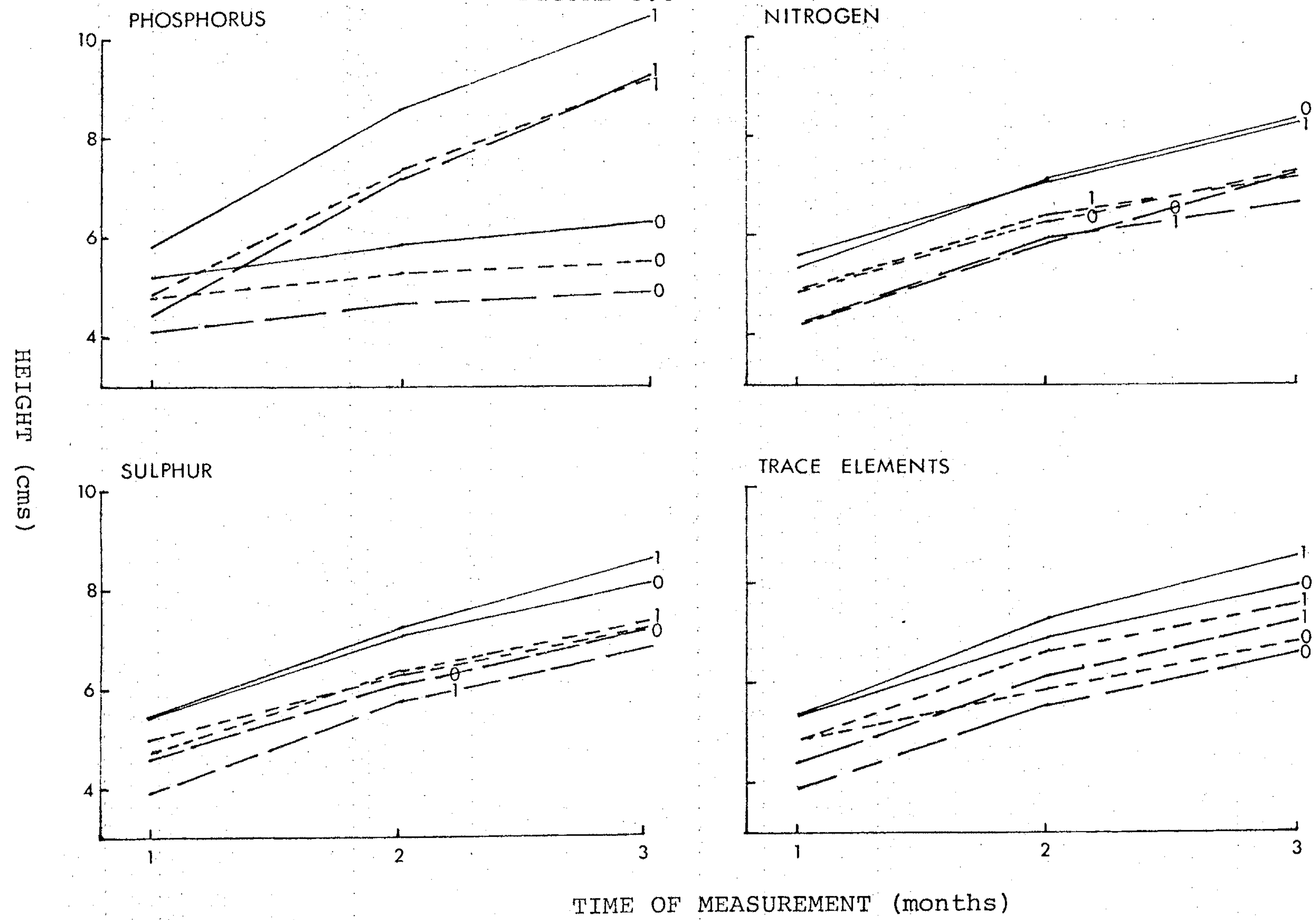

PHOSPHORUS
NITROGEN
SULPHUR
TRACE ELEMENTS
HEIGHT (cms)
TIME OF MEASUREMENT (months)
10
8
6
4
1
2
3

FIGURE 8.6



PHOSPHORUS
NITROGEN
SULPHUR
TRACE ELEMENTS
HEIGHT (cms)
10
8
6
4
1
2
3
0
TIME OF MEASUREMENT (months)

included both main effects and interactions.

(i) Initial Response

The initial response was considered to be the difference between the "minus fertiliser" and "plus fertiliser" treatments one month after fertilisation.

Only the most obvious trends were considered. The Queensland provenance responded positively to phosphorus on both soils, whereas the M.P.R. provenance did not respond on either of the soils. The Alamicamban provenance responded to phosphorus on the PBO-10 cm soil but not at all on the Three Ways soil. The Queensland provenance responded positively to nitrogen and sulphur on both soils, whereas the Alamicamban provenance responded negatively to sulphur on both soils (figures 8.5 and 8.6).

(ii) Response Two to Three Months after Fertilisation

It was apparent that the largest response was to phosphorus on both soils (figures 8.5 and 8.6). The provenances were slowing down in height growth possibly due to removal of the shade cover two months after fertilisation. Nitrogen toxicity did not appear to be slowing down the height growth, since referring to figure 8.6, the Queensland and M.P.R. provenances were not affected by nitrogen application, yet the height growth was decreasing relative to the one to two month period after fertilisation. It was possible that nitrogen application was causing a reduction in height growth on the Three Ways soil.

8.3.3 Growth Response Three Months After Fertilisation

An analysis of variance was conducted over the three soils, sixteen fertiliser regimes and three provenances. With the fertiliser regimes pooled, there were significant differences (0.001 level) between fertiliser treatments for all variables (table 8.1). An analysis of variance, using total dry weight as the variable, was also conducted to find the most significant fertiliser treatment. P was the most significant treatment (0.001 level). T, N x S, S, P x T, T x S, P x N x S, N x T x S, P x S and P x T x S were also significant (table 8.11).

The mean total dry weight of the "minus phosphorus" treatments averaged over all soils and provenances was 0.32 g/seedling, whereas the "plus phosphorus" treatments had a mean total dry weight of 0.76 g/seedling, a 138% increase in total dry weight. Anon. (1970, 1972), Platteborze et al. (1971), Bevege (1973) and Bevege and Simpson (1973) have all noted the importance of phosphorus for *P. caribaea*.

There was little response to nitrogen in this trial. The mean total dry weight of the "minus nitrogen" treatments averaged over all soils and provenances was 0.53 g/seedling, and for the "plus nitrogen" treatments 0.56 g/seedling.

TABLE 8.11

Analysis of variance over 3 soils, 16 fertiliser regimes and 3 provenances 3 months after fertilisation with total dry weight as the variate (VR = Variance ratio).

SOURCE OF VARIATION	DF	SS	SS%	MS	VR
SO STRATUM					
SOIL	2	2.65924	8.70	1.32962	
TOTAL	2	2.65924	8.70	1.32962	59.799
SO.POT STRATUM					
N	1	0.08100	0.27	0.08100	2.106
P	1	13.61115	44.54	13.61115	353.832***
T	1	0.37483	1.23	0.37483	9.744**
S	1	0.22167	0.73	0.22167	5.762**
SOIL.N	2	0.03031	0.10	0.01515	0.394
SOIL.P	2	2.03126	6.65	1.01563	26.402***
N.P	1	0.04728	0.15	0.04728	1.229
SOIL.T	2	0.20592	0.67	0.10296	2.677
N.T	1	0.00398	0.01	0.00398	0.103
P.T	1	0.25980	0.85	0.25980	6.754*
SOIL.S	2	0.06588	0.22	0.03294	0.856
N.S	1	0.34653	1.13	0.34653	9.008**
P.S	1	0.16675	0.55	0.16675	4.335*
T.S	1	0.21615	0.71	0.21615	5.619*
SOIL.N.P	2	0.04663	0.15	0.02332	0.606
SOIL.N.T	2	0.23368	0.76	0.11684	3.037
SOIL.P.T	2	0.12751	0.42	0.06376	1.657
N.P.T	1	0.01665	0.05	0.01665	0.433
SOIL.N.S	2	0.02177	0.07	0.01089	0.283
SOIL.P.S	2	0.02736	0.09	0.01368	0.356
N.P.S	1	0.19479	0.64	0.19479	5.064*
SOIL.T.S	2	0.10717	0.35	0.05359	1.393
N.T.S	1	0.17850	0.58	0.17850	4.640*
P.T.S	1	0.15820	0.52	0.15820	4.113*
SOIL.N.P.T	2	0.21681	0.71	0.10840	2.818
SOIL.N.P.S	2	0.01434	0.05	0.00717	0.186
SOIL.N.T.S	2	0.19893	0.65	0.09947	2.586
SOIL.P.T.S	2	0.00310	0.01	0.00155	0.040
N.P.T.S	1	0.03445	0.11	0.03445	0.896
RESIDUAL	50	1.92339	6.29	0.03847	1.730
TOTAL	93	21.16582	69.27	0.22759	10.236
SO.POT.TREE STRATUM					
PROV	2	1.70538	5.58	0.85269	38.349***
SOIL.PROV	4	0.23013	0.75	0.05753	2.587*
PROV.N	2	0.02601	0.09	0.01300	0.585
PROV.P	2	0.26432	0.87	0.13216	5.944**
PROV.T	2	0.03320	0.11	0.01660	0.747
PROV.S	2	0.39854	1.30	0.19927	8.962***
SOIL.PROV.N	4	0.09883	0.32	0.02471	1.111
SOIL.PROV.P	4	0.16974	0.56	0.04243	1.908
PROV.N.P	2	0.00872	0.03	0.00436	0.196
SOIL.PROV.T	4	0.04904	0.16	0.01226	0.551
PROV.N.T	2	0.03604	0.12	0.01802	0.811
PROV.P.T	2	0.00145	0.00	0.00073	0.033
SOIL.PROV.S	4	0.09285	0.30	0.02321	1.044
PROV.N.S	2	0.06381	0.21	0.03190	1.435
PROV.P.S	2	0.15842	0.52	0.07921	3.563*
PROV.T.S	2	0.04076	0.13	0.02038	0.917
SOIL.PROV.N.P	4	0.07975	0.26	0.01994	0.897
SOIL.PROV.N.T	4	0.02116	0.07	0.00529	0.238
SOIL.PROV.P.T	4	0.02682	0.09	0.00671	0.302
PROV.N.P.T	2	0.07576	0.25	0.03788	1.704
SOIL.PROV.N.S	4	0.02679	0.09	0.00670	0.301
SOIL.PROV.P.S	4	0.05966	0.20	0.01492	0.671
PROV.N.P.S	2	0.05854	0.19	0.02927	1.316
SOIL.PROV.T.S	4	0.17066	0.56	0.04267	1.919
PROV.N.T.S	2	0.16403	0.54	0.08202	3.689*
PROV.P.T.S	2	0.04847	0.16	0.02424	1.090
RESIDUAL	118	2.62371	8.59	0.02223	
TOTAL	192	6.73260	22.03	0.03507	
GRAND TOTAL	287	30.55767	100.00		

GRAND MEAN 0.5383
TOTAL NUMBER OF OBSERVATIONS 288

*** Signif. 0.001 level
** " 0.01 "
* " 0.05 "

Richards and From (1965) noted in a pot trial with *P. caribaea* that soil nitrate depressed the yield of *P. caribaea* in this early stage of the trial, but that there was no growth depression after thirty weeks.

Sulphur had a significant effect (0.01 level) on total dry weight (table 8.11). The "minus sulphur" treatments averaged over all soils and provenances had a mean total dry weight of 0.51 g/seedling, whereas the plus sulphur treatments had a mean of 0.57 g/seedling. Bevege and Simpson (1973) have also noted the importance of sulphur for growth of *P. caribaea* provenances in an omission trial.

The trace element mixture also had a significant effect (0.01 level) on total dry weight (table 8.11). The "minus T" treatments averaged over all soils and provenances had a mean of 0.50 g/seedling and the mean for the "plus T" treatments was 0.57 g/seedling. Bevege and Simpson (1973) and Nikles (pers. comm.) have shown that there is a large variation in response of *P. caribaea* provenances to trace elements in pot and field trials respectively.

The N x S interaction was significant at the 0.001 level (table 8.11). Sulphur and nitrogen added by themselves decreased total dry weight production relative to the control. Sulphur and nitrogen added together markedly increased dry weight production (table 8.12). Youngberg and Dyrness (1965) also noted an N x S interaction in terms of dry weight, with *P. ponderosa* on pumice soils.

The P x N x S interaction was significant at the 0.05 level for total dry weight (table 8.11). The S x N interaction was only small without phosphorus application. When phosphorus was added, there was a substantial increase in growth of the PNS treatment (0.92 g/seedling) over the P(0.74g), PN (0.67g) and PS(0.72g) treatments (table 8.12). The P x N x S interaction is also shown in photos 4 and 5. Cameron (1971) reported P x N x T interaction with *Khaya senegalensis* on a lateritic red earth and lateritic podzolic in a glasshouse trial at Darwin. He suggested the significant nutrient in the T component could be sulphur. Youngberg and Dyrness (1965) noted a significant P x N x S interaction with *P. ponderosa* in a glasshouse trial on four pumice soils. Klemmedson and Ferguson (1973) have also reported this interaction on infertile sulphur-deficient granitic soils with *Purshia tridentata* as the test species.

The P x T interaction was significant at the 0.05 level (table 8.11). Zinc could possibly have been an important element in the T component, since the phosphorus/ zinc ratio had the highest correlation with growth on the PBO-10 cm soil, high P/Zn ratios have been noted on the areas of poor growth on the local nutrition trial at Three Ways, and also because there has been a response to zinc in terms of needle length and needle colour in this same trial.

TABLE 8.12

Interactions between P, S and N in terms of total dry weight (g/seedling) (averaged over all soils and provenances).

	S0	S1
N0	0.53	0.51
N1	0.49	0.62

	S0	S1
P0	0.32	0.32
P1	0.70	0.81

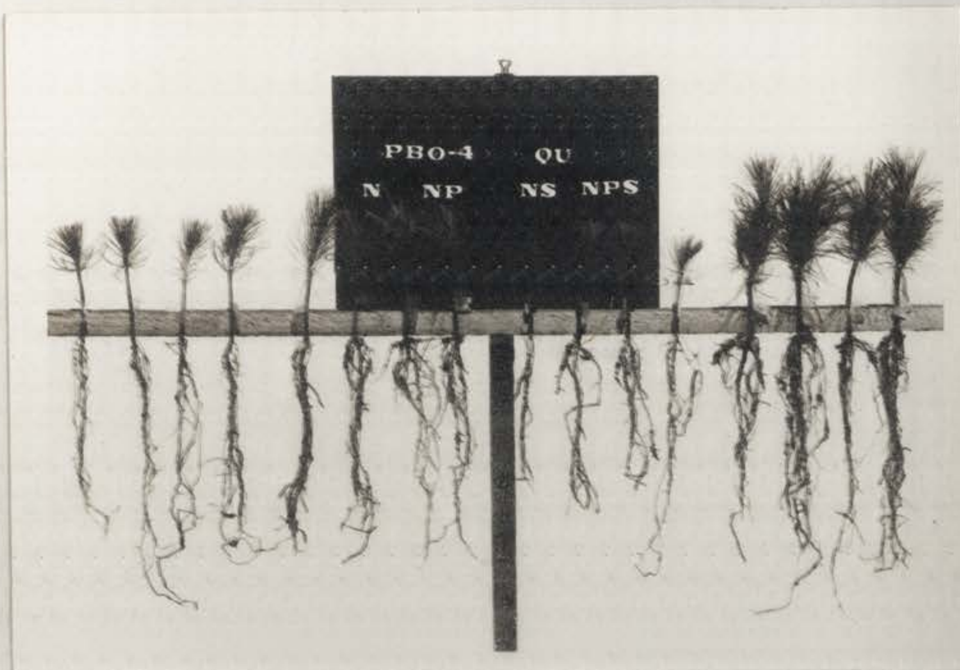
	P0S0	P0S1	P1S0	P1S1
N0	0.32	0.31	0.74	0.72
N1	0.31	0.34	0.67	0.92

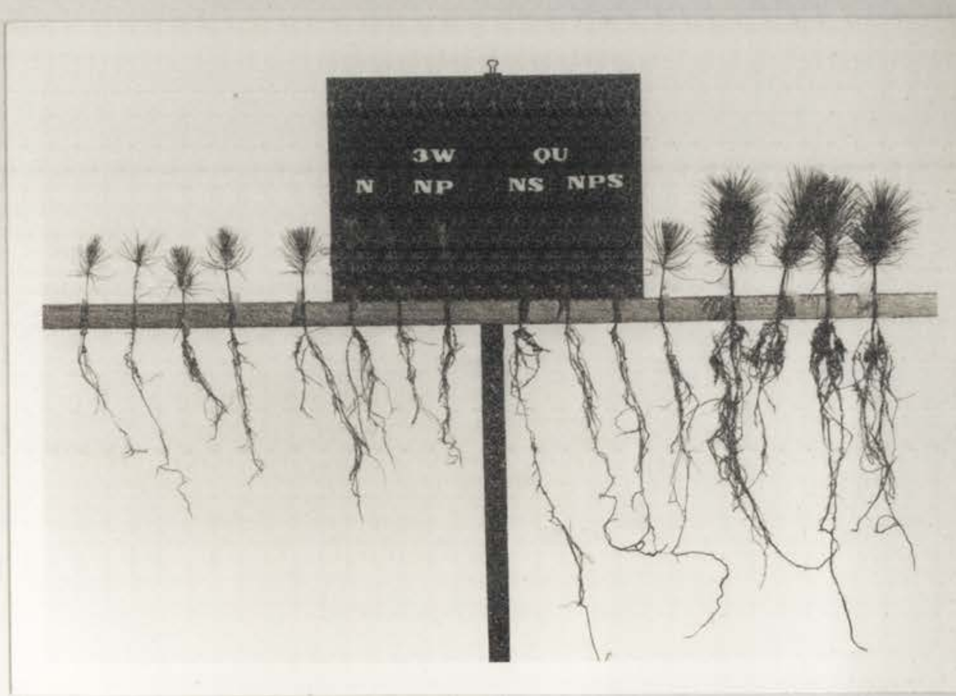
0 = Minus application

1 = Plus application

PHOTOS 4 AND 5

Response of the Queensland provenance of *P. caribaea* to the NPS treatment.





Safaya (1976) reported the P x Zn interaction with maize in terms of shoot dry weight. Edwards (1974) has also observed this interaction with wheat in terms of top dry weight on a Darling Downs black earth.

The P x S interaction was significant at the 0.05 level (table 8.11). The larger response was to phosphorus, but the addition of sulphur resulted in a slight increase in total dry weight (Table 8.12).

Phosphorus application influenced branch number, since the eight treatments with the largest number of branches all included phosphorus (figure 8.7). This could be related to the large influence of phosphorus on growth. Nitrogen also had an influence on branch number, since the nitrogen treatments were at the higher end of the "minus phosphorus" and "plus phosphorus" treatments in terms of branch numbers. Knight (1973) observed an increase in the net number of branches with increase in nitrogen supply for *P. radiata*.

Fertilisers had a significant effect (0.001 level) on the shoot/root ratio (table 8.1). This ratio was the least significantly influenced by fertilisers of the three dry weight ratios. The range of shoot/root ratios for the sixteen fertiliser regimes (averaged over all soils and

FIGURES 8.7 AND 8.8

EFFECT OF FERTILISERS (AVERAGED OVER THREE SOILS AND THREE PROVENANCES) ON NUMBER OF BRANCHES AND THE SHOOT/ROOT RATIO

FIGURE 8.7

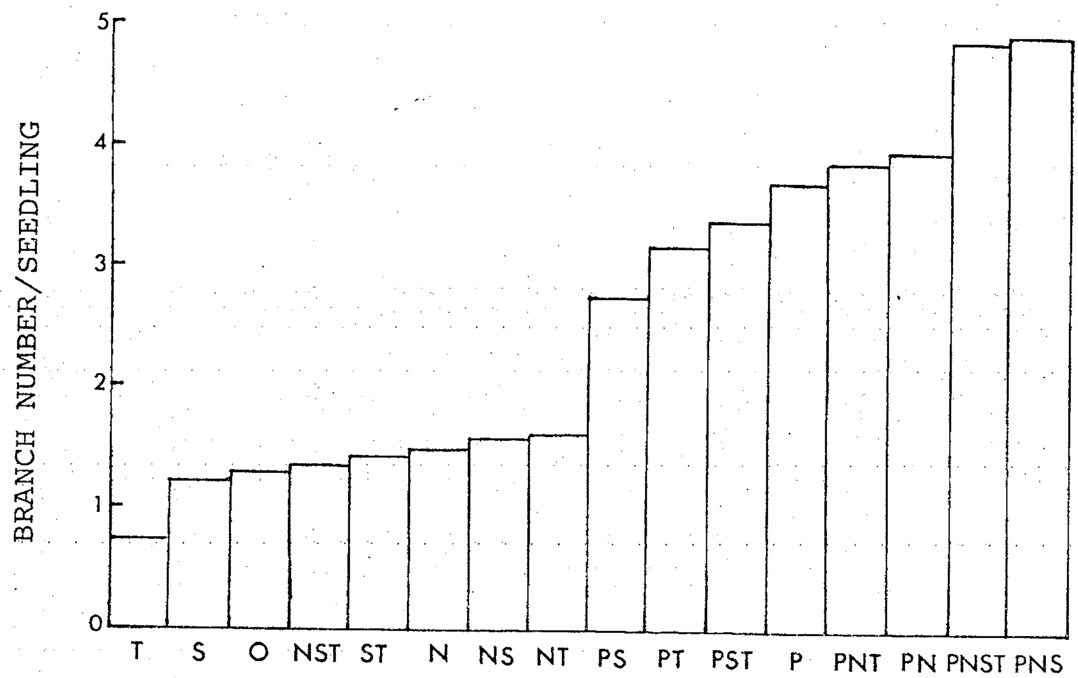
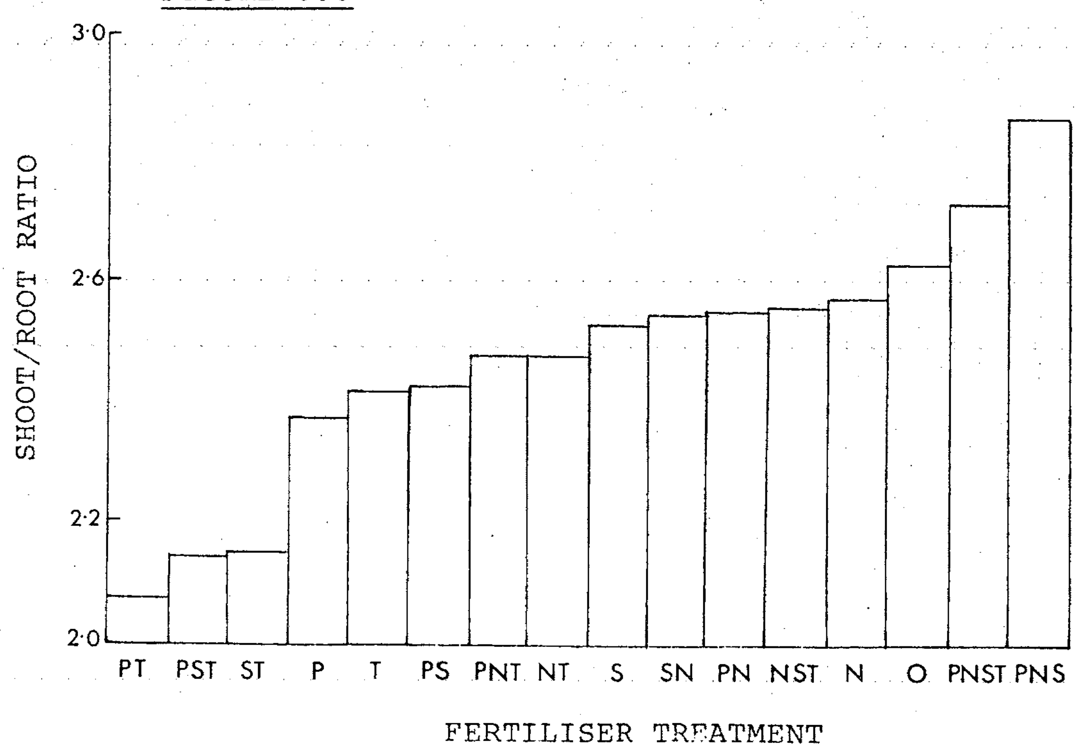


FIGURE 8.8



provenances) was from 2.1 to 2.9 (figure 8.8). Nitrogen appeared to have the major influence on this ratio, since at the low ratios from 2.1 to 2.4, nitrogen was not included in any of these treatements.

Travers (1965) found the shoot/root ratio in a *P. radiata* PNK trial varied between 2.62 and 6.25. He noted that the ratio increased with increasing phosphorus and nitrogen, but that nitrogen was the more important. Aldrich-Blake (1932) also reported the shoot/root ratio increased with increasing nitrogen supply. The results found by both these authors are thus in agreement with the results found for *P. caribaea* in this trial.

The foliage/total dry weight ratio ranged from 0.47 to 0.54 for the sixteen fertiliser regimes (averaged over all soils and provenances) (figure 8.9). The most influential factor on this ratio appeared to be the nitrogen/sulphur ratio. The foliage/total dry weight ratio was low for treatments with nitrogen and without sulphur. The ratio increased when nitrogen and sulphur were added without phosphorus, and increased to a maximum with the PNS treatment. The above ratios are considerably higher than those observed by Steinbeck (1971) with American sycamore *(Platanus occidentalis)*. With increasing concentration of Hoagland's solution from 0.1 strength to triple strength, this ratio increased from 0.26 to 0.31.

FIGURES 8.9 AND 8.10

EFFECT OF FERTILISERS (AVERAGED OVER THREE SOILS AND THREE PROVENANCES) ON DRY WEIGHT RATIOS

FIGURE 8.9

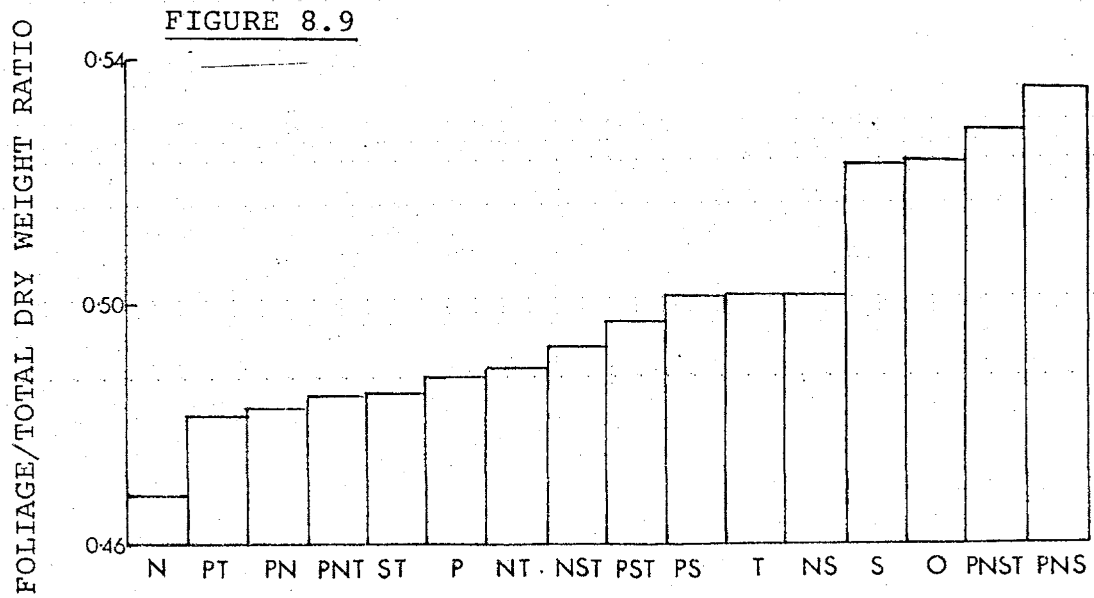
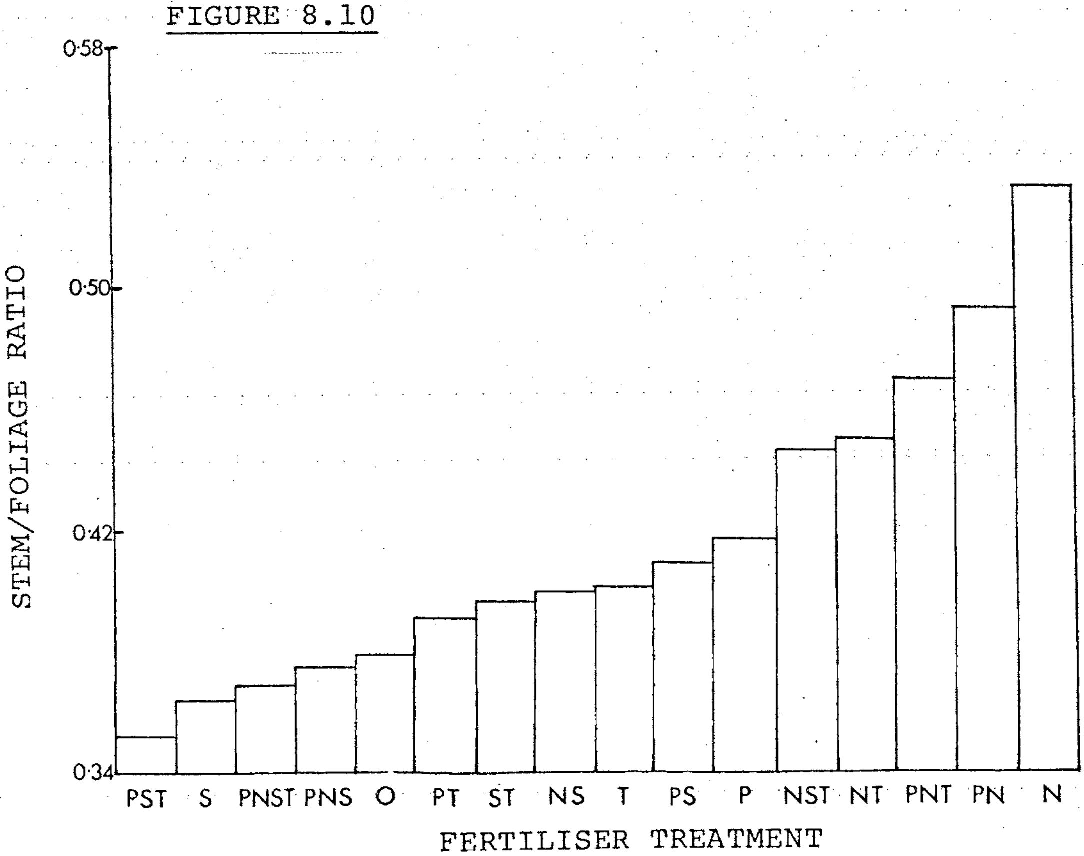


FIGURE 8.10



The nitrogen/sulphur ratio appeared to be also influencing the stem/foliage ratio (figure 8.10), which ranged from 0.35 to 0.53. The ratio was high when nitrogen was applied and sulphur was not. This indicated that nitrogen application results in the seedlings having more dry weight in the stems than the foliage relative to other fertiliser treatments.

8.3.4 Concentration and Uptake of Phosphorus, Nitrogen and Cations Three Months After Fertilisation

Shoot phosphorus concentration ranged from 0.040 to 0.214% for the sixteen fertiliser treatments (averaged over the PBO-10 cm and Three Ways soils and all provenances) (table 8.13). Application of phosphorus considerably increased this concentration. Application of nitrogen, sulphur and trace elements caused a reduction in the phosphorus concentration.

Nitrogen concentrations ranged from 1.4% to 3.0% for the same treatments as above for phosphorus concentration (table 8.13). Phosphorus application without nitrogen caused a reduction in the nitrogen concentration compared to the treatments without both nitrogen and phosphorus application (table 8.13). Phosphorus application with nitrogen did not result in a marked decrease in nitrogen concentrations compared to nitrogen application without

TABLE 8.13

Effect of fertiliser treatments on three phosphorus - nitrogen variables (averaged over two soils and three provenances)

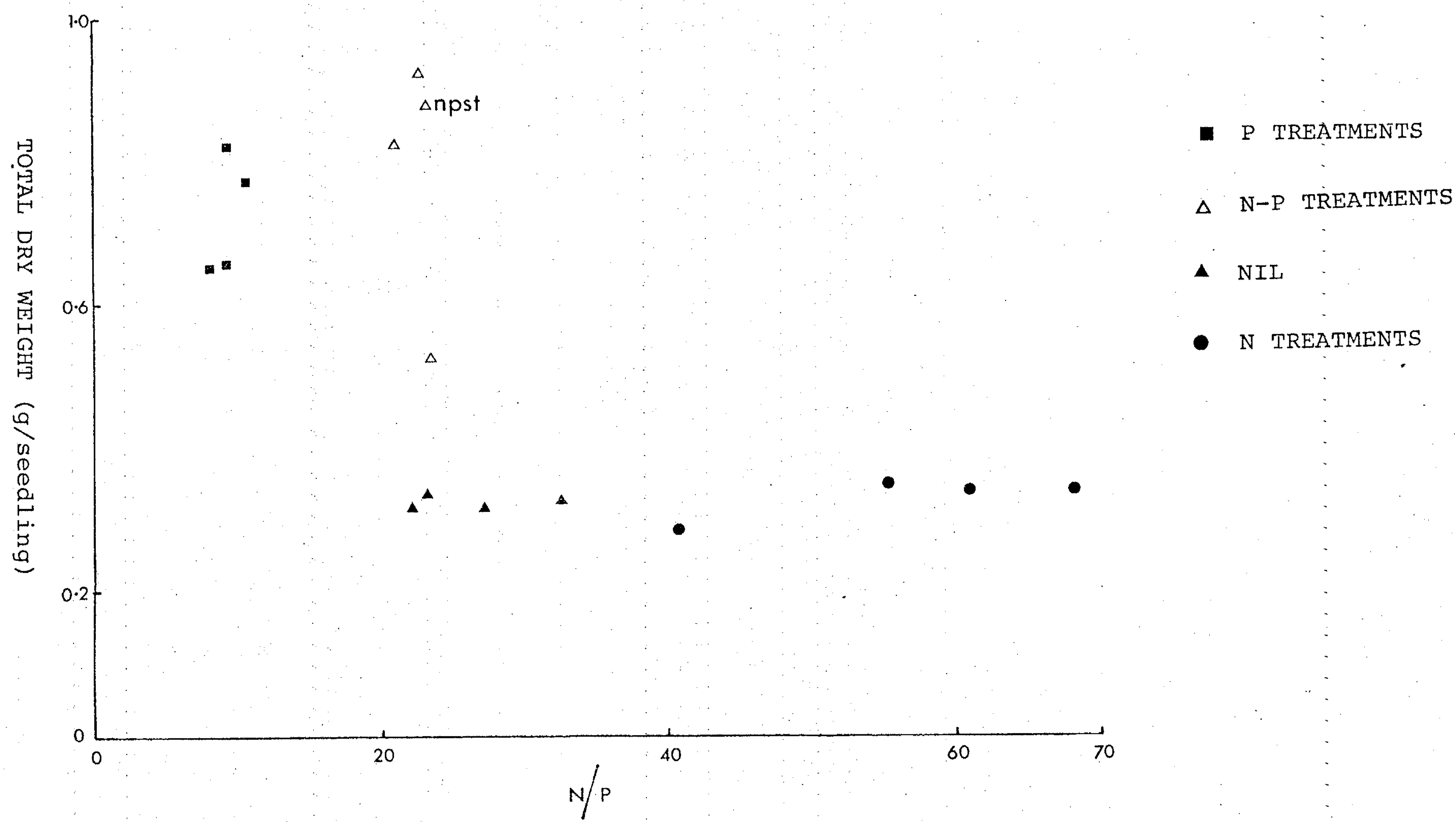
Fertiliser Regime	Shoot P Concentration (%)	Shoot N Concentration (%)	Total P Uptake (mg/seedling)
0	0.083	2.0	0.28
T	0.086	2.0	0.27
S	0.067	1.8	0.19
ST	0.064	2.1	0.19
P	0.214	1.7	1.37
PT	0.149	1.4	1.21
PS	0.157	1.5	0.98
PST	0.144	1.6	1.16
N	0.068	2.8	0.17
NT	0.048	2.7	0.18
NS	0.048	3.0	0.15
NST	0.040	2.7	0.15
PN	0.122	3.0	0.61
PNT	0.122	2.6	1.02
PNS	0.113	2.6	1.18
PNST	0.105	2.5	0.91

phosphorus, but did result in a marked decrease in the N/P ratios.

The N/P ratios ranged from 8 to 68 (Figure 8.11). Application of phosphorus caused a marked reduction in the N/P ratios to between 8 and 11. Application of nitrogen without phosphorus resulted in ratios ranging from 42 to 68. Application of phosphorus and nitrogen resulted in ratios ranging from 21 to 24. Increasing the nitrogen supply was of benefit to the seedings in terms of total dry weight when phosphorus was also applied (figure 8.11), since the treatments with phosphorus and nitrogen had larger dry weights than the treatments with phosphorus and without nitrogen (except for the PN treatment). There did not appear to be a nitrogen deficiency for these later treatments since the nitrogen concentration ranged from 1.4% to 1.7%. The PNS treatment had the optimum dry weight production (averaged over all soils and provenances). The N/P ratio for this treatment was 23 (figure 8.11). This is considerably higher than the authors below have noted. However, it is probable that this ratio would have been lower if the nitrogen application had been lower.

Nitrogen application without phosphorus did not appear to affect total dry weight production relative to the seedlings without both nitrogen and phosphorus application

FIGURE 8.11 RELATIONSHIP BETWEEN TOTAL DRY WEIGHT AND THE N/P RATIO FOR SIXTEEN FERTILISER REGIMES (AVERAGED OVER TWO SOILS AND THREE PROVENANCES)



(figure 8.11). However, nitrogen application resulted in the N/P ratios increasing substantially over the seedlings without nitrogen and phosphorus. This will be further considered in the Ainslie trial.

Clarke (1971) noted an N/P ratio of 10 as optimum for *P radiata*, and that 6 and 16 were the limits for an acceptable N/P balance. Richards (1959) found the optimum yield occurred at an N/P ratio of 10.4 with *P. taeda* in a pot trial. Van Goor (1953) reported the optimum ratio for Japanese Larch *(Larix leptolepis)* ranged from 9.2 to 11.5.

The Queensland, M.P.R. and Alamicamban provenances had seed N/P ratios of 4.8, 5.2 and 5.4 respectively (table 6.2). However, the treatments without both nitrogen and phosphorus had N/P ratios ranging from 23 to 33 (figure 8.11). This indicated that nitrogen was more available in the soil than phosphorus.

Total phosphorus uptake (foliage, stems and roots) ranged from 0.15 to 1.37 mg/seedling for the sixteen fertiliser regimes (averaged over all soils and provenances) (table 8.13). Nitrogen and sulphur (without phosphorus) appeared to cause reduction in phosphorus uptake relative to the control. The trace element mixture appeared to be having little influence on phosphorus uptake. The phosphorus concentrations for the control, trace element, sulphur and nitrogen treatments were respectively 0.083%, 0.086%, 0.067% and 0.068% (table 8.13). The critical value for phosphorus is in the range from 0.065% to 0.070% (Anon., 1975). Thus, sulphur and nitrogen were possibly causing a deficiency of phosphorus, and this then restricted growth and phosphorus uptake.

In general, nitrogen, sulphur, and trace element application caused a reduction in phosphorus concentration with and without phosphorus application (Table 8.13). This was due to the face that deficiencies were corrected, with the result that phosphorus was utilised more efficiently.

A correlation analysis was conducted using SPSS sub-programme REGRESSION. Nitrogen and phosphorus variables were correlated with total dry weight for two soils and all provenances and fertiliser regimes. Shoot phosphorus uptake (foliage and stem) was most highly correlated with total dry weight production (r = 0.92, table 8.14). Shoot nitrogen uptake had a correlation coefficient with total dry weight of 0.85. However, the reason for this was that phosphorus, due to its substantial influence on growth, caused an increase in nitrogen uptake. Indeed shoot phosphorus uptake

TABLE 8.14

Correlation coefficients between plant chemical and total dry weight variables.

	PCS	NCS	PCR	NCR	UPS	UNS	TOT
PCS	-	-	-	-	-	-	-
NCS	-0.50	-	-	-	-	-	-
PCR	0.83	-0.44	-	-	-	-	-
NCR	-0.32	0.84	-0.20	-	-	-	-
UPS	0.78	-0.41	0.75	-0.22	-	-	-
UNS	0.24	0.20	0.40	0.32	0.68	-	-
TOT	0.52	-0.28	0.59	-0.11	0.92	0.85	-

PCS = shoot phosphorus concentration

NCS = shoot nitrogen concentration

PCR = root phosphorus concentration

NCR = root nitrogen concentration

UPS = shoot phosphorus uptake

UNS = shoot nitrogen uptake

TOT = Total dry weight

had a correlation coefficient 0.68 with shoot nitrogen uptake. Shoot phosphorus concentration was less correlated with total dry weight (r = 0.52), since nitrogen concentration relative to phosphorus concentration had an important influence on total dry weight production (Figure 8.11).

The distribution of phosphorus and nitrogen between the foliage, stems and roots was also studied on the PBO-10 cm and Three Ways soils for phosphorus treatments only (averaged over all provenances). The phosphorus concentration was highest in the foliage in fourteen of sixteen cases (Table 8.15). The mean value for foliage phosphorus concentration over the eight fertiliser regimes on each soil was 0.15%. There was no clear relationship between the stems and roots, but the mean phosphorus concentration over the eight treatments was slightly higher in the stems (0.11%) than the roots (0.10%) for both soils.

The foliage had the greatest nitrogen concentration for all treatments (averaged over the three provenances) on both soils (Table 8.15). The roots had a higher nitrogen concentration than the stems in thirteen of the sixteen cases. The foliage, stem and root nitrogen concentrations over the eight fertiliser regimes were 2.4%, 1.1% and 1.2% respectively on the PBO-10 cm soil and 2.6%, 1.2%

TABLE 8.15

Effect of fertilisers (averaged over three provenances) on the phosphorus and nitrogen concentration of the foliage, stems and roots.

Soil and Treatment		P CONCENTRATION (%)			N CONCENTRATION (%)		
		Foliage	Stems	Roots	Foliage	Stems	Roots
PBO-10	P	0.24	0.20	0.13	2.2	0.9	1.0
	PT	0.18	0.11	0.10	1.7	0.6	0.9
	PN	0.13	0.08	0.09	3.0	1.6	1.6
	PNT	0.12	0.10	0.09	2.9	1.4	1.5
	PS	0.16	0.14	0.14	2.0	1.0	1.0
	PST	0.16	0.10	0.09	1.9	0.6	0.8
	PNS	0.13	0.08	0.10	2.8	1.3	1.7
	PNST	0.11	0.06	0.08	2.6	1.1	1.4
MEAN		0.15	0.11	0.10	2.4	1.1	1.2
3W	P	0.20	0.20	0.11	1.9	0.7	0.8
	PT	0.16	0.12	0.10	1.8	0.6	0.9
	PN	0.15	0.10	0.06	3.7	2.7	2.1
	PNT	0.13	0.08	0.09	3.2	1.6	1.7
	PS	0.17	0.13	0.11	1.6	0.6	0.8
	PST	0.16	0.11	0.11	1.8	0.6	0.9
	PNS	0.12	0.08	0.10	3.3	1.5	1.8
	PNST	0.10	0.08	0.10	3.7	1.6	1.8
MEAN		0.15	0.11	0.10	2.6	1.2	1.4

and 1.4% respectively on the Three Ways soil. There was a larger difference between the foliage and the roots or stems in terms of nitrogen concentration than phosphorus concentration. This was possibly due to the fact that phosphorus was the most important nutrient for plant growth and was thus rapidly utilised once it entered the foliage.

A correlation analysis was conducted on the P/Ca, P/Mg, P/K,P/Zn and P/Mn concentration ratios with total dry weight for the PBO-10 and Three Ways soils, the three provenances and all treatments including phosphorus. This was done using SPSS subprogramme REGRESSION. All the ratios had negative correlation coefficients with total dry weight except for the P/Mg ratio on the Three Ways soil (table 8.16). This indicated the importance of these cations for plant growth.

All the ratios were larger on the Three Ways soil than the PBO-10 cm soil except for the P/Zn ratio (table 8.16). The P/Zn ratio was also most highly correlated with total dry weight on the PBO-10 cm soil (-0.28) and second most highly correlated with total dry weight on the Three Ways soil (-0.25). Because of these factors it was decided to investigate the influence of fertiliser regimes on this ratio (phosphorus was included in all the regimes) on the above two soils. On the Three Ways soil the range of

TABLE 8.16

Phosphorus/cation concentration ratios (averaged over three provenances and eight phosphorus fertiliser treatments) and correlation coefficients of these ratios with total dry weight.

Ratio	3W	PBO-10	Correlation Coefficients 3W	Correlation Coefficients PBO-10
P/Ca	0.48	0.38	- 0.37	- 0.19
P/Mg	0.73	0.65	+ 0.12	- 0.06
P/K	0.13	0.09	- 0.11	- 0.04
P/Zn	36	77	- 0.25	- 0.28
P/Mn	5.8	3.7	- 0.13	- 0.14

P/Zn ratios for the eight phosphorus treatments (over all provenances) was from 22 to 48, but on the PB0-10 cm soil it was from 33 to 153 (Figure 8.12). The highest ratios occurred for the P and PS treatments on both soils. Indeed, the P treatment on the PBO-10 soil had the P/Zn ratio of 153. Dwivedi, Randhawa and Bansal (1975) reported the optimum P/Zn ratio for maize was 50. It was thus quite probable that the *P. caribaea* seedlings treated with phosphorus only were zinc deficient on the PBO-10 soil.

The ratio averaged 36 on the Three Ways soil and 77 on the PBO-10 cm soil (table 8.16). The larger ratio on the PBO-10 soil was probably due to a larger phosphorus uptake and a smaller zinc uptake on this soil compared to the Three Ways soil (Tables 8.8 and 8.9).

8.4 Interactions Between Soil, Fertiliser and Provenance

GENSTAT was used to determine the interactions between soils, fertilisers and provenances for growth factors only.

8.4.1 Soil x Fertiliser Interaction

With the sixteen fertilisers pooled in an analysis of variance, the soil x fertiliser interaction was significant for all variables except for the shoot/root and foliage/total dry weight ratios and number of branches (Table 8.1). With the sixteen fertiliser regimes not pooled (total dry weight as the variable), the only significant interaction was the soil x phosphorus interaction, which was significant at the 0.001 level (table 8.11). Seedlings on the PBO-10 cm soil were most responsive to phosphorus, with an increase in total dry weight over the treatments without phosphorus of 194%, and seedlings on the PB10-25 cm soil were least responsive with an increase of 84% (table 8.17). The reasons for the differences in response have been discussed in sections 8.2.1 and 8.2.2. It is of interest to note the response without phosphorus. The seedlings on the PBO-10 cm soil were most responsive, and on the Three Ways soil least responsive (table 8.17). This trend reflected the total soil phosphorus concentration of the three soils (table 6.3).

The soil x fertiliser interaction was significant at the 0.05 level for needle-tip height two months after fertilisation, whereas it was significant at the 0.001 level for needle-tip height three months after fertilisation (table 8.1). This indicated that the difference in response of the three soils to phosphorus was increasing with time. Indeed, the three provenances were all responding to phosphorus (in terms of height growth) at a greater rate on the PBO-10 cm soil than the Three Ways soil (Figures 8.5 and 8.6).

TABLE 8.17

Effect of phosphorus addition on total dry weight production (averaged over all provenances) (g/seedling)

Soil	Po	P_1	% Response
PBO-10	0.34	1.00	194
PB10-25	0.32	0.59	84
3W	0.30	0.68	127

8.4.2 Soil x Provenance Interaction

The soil x provenance interaction was significant at the 0.05 level for foliage, root and total dry weight and needle-tip height (two months after fertilisation), and not signficant for all other growth variables (Table 8.1). The main conclusion, in terms of total dry weight, was that the Queensland provenance responded best on all the soils and the Alamicamban provenance least (Table 8.2).

Bevege and Simpson (1973) and Nikles (pers. comm.) have both obtained provenance x site interactions, in terms of height increment, on a grey sandy clay swamp soil and a brown clay loam ridge soil with different provenances of *P. caribaea*. Bevege and Simpson (1973) obtained their interaction in a pot trial whereas Nikles (pers. comm.) obtained his interaction in the field.

8.4.3 Provenance x Fertiliser Interaction

This interaction was significant for all variables except for stem height (cotyledons upwards to where stem ends), root dry weight, the stem/foliage dry weight ratio and number of branches (Table 8.1). This interaction indicated that the three provenances exhibited differential deficiencies and sensitivities.

The provenance x S interaction was highly significant (0.001 level) for total dry weight (fertilisers not pooled)

TABLE 8.18

Effect of phosphorus and sulphur addition on total dry weight production of three provenances (averaged over all soils) (g/seedling).

	S0	S1
QU	0.57	0.70
M.P.R.	0.50	0.57
ALA	0.47	0.43

	PO	P1	% Increase
QU	0.38	0.89	134
M.P.R.	0.34	0.72	112
ALA	0.24	0.65	171

	POSO	POS1	P1SO	P1S1
QU	0.35	0.40	0.78	1.01
M.P.R.	0.35	0.34	0.66	0.79
ALA	0.26	0.23	0.68	0.62

0 = Minus application

1 = Plus application

(table 8.11). This interaction was significant since the Alamicamban provenance responded negatively to sulphur addition (averaged over all soils), while the M.P.R. and Queensland provenances responded positively (table 8.18). The negative response of the Alamicamban provenance to sulphur is also shown, in terms of height response, in figures 8.5 and 8.6. Bevege and Simpson (1973) have also shown that the Alamicamban provenance was more sulphur sensitive than the M.P.R. provenance on ridge and swamp soils, using height increment from four to six months as an index. Thus, it is possible that this provenance is truly sulphur sensitive.

The provenance x P interaction was significant at the 0.01 level in terms of total dry weight (table 8.11). The Alamicamban provenance was most responsive when averaged over all soils, since there was a 171% increase in total dry weight of the phosphorus treatments over the treatments without phosphorus (table 8.18). The M.P.R. was least responsive with an increase of 112%. This provenance also had higher phosphorus concentrations on the PBO-10 cm and Three Ways soil (table 8.8), indicating less efficient utilisation of phosphorus. Bevege and Simpson (1973) have also shown that the M.P.R. provenance was more sensitive to phosphorus application than the Alamicamban provenance on ridge and swamp soils.

The provenance x P x S interaction was significant at the 0.05 level for total dry weight (table 8.11). The Queensland provenance responded to sulphur with and without phosphorus (table 8.18). The M.P.R. provenance did not respond to sulphur without phosphorus and the Alamicamban provenance responded negatively to sulphur with and without phosphorus.

The provenance x N x T x S interaction was also significant (table 8.11). All other provenance x fertiliser interactions were not significant.

8.4.4. Soil x Provenance x Fertiliser Interaction

This was not significant in this trial for any of the variables studied (table 8.1). Indeed, this interaction was slightly less significant in terms of needle-tip height three months after fertilisation than two months after fertilisation.

8.5 Mycorrhizae

8.5.1 Influence on Growth

The pots were inoculated with *Suillus* aff. *granulatus* and *Rhizopogon roseolus* one month after fertilisation, allowing a period of two months for mycorrhizal development. It was realised from the time of collection of the soil that the Three Ways soil could have had mycorrhizae present since the collection site was beside a *P. caribaea* International Provenance trial and a local nutrition trial.

An analysis of variance, using ANOVA, showed that the mycorrhizal effect was significant for all growth variables. (table 8.19). The mycorrhizae x fertiliser, soil and provenance interactions were not significant for height or total dry weight, but the mycorrhizae x soil interaction was significant for the shoot/root ratio.

All provenances were responding to mycorrhizal inoculation, in terms of dry weight, at both levels of nutrition, except for three cases (figures 8.13 and 8.14). With the PNST treatment the response to mycorrhizal inoculation was larger than the response at the nil fertiliser level in four out of the nine cases (table 8.20). This was odd since Dumbroff (1968) reported an inverse relationship between supply of nitrogen and phosphorus and intensity of mycorrhizal development with *Pinus elliottii* and Richards and Wilson (1963) noted this same trend with *P. caribaea*. Anthony (1971) did not find an inverse relationship between nitrogen content and mycorrhizal growth for *P. caribaea*.

The N/P ratio for the PNST treatment averaged over all soils and provenances was 24 (figure 8.11). As previously noted this ratio is high compared to ratios found

TOT	=	Total Dry Weight per seedling
HT	=	Needle-tip height
SR	=	Shoot/Root ratio
PCN	=	Shoot (stem and foliage) phosphorus concentration
NCN	=	Shoot nitrogen concentration
P.UPT	=	Shoot phosphorus uptake per seedling

***	Significant	at	0.001	probability	level
**	"	"	0.01	"	"
*	"	"	0.05	"	"

TABLE 8.19

Analysis of variance on six seedling variables using three provenances, with and without mycorrhizal inoculation, at two levels of nutrition on three different soils.

F Value and Significance

SOURCE OF VARIATION	D.F.	TOT	HT	SR	PCN	NCN	P. UPT.
Main effects	6	31.50***	19.63***	6.45***	8.73***	7.15***	22.33***
Myc.	1	6.07*	4.86*	19.13***	6.04*	8.52**	8.10*
Nutr.	1	144.19***	78.97***	1.12 NS	7.96*	18.63***	91.80***
Soil	2	9.59**	8.70**	4.35*	19.10***	6.30**	11.24***
Prov.	2	9.77**	8.27**	4.88*	0.10 NS	1.56 NS	5.78*
2-Way Interaction	13	0.258 NS	0.99 NS	2.45*	4.91**	0.76 NS	2.76*
Myc. x Nutr.	1	2.44 NS	0.58 NS	0.06 NS	11.54**	0.40 NS	0.08*
Myc. x Soil	2	0.01 NS	0.17 NS	7.55**	7.36**	1.09 NS	0.91 NS
Myc. x Prov.	2	0.45 NS	0.91 NS	1.44 NS	5.38*	0.76 NS	2.62 NS
Nutr. x Soil	2	3.91*	3.98*	5.30*	9.18**	0.58 NS	9.28**
Nutr. x Prov.	2	1.97 NS	0.37 NS	0.14 NS	0.85 NS	0.69 NS	0.98 NS
Soil x Prov.	4	0.77 NS	0.37 NS	0.74 NS	1.70 NS	0.82 NS	2.07 NS
Explained	19	10.91***	6.88***	3.71**	6.12***	2.78*	8.94***
Residual	16						
Total	35						

FIGURE 8.13

EFFECT OF MYCORRHIZAL INOCULATION ON SEEDLING VARIABLES WITHOUT FERTILISERS.

FIGURE 8.14

EFFECT OF MYCORRHIZAL INOCULATION ON THREE SEEDLING VARIABLES WITH THE PNST TREATMENT

LEGEND

QNM = Queensland non-mycorrhizal seedlings

QM = Queensland mycorrhizal seedlings

MNM = M.P.R. non-mycorrhizal seedlings

MM = M.P.R. mycorrhizal seedlings

ANM = Alamicamban non-mycorrhizal seedlings

AM = Alamicamban mycorrhizal seedlings

FIGURE 8.13

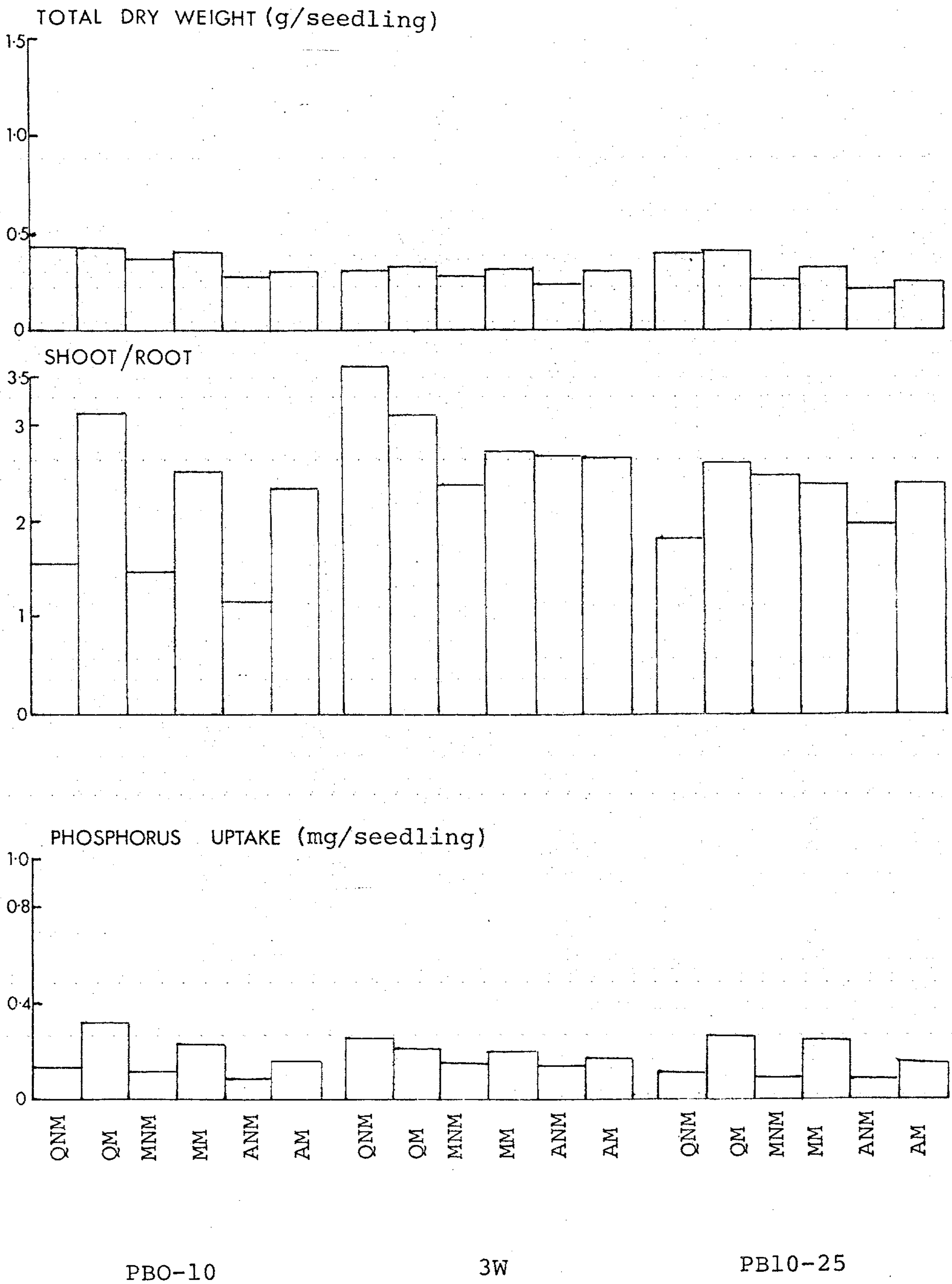

TOTAL DRY WEIGHT (g/seedling)
1·5
1·0
0·5
0
SHOOT/ROOT
3·5
3
2
1
0
PHOSPHORUS UPTAKE (mg/seedling)
1·0
0·8
0·4
0
QNM
QM
MNM
MM
ANM
AM
QNM
QM
MNM
MM
ANM
AM
QNM
QM
MNM
MM
ANM
AM
PBO-10
3W
PB10-25

FIGURE 8.14

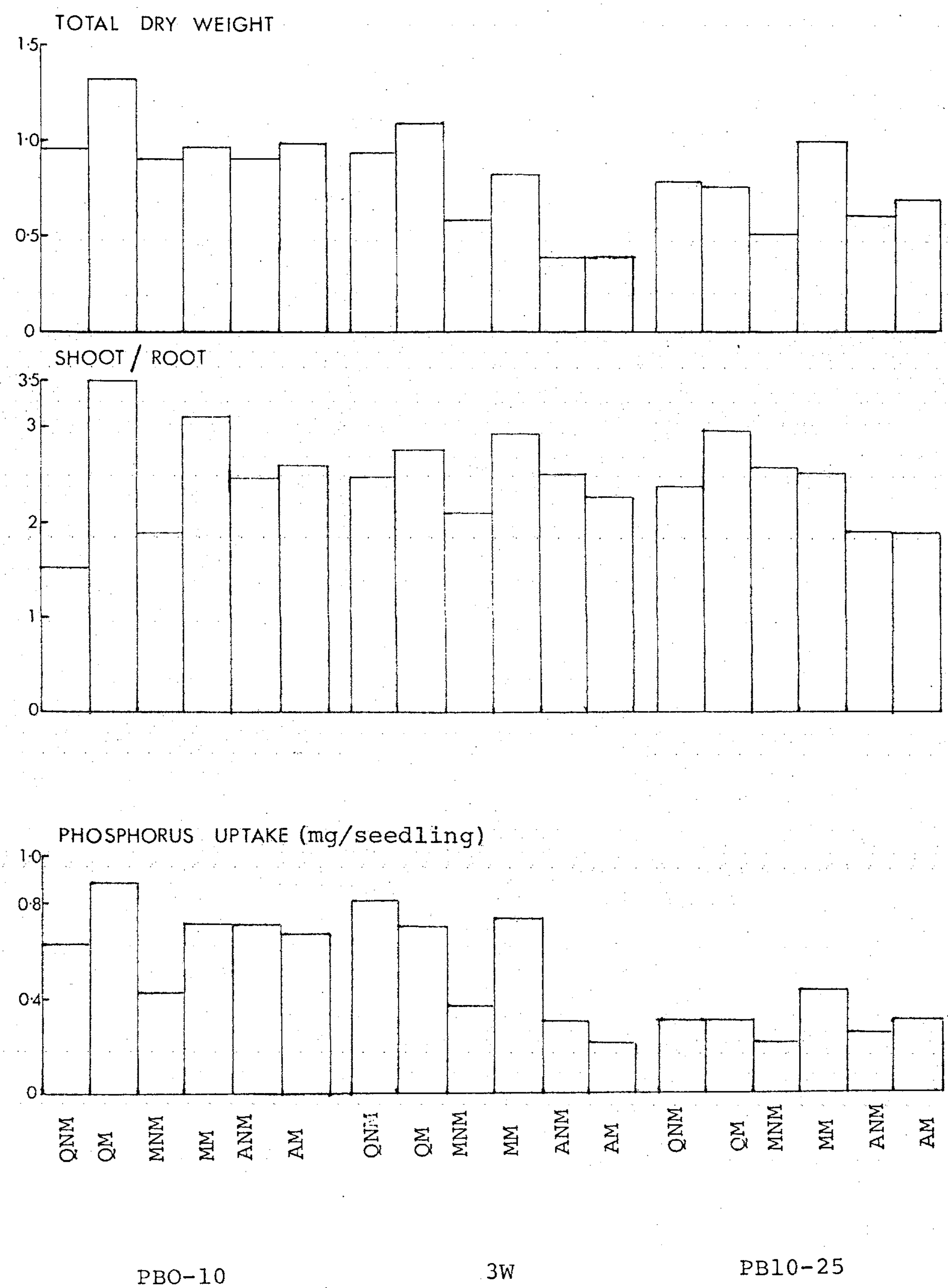

TOTAL DRY WEIGHT
1·5
1·0
0·5
0
SHOOT / ROOT
3·5
3
2
1
0
PHOSPHORUS UPTAKE (mg/seedling)
1·0
0·8
0·4
0
QNM
QM
MNM
MM
ANM
AM
QNM
QM
MNM
MM
ANM
AM
QNM
QM
MNM
MM
ANM
AM
PBO-10
3W
PB10-25

TABLE 8.20

Percentage increase (total dry weight) of mycorrhizal seedlings over the non-mycorrhizal seedlings

Soil and Provenance	Nil Fertiliser	PNST
PBO-10		
QU	- 2	43
M.P.R.	+ 8	7
ALA	+ 11	10
PBO10-25		
QU	+ 5	- 4
M.P.R.	+ 25	+ 88
ALA	+ 19	+ 14
3W		
QU	+ 10	+ 16
M.P.R.	+ 15	+ 42
ALA	+ 35	0

to be optimum for other pine species. It is thus possible that mycorrhizal development was occurring with the PNST treatment due to unbalanced nutrition, since Hatch (1937) suggested that nutrient imbalance favoured mycorrhizal development. However this does not explain the considerable variation in response of the three provenances on the three soils to mycorrhizal inoculation with the PNST treatment.

There were no clear trends among the provenances for response to mycorrhizal inoculation, except for the Queensland provenance, which responded least to inoculation at the nil level of nutrition on all three soils, possibly due to this provenance having a larger amount of nutrients in the seed (table 8.20).

Mycorrhizal inoculation had a significant effect (0.001 level) on the shoot/root ratio (table 8.19). Inoculation increased the ratio (figures 8.13 and 8.14). This was especially evident on the PB0-10 cm soil at both levels of nutrition, except in the case of the Alamicamban provenance with the PNST treatment. Inoculation had a smaller influence on this ratio on the Three Ways soil. This could have been due to the fact that mycorrhizae were already present when the soil was collected. Inoculation had little influence on the shoot/root ratio of the M.P.R. and Alamicamban provenances on the PB10-25 cm soil, but increased the ratio of the Queensland provenance at both levels of nutrition. The large influence of inoculation on the shoot/root ratio on PBO-10 cm soil and the smaller influence on the other two soils, explained why the mycorrhizae x soil interaction was significant for this variable (0.01 level)(table 8.19).

Richards (1959) also noted the influence of mycorrhizae on the shoot/root ratio with *Pinus taeda*. With low phosphorus application the shoot/root ratio was 1.54, and with high phosphorus the ratio was only increased to 1.58. However, when mycorrhizae were applied the ratios were respectively 1.63 and 2.04.

8.5.2 Mycorrhizae Influence on Concentration and Uptake of Nutrients

Inoculation had a significant effect on shoot phosphorus concentration (0.05 level). The mycorrhizae x fertiliser interaction and mycorrhizae x soil interactions were significant at the 0.01 level and the mycorrhizae x provenance interaction was significant at the 0.05 level for shoot phosphorus concentration (table 8.19). Inoculation had a significant effect (0.05 level) on shoot phosphorus uptake. However, no interactions between mycorrhizae and fertilisers, soil and provenance were significant for this variable. Mycorrhizae increased phosphorus uptake in most cases (Figures 8.13 and 8.14).

Inoculation had a significant effect (0.01 level) on shoot nitrogen concentration (table 8.19). Inoculation resulted in a decrease in nitrogen concentration with all provenances at the nil fertiliser level on all three soils (Table 8.21). However, at the high fertiliser level, inoculation resulted in a decrease in shoot nitrogen concentration in only four cases out of nine (table 8.21). Inoculation resulted in a decrease in nitrogen concentration with the Queensland and M.P.R. provenances on the two Point Blaze soils, but not on the Three Ways soil. Inoculation did not result in a decrease in the nitrogen concentration with the Alamicamban provenance on any of the three soils (at high level of nutrition).

TABLE 8.21

Effect of mycorrhizal inoculation on shoot nitrogen concentration of seedlings with and without fertilisation.

Inoculated or Uninoculated	Provenance	Soil	Shoot N Concentration (%) No Fertilisation	Shoot N Concentration (%) PNST Treatment
NM	QU	PBO-10	2.2	2.8
MYC	QU		1.9	1.9
NM	M.P.R.		2.3	3.2
MYC	M.P.R.		1.9	2.2
NM	ALA		2.4	2.3
MYC	ALA		2.0	2.5
NM	QU	PB10-25	1.8	2.5
MYC	QU		1.6	1.2
NM	M.P.R.		1.9	2.7
MYC	M.P.R.		1.8	2.2
NM	ALA		2.2	2.7
MYC	ALA		1.8	2.8
NM	QU	3W	2.6	2.7
MYC	QU		2.1	3.0
NM	M.P.R.		2.5	2.5
MYC	M.P.R.		1.9	3.2
NM	ALA		2.6	3.0
MYC	ALA		2.0	3.1

NM = seedlings not inoculated with mycorrhizae
MYC = seedlings inoculated with mycorrhizae

A I N S L I E   T R I A L

CHAPTER 9.

INTRODUCTION

The trial was a 5 x 5 factorial with five replications testing for the interaction between phosphorus and nitrogen. This trial was not considered in the same detail as the Darwin trial.

9.1 Provenance and Site Details

The Poptun provenance from Guatemala was used in this trial. This provenance is one of the most widely known inland provenances of *P. caribaea* var. *hondurensis* and together with the Mount Pine Ridge stand, these stands are the most important commercial seed source of this variety (Lamb, 1973). The Poptun provenance occurs to the south of the Mount Pine Ridge provenance (map 1). The Poptun provenance grows at a similar altitude (500 metres), has a similar rainfall (1700 mm), and a similar length of dry season (three months), compared to the Mount Pine Ridge provenance (400 metres, 1600 mm, and two months respectively) (tables 9.1 and 6.1).

The Poptun provenance grows on soils with a loam texture in Guatemala (table 9.1). The Mount Ainslie red earth has a sandy loam texture (table 9.2). The pH of the Ainslie soil is slightly less acid (pH 6.2) than the soil in the native range (pH 5.0, table 9.2). This provenance

TABLE 9.1

Site details from which the Poptun provenance originated

Country of Origin	Guatemala
Latitude	16.5^{O}N
Longitude	89.5^{O}W
Altitude	500 metres
Precip.	1700 mm.
Dry Season	3 months
Parent Material	Alluvium
Soil Texture	Loam
Drainage	Good
pH	5.0
Collector of Seed	Timmers and Leyer

would probably grow better if this soil had a lower pH, since Humphreys (1972) has noted that soils with a pH greater than 6.0 could be unsuitable for the growth of *P. caribaea*.

9.2 Soil

This trial, like the Darwin trial, was conducted on a red earth. However, the Ainslie red earth had a much higher fertility status in every important nutrient measured (Table 9.2). The total phosphorus concentration was three times that of the PBO-10 cm soil. However, a response to phosphorus was still expected since the iron concentration of this soil was high and it was expected that the phosphorus present in the soil would be fixed. Also, the total soil phosphorus was low in this soil according to Humphreys' (1972) classification. The total nitrogen concentration was four times that of the PBO-10 cm soil. The total cations and exchangeable cations were both markedly higher on the Ainslie soil. The organic matter and moisture retention were all higher on the Ainslie soil (Table 9.2). This soil fixed less phosphorus at the same initial concentrations of phosphorus than the three Darwin soils (Figure 8.4).

CHAPTER 10.

MATERIALS AND METHODS.

10.1 Design

The design was a 5 x 5 factorial with five replications testing for the interaction between phosphorus and nitrogen. One replicate of each treatment was included in one of five blocks.

10.2 Germination and Maintenance

Seeds were placed on moist filter paper underlain by sand in Petri dishes, placed in the germination cabinet at 25^{o}C until germination occurred (7-8 days), and then transferred to coarse sand containers. When the hypocotyls were three cms long, the seedlings were pricked out over a four day period, with three seedlings per pot.

Field capacity (1/3 bar) was measured at the start of this trial. The seedlings were watered daily with distilled water. The pots were weighed occasionally and the weight adjusted precisely to field capacity. As the phosphorus treatments progressed they received more water relative to the controls.

Temperature throughout the trial was maintained at 18 to 25^{o}C with artificial heating. Artificial lighting was applied to the trial and the seedlings received sixteen hours of light per day.

10.3 Location and Duration

The trial was conducted in the glasshouses at the Forestry Department, A.N.U. over 202 days, 167 of these days with fertiliser.

10.4 Treatments

10.4.1 Soil

A red earth (sandy loam texture) was collected from near the top of Mt. Ainslie in the A.C.T. The site consists of low, open forest with *Eucalyptus bridgesiana* dominant. The 0 to 10 cm layer was collected, with an 0.4 cm sieve, homogenised and dried, and then 1400 gms of this air dry soil (equivalent to 1000 gm air dry, stone-free soil) was put into each pot.

10.4.2 Fertilisers

Fertilisers were applied to the pots 35 days after pricking out. The levels of nitrogen and phosphorus applied are given below:

Nitrogen (milligrams/pot)	Phosphorus (milligrams/pot)
0	0
10	10
20	20
40	40
80	80

Nitrogen was applied as analytical grade NH_4NO_3 and phosphorus as $NaH_2PO_4.2H_20$, both being applied in liquid form evenly over the pot surface. A basal application of elements other than nitrogen or phosphorus was intended but due to circumstances beyond the control of the author this could not be done.

10.4.3 Provenance

P. caribaea var. *hondurensis* was used. The provenance was from Poptun in Guatemala (C.S.I.R.O. Code S11686).

10.5 Measurements

During the trial height was measured every three to four weeks. The height was measured from stem base to the top of the seedling. On termination of the trial, branch number and deficiency symptoms were observed. Dry weight was measured at the end of the trial.

10.6 Harvest Procedure

The three seedlings per pot were bulked and then divided into foliage, stem and roots. The roots were separated from the soil with a jet of tapwater. This material was then placed in paper bags and dried for between 24 and 48 hours at 85^{o}C. for dry weight analysis. All the foliage samples and some of the stem and root material was then ground.

10.7 Chemical Analysis

The same methods for soil and chemical analysis were used as discussed for the Darwin trial.

10.8 Statistical Analysis

(i) ANOVA (SPSS)

ANOVA was used to analyse the main effects of nitrogen and phosphorus and their interactions on eleven different plant growth variables.

(ii) REGRESSION (SPSS)

Correlation coefficients between eleven different variables using SPSS subprogramme REGRESSION were generated.

CHAPTER 11.

RESULTS AND DISCUSSION

11.1 Fertiliser Effect

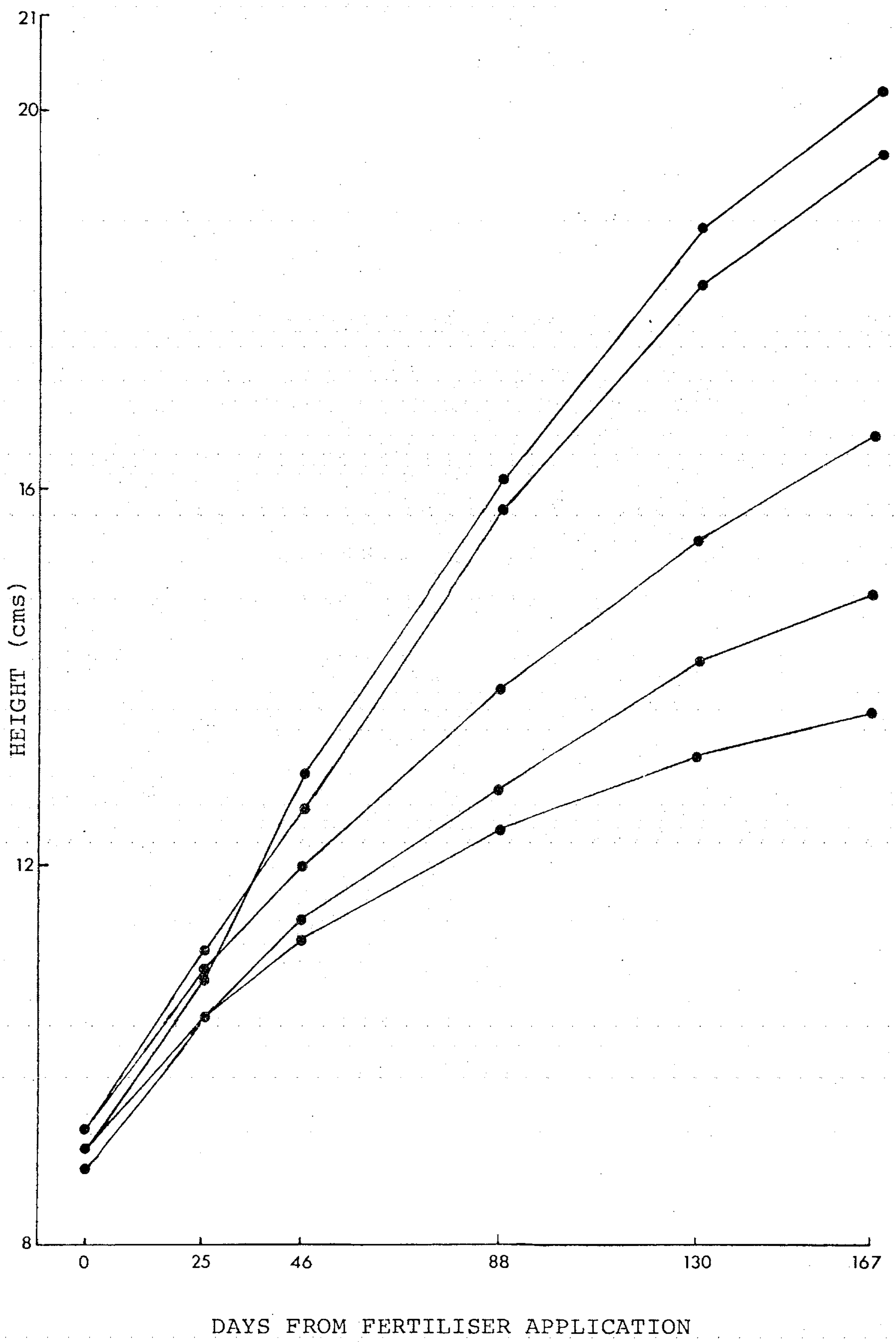
Since there was little response to increasing nitrogen supply in terms of total dry weight (figure 11.2a), only the height response to phosphorus, over time, was examined. The height of the seedlings at the five phosphorus levels (nil nitrogen application) did not markedly diverge twenty-five days after phosphorus application (figure 11.1). This followed the same pattern as the Mount Pine Ridge provenance in Darwin on the Three Ways and PBO-10 cm soils (figures 8.5 and 8.6), since this provenance had not responded to phosphorus application one month after phosphorus application. After twenty-five days, the heights of the seedlings at five different phosphorus levels diverged, and this pattern continued to the termination of the trial. At this stage, it was apparent that the seedlings were responding well to the P10 (10 mg/pot), P20 and P40 treatments, but there was only a slight response to the P80 treatment over the P40 treatment (figure 11.1). It was probable that a deficiency other than phosphorus was limiting height growth at the P80 level.

11.1.1 Growth 5 1/2 Months after Fertilisation

Nitrogen supply did not have a significant effect on total dry weight (table 11.1), since the total soil nitrogen

FIGURE 11.1

INFLUENCE OF PHOSPHORUS APPLICATION (NIL NITROGEN APPLICATION) ON HEIGHT GROWTH OVER TIME



F Value and Significance of F

Source of Variation	DF	HT	TOT	BRN	SR	SF	F/T	PCN	N UPT	P UPT	N/P	Nitrogen
Main effects	8	15.3***	46.4***	14.1***	3.6***	1.3 NS	1.2 NS	24.3***	31.3***	54.2***	39.5***	1.7 NS
N	4	1.7 NS	0.3 NS	0.7 NS	2.9*	1.3 NS	1.2 NS	2.3 NS	0.3 NS	0.8 NS	3.0*	1.2 NS
P	4	28.9***	92.5***	27.5***	4.3**	1.2 NS	1.2 NS	46.2***	62.4***	107.6***	76.0***	2.2 NS
2-Way Interactions	16	1.2 NS	0.6 NS	0.9 NS	0.6 NS	1.0 NS	0.8 NS	0.8 NS	0.5 NS	1.0 NS	1.1 NS	0.7 NS
N P	16	1.2 NS	0.6 NS	0.9 NS	0.6 NS	1.0 NS	0.8 NS	0.8 NS	0.5 NS	1.0 NS	1.1 NS	0.7 NS
Explained	24	5.9***	15.8***	5.3***	1.6*	1.1 NS	0.9 NS	8.6***	10.8***	18.8***	15.1***	1.2 NS
Residual	100											
Totals	124											

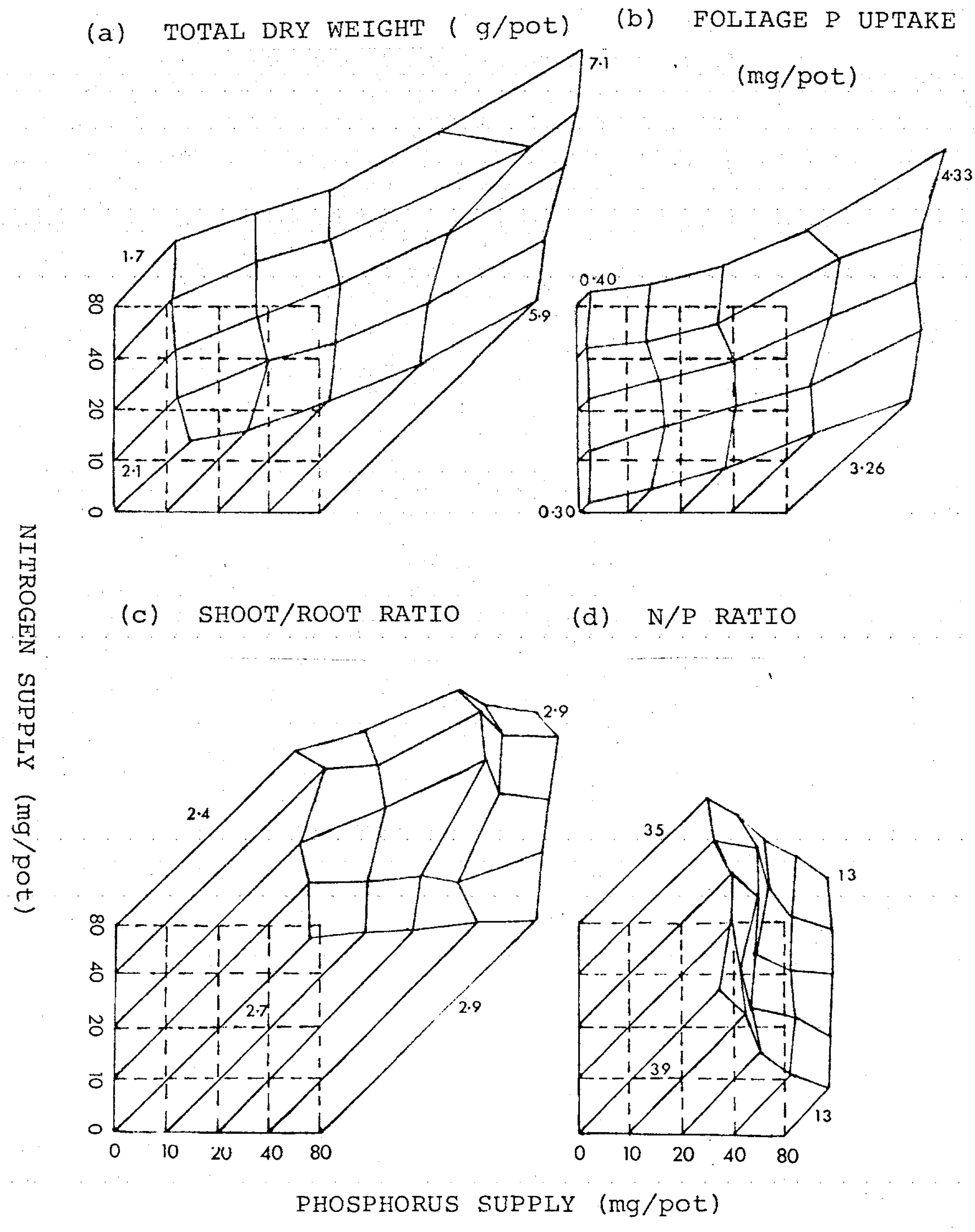
Key

*** Significant at 0.001 probability level
** 0.01
* 0.05

TABLE 11.1 Analysis of variance on eleven plant variables over 25 Nitrogen-phosphorus treatments (125 pots).

FIGURE 11.2

RESPONSE SURFACES SHOWING THE EFFECT OF INCREASING PHOSPHORUS AND NITROGEN ON FOUR PLANT VARIABLES.



was adequate even before nitrogen application. There appeared to be little response to nitrogen at the three lowest levels of phosphorus application in terms of total dry weight (figure 11.2a). Little response was expected since in general the N/P ratios were high (greater than 20) at these lower levels of phosphorus application (figure 11.2d). There was a slight response to increasing nitrogen at the two highest levels of phosphorus application (figure 11.2a). This was probably due to the fact that the N/P ratio was lower for these two levels (less than 20) (figure 11.2d).

Phosphorus had a significant effect (0.001 probability level) on total dry weight, height and branch number (table 11.1). The response to phosphorus was obvious in terms of total dry weight (figure 11.2a). This response in terms of shoot dry weight and root dry weight is shown in photos 6 and 7. However with increasing phosphorus supply, response to phosphorus in terms of total dry weight increased, but at a decreasing rate (figure 11.3). This was probably due to a deficiency of an element other than phosphorus. The response to phosphorus, in terms of height, was not as significant as for total dry weight response (table 11.1). This was due to the fact that height was measured from the stem base and not from the cotyledons. Height had a correlation coefficient of 0.71 with total dry weight (table 11.2). Thus, height can be used to estimate response to fertilisers.

PHOTOS 6 AND 7

Response of *P. caribaea* seedlings to phosphorus (in terms of shoot and root growth).

FIGURE 11.3

INFLUENCE OF PHOSPHORUS SUPPLY ON TOTAL DRY WEIGHT (AVERAGED OVER FIVE NITROGEN LEVELS) (STANDARD DEVIATIONS INCLUDED)

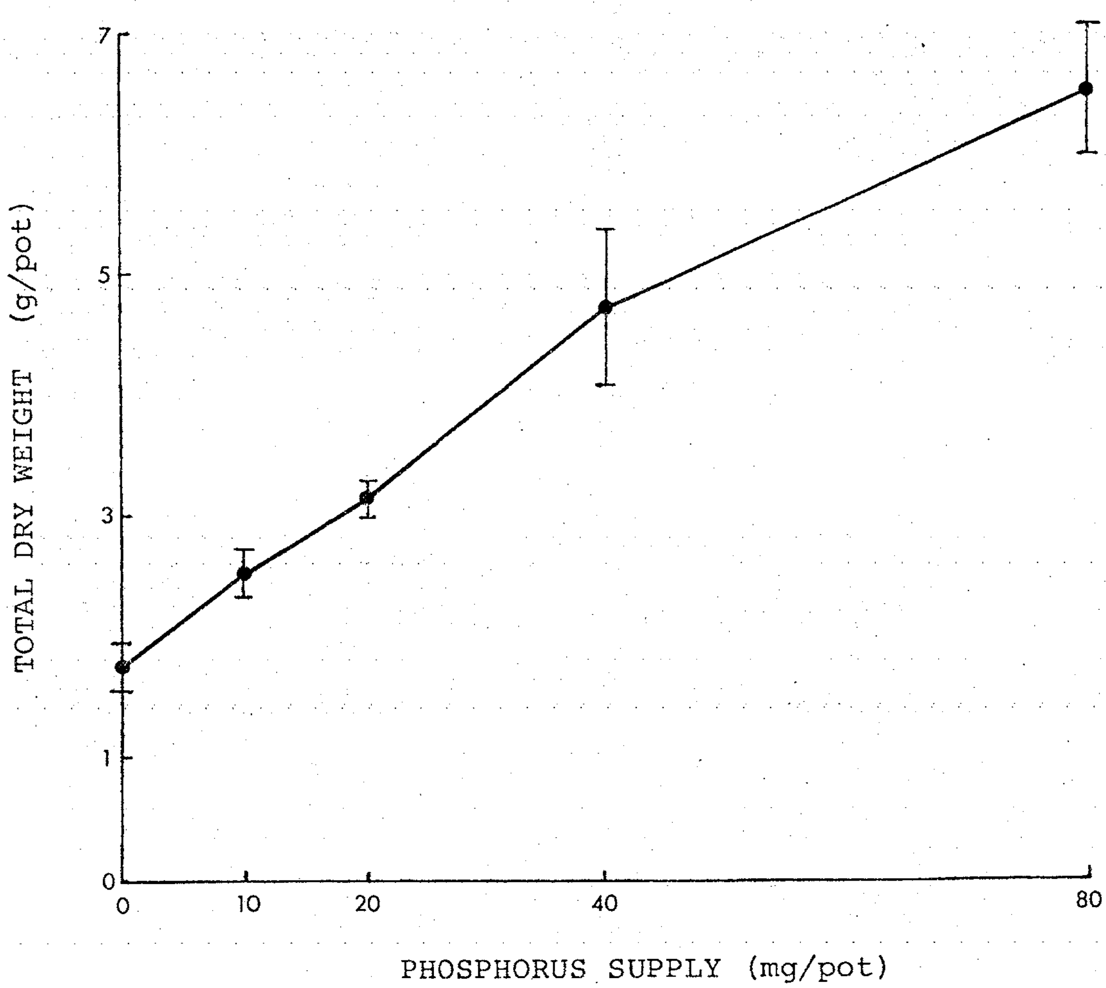


TABLE 11.2

Correlation coefficients between 11 plant growth and chemical variables over 25 treatments (125 pots)

	TOT	SR	BR	SF	FT	NCN	PCN	NP	NU	PU	HT
TOT (TOT DRY WEIGHT)	-	-	-	-	-	-	-	-	-	-	-
SR (SHOOT/ROOT)	0.16	-	-	-	-	-	-	-	-	-	-
BR (BRANCH NUMBER)	0.67	0.16	-	-	-	-	-	-	-	-	-
SF (STEM/FOL)	-0.03	-0.03	-0.03	-	-	-	-	-	-	-	-
FT (FOL/TOT)	0.11	0.54	0.22	-0.15	-	-	-	-	-	-	-
NCN (NITROGEN CONC.)	0.13	-0.06	0.17	0.08	-0.12	-	-	-	-	-	-
PCN (PHOSPHORUS CONC.)	0.64	0.12	0.58	0.06	-0.02	0.53	-	-	-	-	-
NP (NITROGEN/PHOSP)	-0.66	0.17	-0.54	-0.06	-0.04	-0.22	-0.83	-	-	-	-
NU (NITROGEN UPTAKE)	0.93	0.18	0.60	-0.03	0.16	0.40	0.67	-0.64	-	-	-
PU (PHOSPHORUS UPTAKE)	0.91	0.16	0.63	-0.01	0.10	0.33	0.85	-0.76	0.92	-	-
HT (HEIGHT)	0.71	0.10	0.47	0.01	-0.10	0.24	0.66	-0.70	0.67	0.71	-

As phosphorus supply increased from 0 to 80 mg per pot, the mean branch number increased from 1.1 to 7.9 branches per pot (Figure 11.4). Increasing phosphorus supply also resulted in increased branch numbers in the Darwin trial (Figure 8.7). It was noted in the Darwin trial that nitrogen had an effect on branch number (figure 8.7). This did not appear to be the case on the Ainslie soil (Figure 11.4). This was due to the fact that increasing nitrogen supply had little effect on nitrogen uptake (figure 11.5b). However, nitrogen could still have been influencing branch number in this trial, since increasing the phosphorus supply resulted in increased nitrogen uptake (figure 11.5b). This increased nitrogen uptake could have been used in the formation of branches.

Nitrogen application had a significant effect (0.05 level) on the shoot/root ratio on the Ainslie soil (table 11.1). Nitrogen also had an influence on this ratio in the Darwin trial. However, phosphorus had a larger effect on this ratio in this trial, since it was significant at the 0.01 level (table 11.1). The shoot/root ratio increased from the P0 to the P20 treatment and then declined. The ratio increased from N0 to N40 treatments, and then also declined (figure 11.2c). This behaviour could be due to the deficiency that was restricting dry weight production.

FIGURE 11.4

EFFECT OF INCREASING PHOSPHORUS (AVERAGED OVER FIVE NITROGEN LEVELS) AND INCREASING NITROGEN (AVERAGED OVER FIVE PHOSPHORUS LEVELS) ON NUMBER OF BRANCHES. (STANDARD DEVIATIONS INCLUDED)

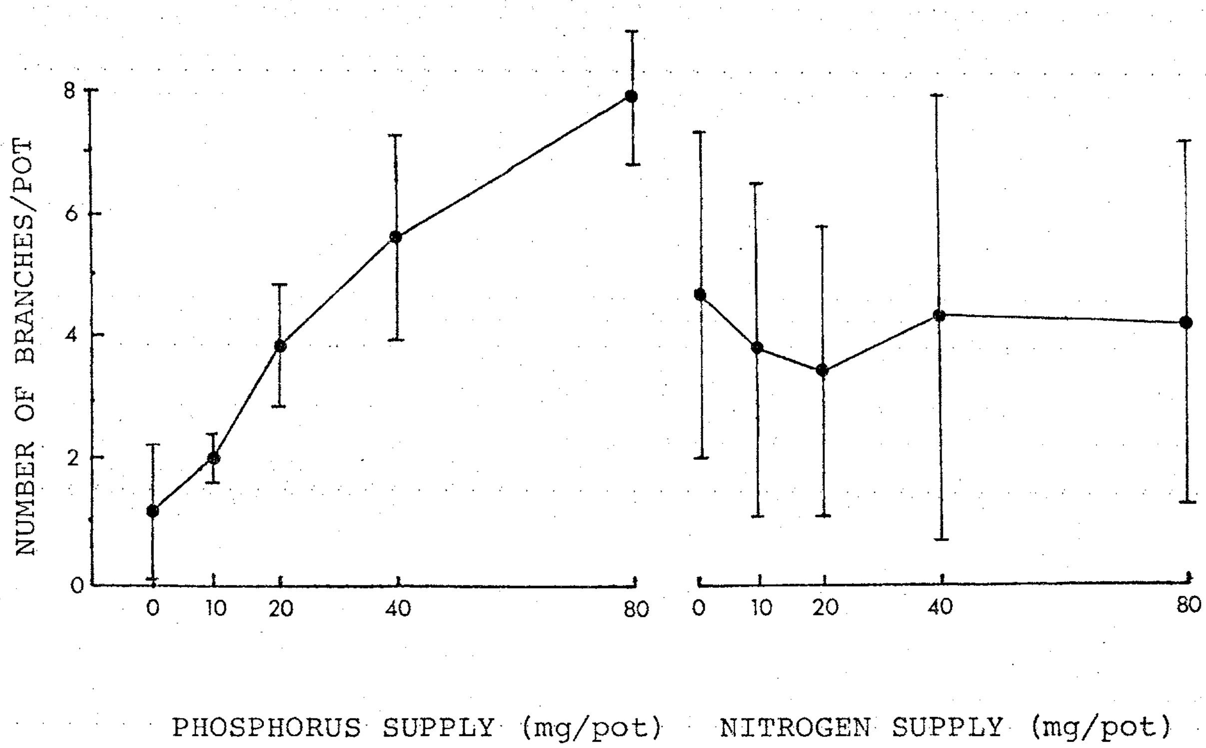
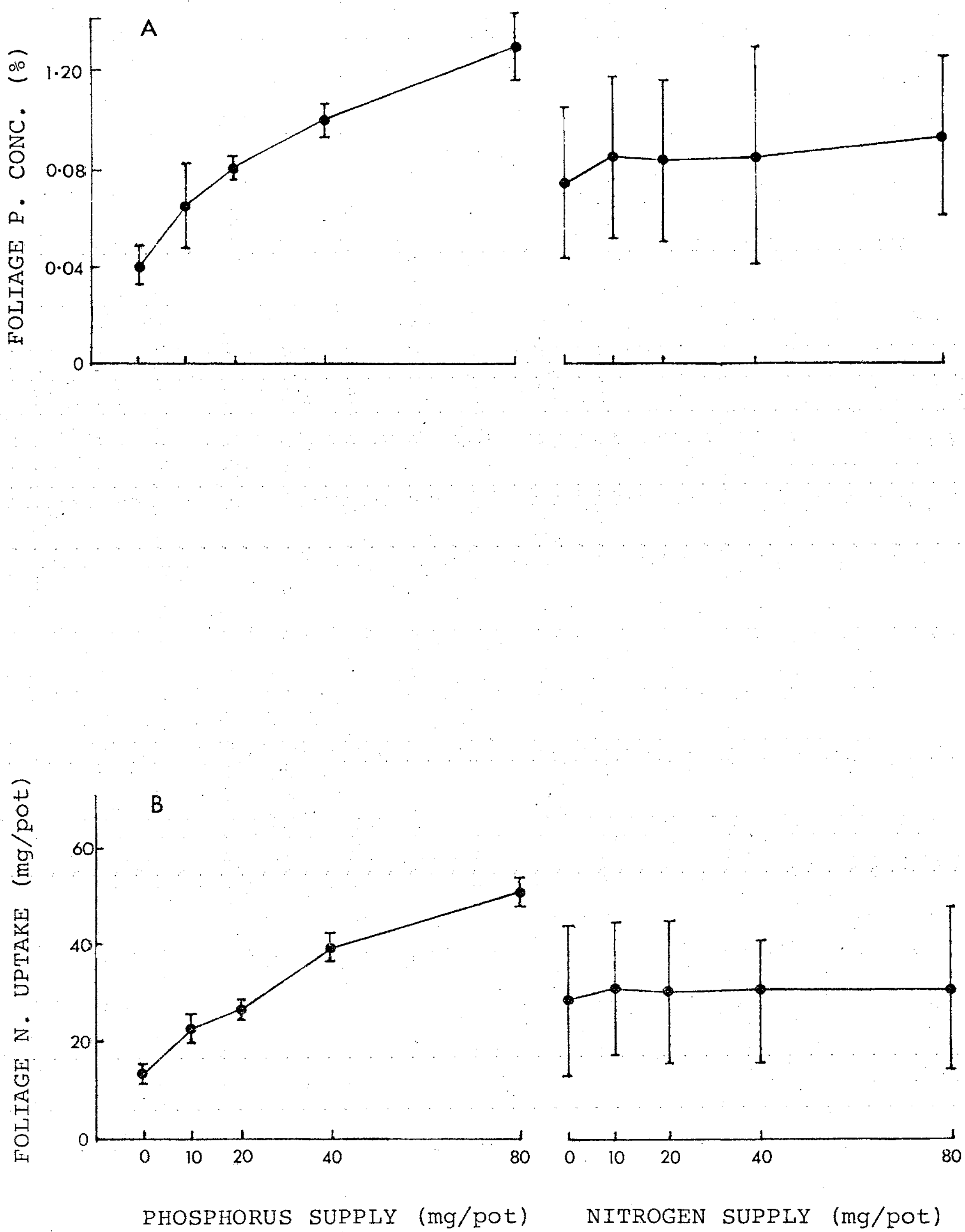


FIGURE 11.5

EFFECT OF INCREASING PHOSPHORUS (AVERAGED OVER FIVE NITROGEN LEVELS) AND INCREASING NITROGEN (AVERAGED OVER FIVE PHOSPHORUS LEVELS) ON PHOSPHORUS CONCENTRATION AND NITROGEN UPTAKE. (STANDARD DEVIATIONS INCLUDED)



The seedlings on the Ainslie soil had a larger range of shoot/root ratios (2.4 to 3.7) and a larger grand mean (2.9) for the twenty five fertiliser treatments than the Darwin trial with a range of shoot/root ratios for the sixteen fertiliser treatments from 2.1 to 2.9 and a mean of 2.5 (averaged over three soils and three provenances) (figures 11.2c and 8.8 respectively). The larger shoot/root ratio on the Ainslie soil could be due to the higher nitrogen status of this soil, since it has already been shown in the Darwin trial that nitrogen application resulted in an increase in the shoot/root ratio (figure 8.8). Time factors could have influenced this result since the Ainslie trial was conducted for an extra 2 1/2 months (with fertilisers). There was no mycorrhizal inoculation of the Ainslie soil, and since it has been shown that mycorrhizae have a significant influence on the shoot/root ratio (table 8.19), this only emphasises that other factors are important in determining the high ratio on the Ainslie soil.

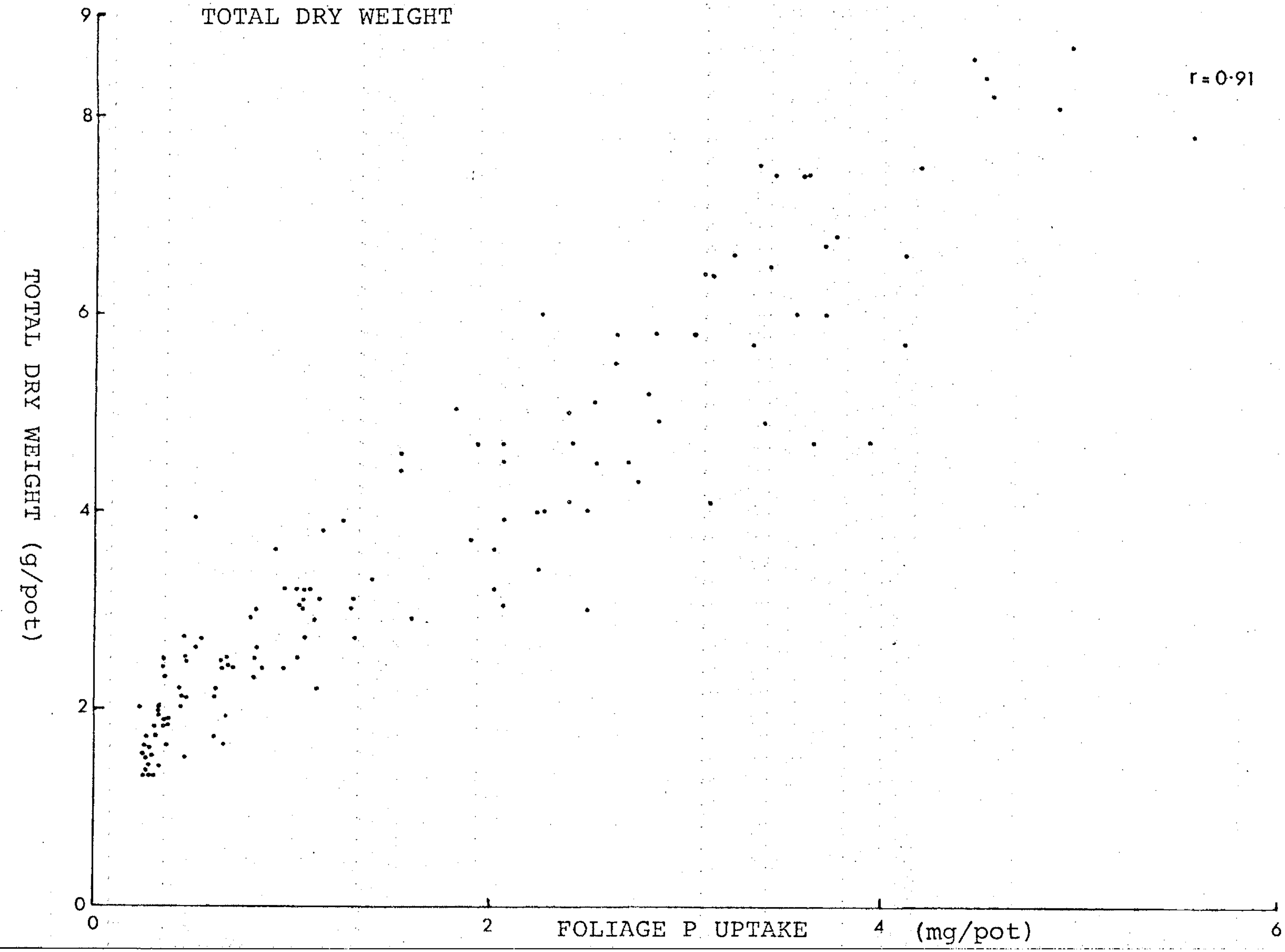
The stem/foliage and foliage/total dry weight ratios were not significantly influenced by nitrogen or phosphorus supply (table 11.1). However, in the Darwin trial fertilisers had a significant effect (0.001 level) on these two ratios. This was possibly due to the fact that sulphur was included in the Darwin trial. This nutrient appeared to exert a considerable influence on the above two ratios through the nitrogen/sulphur ratio.

11.1.2 Concentration and Uptake of Phosphorus and Nitrogen

Applied nitrogen did not have a significant effect on phosphorus concentration, phosphorus uptake, nitrogen concentration or nitrogen uptake (table 11.1). This was so since nitrogen supply did not have a significant effect on growth (table 11.1). The lack of influence of increasing nitrogen supply on phosphorus uptake, phosphorus concentration and nitrogen uptake is shown in figures 11.2b, 11.5a, b respectively.

Applied phosphorus had a significant effect (0.001 level) on phosphorus concentration and uptake, and nitrogen uptake, and no effect on nitrogen concentration (table 11.1). Increasing the phosphorus supply resulted in increased phosphorus uptake (figure 11.2b). Phosphorus uptake had a correlation coefficient of 0.91 with total dry weight (table 11.2, figure 11.6). This demonstrates the importance of this nutrient for the growth of *P. caribaea*. The phosphorus concentration (over all five nitrogen levels of application) increased with increased phosphorus supply, but at a decreasing rate (Fig. 11.5a). Increasing the phosphorus supply resulted in increased nitrogen uptake (figure 11.5b). Increased nitrogen supply had no influence on nitrogen uptake (figure 11.5.b). It is thus apparent that phosphorus only was influencing nitrogen uptake. Indeed phosphorus uptake had a correlation coefficient of 0.92 with nitrogen uptake

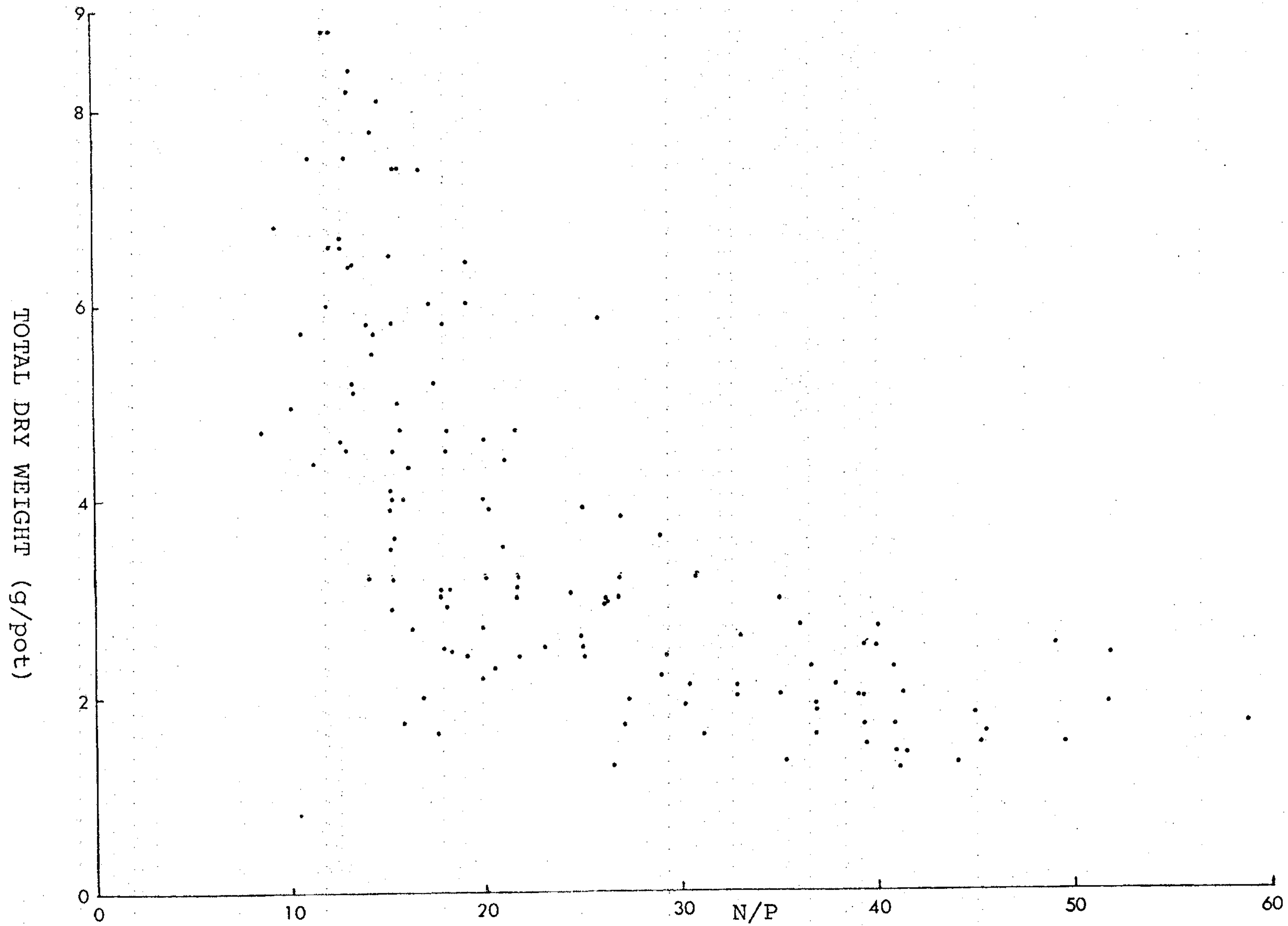
FIGURE 11.6 RELATIONSHIP BETWEEN FOLIAGE PHOSPHORUS UPTAKE AND TOTAL DRY WEIGHT



(table 11.2). Phosphorus and nitrogen supply did not have a significant effect on nitrogen concentration (Table 11.1). This indicated that the increased nitrogen uptake, with increased phosphorus supply, had been utilised. Anthony (1971) also noted with *P. caribaea* in a pot trial in Malaysia that at all levels of phosphorus application, the nitrogen concentration of the shoot remained relatively constant.

The N/P concentration ratio was significantly influenced by nitrogen (0.05 level) and phosphorus application (0.001 level) (table 11.1). Increasing the supply of phosphorus markedly reduced this ratio (figure 11.2d). The correlation coefficient between the N/P ratio and total dry weight was - 0.66 (table 11.2). With increasing phosphorus application the total dry weight production did not increase substantially, down to an N/P ratio in the region of 18 (figure 11.7). This was possibly due either to the fact that nitrogen was toxic to the seedlings or to a decrease in the rate of protein synthesis due to a phosphorus deficiency. When more phosphorus was added, the total dry weight production increased at a greater rate. The optimum N/P ratio in this trial was approximately 10. However, the ratio did not fall below 10 in this trial, so it is possible that if the level of phosphorus supply had been greater than P80, this optimum ratio would have been lower.

FIGURE 11.7 RELATIONSHIP BETWEEN THE N/P RATIO AND TOTAL DRY WEIGHT



11.2 Distribution of Phosphorus and Nitrogen after Fertilisation

The distribution of phosphorus and nitrogen in the plant and in the soil was determined 5 1/2 months after fertilisation using seven of the twenty-five treatments.

11.2.1 In the Plant

(i) Uptake

Phosphorus and nitrogen concentration and uptake were determined in the foliage, stems and roots of seven treatments using three replicates. Seed phosphorus and nitrogen were measured and subtracted from total uptake.

The treatments with 80 mg/pot had the highest phosphorus amounts, with the N0P80 and N80P80 treatments having amounts of 7.37 and 7.95 mg/pot respectively (table 11.3). The treatments without phosphorus application (N0P0, N20P0, N80P0) had phosphorus amounts of 0.15, 0.12, and 0.35 mg/pot respectively. It is thus apparent that *P. caribaea* seedlings were obtaining some phosphorus from the soil (Table 11.3). In the fertilised pots the amount of phosphorus taken up ranged from 6.3 to 11.4% of the amount applied, indicating that the seedlings had utilised only a small portion of the applied phosphorus (Table 11.3). Undoubtedly, some of this applied phosphorus would have been fixed since the soil has a high phosphorus soprtion capacity (Figure 8.4).

TABLE 11.3

Plant phosphorus uptake 5 1/2 months after fertilisation (mean of three pots)

Treatment	Amount of P Applied (mg/pot)	Total P Uptake (mg/pot)	Uptake as a Percentage of Applied P
0	0	0.15	-
NOP20	20	1.26	6.3
NOP80	80	7.37	9.2
N20P0	0	0.12	-
N20P20	20	2.28	11.4
N80P0	0	0.35	-
N80P80	80	7.05	8.8

NOTE

(1) Total soil phosphorus per pot before fertilisation equals 350 mg (six replicates).

(2) Seed phosphorus per pot equals 0.49 mg (three replicates).

(3) Total phosphorus uptake is the uptake of phosphorus in the foliage, stems and roots minus the seed phosphorus

The treatments with the highest phosphorus applications had the largest nitrogen amounts. The uptake of nitrogen as a percentage of applied nitrogen ranged from 31% for the N20P0 treatment to 237% for the N20P20 treatment (table 11.4). The later percentage indicated that more nitrogen was obtained from the soil nitrogen than from the applied nitrogen for that treatment.

(ii) Concentration

The phosphorus and nitrogen concentration of the foliage, stems and roots was also examined, using the same three replicates for the seven treatments. The phosphorus concentration was higher in the foliage than in the roots and stems (figure 11.8). The P20 and P80 treatements showed this trend more clearly than the treatments without phosphorus, where the foliage and roots had similar phosphorus concentrations and the stems slightly less. This could indicate that the phosphorus is rapidly utilised once it enters the foliage when phosphorus deficiency is present.

In the Darwin trial, phosphorus concentration, averaged over all provenances, was highest in the foliage on both the Three Ways and PBO-10cm soils (table 8.15). This is in agreement with the Ainslie trial. However, for phosphorus concentration in the stems and roots there was no clear pattern. This is in contradiction with the Ainslie trial, where there was a clear trend of decreasing

TABLE 11.4

Plant nitrogen uptake 5 1/2 months after fertilisation (mean of three pots).

Treatment	Amount of N Applied (mg/pot)	Total N Uptake (mg/pot)	Uptake as a Percentage of Applied P
0	0	25.1	-
N0P20	0	36.5	-
N0P80	0	89.4	-
N20P0	20	21.2	106
N20P20	20	47.3	237
N80P0	80	24.4	31
P80N80	80	93.1	116

NOTE

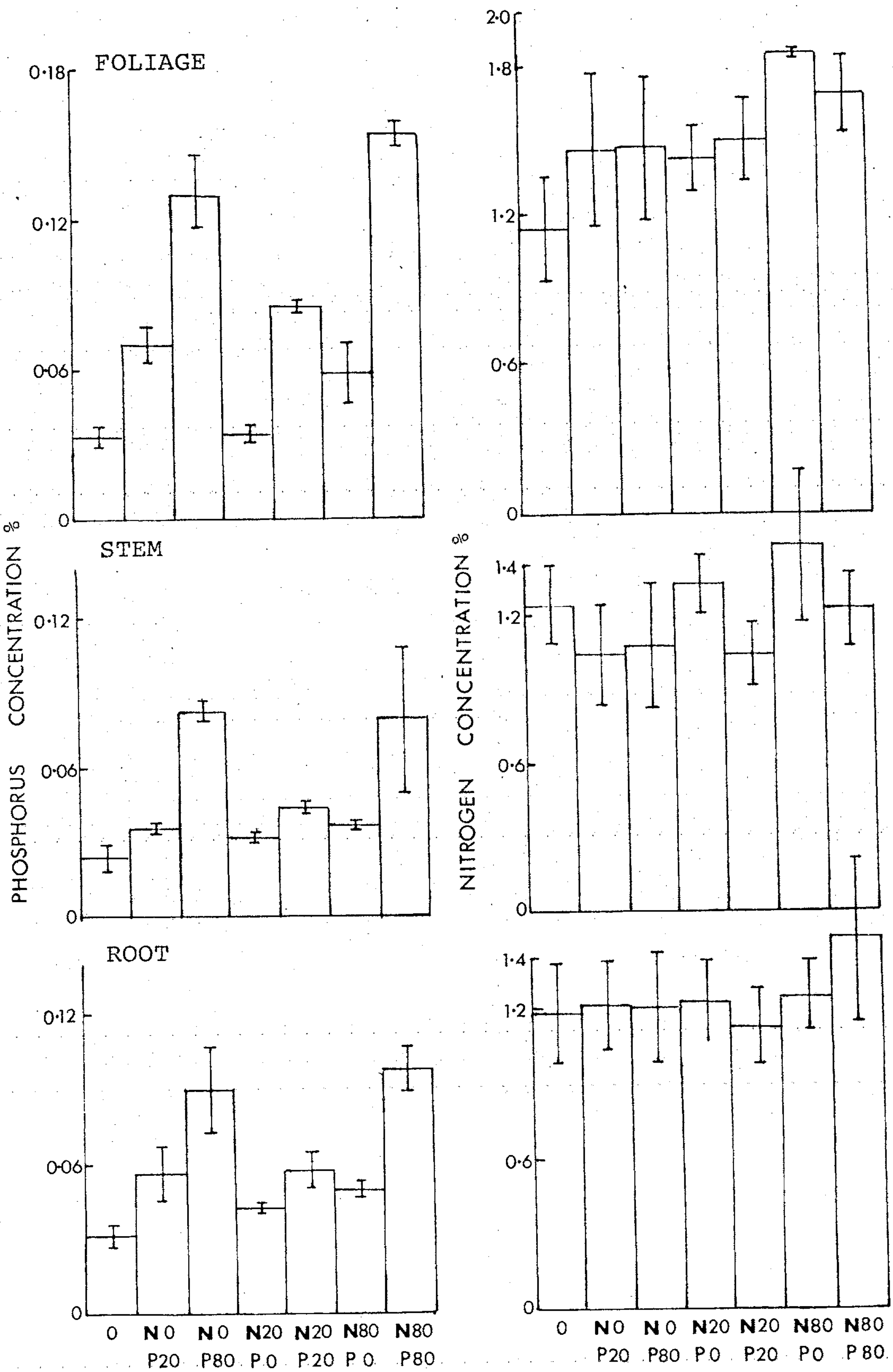
(1) Total soil nitrogen per pot before fertilisation equals 4000 mg (six replicates)

(2) seed nitrogen per pot equals 2.29 mg (three replicates).

(3) Total nitrogen uptake is the uptake of nitrogen in the foliage, stems and roots minus the seed nitrogen.

FIGURE 11.8

EFFECT OF SEVEN NITROGEN–PHOSPHORUS FERTILISER RÉGIMES ON NITROGEN AND PHOSPHORUS CONCENTRATION IN THE FOLIAGE, STEMS AND ROOTS (STANDARD DEVIATIONS INCLUDED).



phosphorus concentration from the foliage to the root to the stem.

Iyambo (1973) noted with *P. caribaea* trees in Miango (Nigeria) that phosphorus concentration was highest in the foliage (0.41%), followed by the roots (0.30%) and lowest in the stems (0.28%). This is in agreement with the Ainslie trial. However, both the results from the Darwin and Ainslie trials are in contrast to the results reported for *Pinus elliottii*. McGee (1963) reported that the phosphorus concentration was higher in the roots than in the shoots for seedlings in sand culture, and Ryan (1973) noted that the concentration was least in the foliage and greatest in the stems.

In all cases, except the control, nitrogen concentration was highest in the foliage, with no clear relationship between the stems and the roots (figure 11.8). The three above authors also reported higher nitrogen concentrations in the foliage than the stems and roots. Indeed, the difference between the foliage and stems or roots in terms of concentration was greater than with phosphorus. With the Ainslie trial there was only a slight difference in nitrogen concentration between the foliage, stems and roots (figure 11.8), due to the high initial total nitrogen concentration.

11.2.2 <u>In the Soil</u>

The total soil phosphorus and nitrogen values were also determined using two replicates of the top one cm and bottom one cm of two of the three pots used to estimate plant uptake.

The N0P0, N20P0 and N80P0 treatments had values less than or equal to the total soil phosphorus concentration before fertilisation in both one cm layers (350 p.p.m., Table 11.5). The N0P80 and N80P80 treatments had a considerably higher total phosphorus concentration in the upper one cm (460 p.p.m. and 490 p.p.m. respectively), whereas in the lower one cm, the concentration of both treatments was only 380 p.p.m. (table 11.5). This suggested that some of the applied phosphorus was getting to the lower soil depths. The higher concentration of phosphorus in the upper one cm suggested that the seedlings were either taking up large quantities of phosphorus from the lower soil depths or that the phosphorus was being fixed at the top of the pots.

In this trial the seedlings had the largest root density (mainly lateral roots) in the top portion of the pot. Photo 7 shows this but not very clearly. Williams (1974) found that root density of potted *P. caribaea* seedlings decreased with depth. Anthony and Freezaillah

TABLE 11.5

Distribution of phosphorus and nitrogen in the soil 5 1/2 months after fertilisation (mean of two pots)

Treatment	P CONC. (p.p.m.)		N CONC. (p.p.m.)	
	Top 1cm	Bottom 1cm	Top 1cm	Bottom 1cm
0	340	350	3900	3400
N0P20	390	340	4000	3300
N0P80	460	380	3900	3800
N20P0	340	330	3900	3800
N20P20	400	340	3900	3400
N80P0	330	320	3900	3500
N80P80	490	380	4000	3400

(1969) observed that *P. caribaea* seedlings with fertiliser application had fibrous root systems with laterals concentrated superficially. Since the phosphorus concentration was highest in the top portion of the pots, where the seedlings had the largest root density, this zone was probably an important zone for phosphorus uptake.

The total nitrogen was also highest in the top portion of the pot in all seven cases (table 11.5). It is apparent that the seedlings were obtaining most of their nitrogen from the lower one cm of the pot, and only a small portion from the top of the pot, since the treatments without nitrogen application had markedly lower nitrogen concentrations in the lower one cm than in the top one cm (except for the N0P80 treatment with only a slightly lower concentration).

None of the pots had nitrogen concentrations greater than 4000 p.p.m. The maximum nitrogen application was only 80 mg/pot, which was equal to 80 p.p.m. in the soil (since 1000 grams air dry stone-free soil per pot). This was very small compared with 4000 p.p.m. Thus, since the seedlings need considerable nitrogen for growth, it would not be expected that any of the pots would have had a total nitrogen concentration greater than 4000 p.p.m.

11.3 Deficiency Symptoms

Two deficiencies were observed in this trial, one being phosphorus and the other unidentified.

11.3.1 Phosphorus Deficiency

This symptom was obvious in browning of the cotyledons and in severe cases death of the lower needles (photo 8). The deficiency was most severe in the P0 and P10 treatments. The concentrations of phosphorus at these two lower levels (each phosphorus level averaged over five nitrogen levels) were 0.039% and 0.064% (figure 11.5a). Indeed, it has been reported that the critical phosphorus concentration for *P. caribaea* is 0.065% to 0.070% on most sites (Anon., 1975). The three highest levels of phosphorus application had concentrations of 0.092%, 0.096%, and 0.147%. (figure 11.5a). These levels appeared adequate for *P. caribaea* since phosphorus deficiency symptoms did not appear to be occurring at these levels.

11.3.2 Unidentified Deficiency

Phosphorus application resulted in the correction of phosphorus deficiency, but resulted in an increase in intensity of another deficiency.

The deficiency resulted in the appareance of bright yellow needles in the upper foliage, and in extreme cases

PHOTOS 8 AND 9

Deficiency symptoms present in the Ainslie trial.

PHOSPHORUS

UNIDENTIFIED

over the whole foliage (photo 9). However, the lower foliage was usually green. This suggests the deficiency was caused by an immobile nutrient. Indeed, Dykshoorn and Van Wyk (1967) noted that because of the low rate of translocation of sulphate, the upper leaves turn yellow first. Thus sulphur concentrations in the seedlings were measured.

Leaf (1967) considered levels for sulphur deficient seedlings and quoted Ingestad (1960/62) who observed sulphur deficiency symptoms with *Picea abies* when the sulphur concentration was less than 0.13% and with *Pinus sylvestris* when the concentration was less than 0.15%. In the Ainslie trial, the total sulphur concentration ranged from 0.16% to 0.21% over five phosphorus levels of application (nil nitrogen application) (table 11.6). The total nitrogen/total sulphur ratio (N/S) ranged from 7.3 to 10.2 over the same phosphorus treatments (table 11.6). Stewart and Porter (1969) reported a N/S ratio of greater than 20 indicated a sulphur deficiency with maize *(Zea mays)* and beans *(Phaseolus vulgaris)*. Terman, Allen, and Giordano (1973), also with maize, considered a ratio of 16 to indicate a proper balance. Thus, sulphur concentrations did not decrease with increasing phosphorus application, were higher than Ingestad (1960/62) suggested for sulphur deficiency, and the N/S ratios were similar with increasing phosphorus. Thus, the deficiency was probably

TABLE 11.6

Total sulphur and total nitrogen/sulphur ratios with increasing phosphorus supply (two replicates)

P Applied (mg/pot)	Total S (%)	Total N/Total S Ratio
0	0.17	10.0
10	0.16	10.2
20	0.21	7.3
40	0.17	8.1
80	0.20	8.3

not due to sulphur. Other possibilities are manganese and molybdenum. However, the total soil manganese concentration appeared to be adequate (818 p.p.m., table 9.2).

CHAPTER 12.

CONCLUSION FOR DARWIN AND AINSLIE TRIALS

The Ainslie and Darwin pot trials will be considered together in this chapter. Pot trials have the advantages over field trials shown below:

(i) allow complicated designs

(ii) less variable soil and climatic conditions

(iii) results are obtainable in a shorter time (Mead and Pritchett, 1971).

Thus, pot trials are the ideal way to measure differences in seedling response on different soils and to different fertilisers with a short term project.

12.1 Provenance Effect

Variation in the seed nutrient content and seed weight exerted a considerable influence on the results obtained in this Darwin trial, since provenance differences in shoot and root development were evident at the time of fertilisation. This resulted in variations between the provenances, in nutrient uptake ability and efficiency of utilisation of nutrients at the time of fertilisation. However, there is little that can be done to solve this problem.

The Queensland provenance was the most productive in terms of total dry weight (averaged over all soil and fertiliser regimes) and the Alamicamban provenance was least productive. This followed the same trends as seed size and nutrient content of the seed of the three provenances. The Queensland and the M.P.R. provenances (both derived from Mount Pine Ridge) had similar seed nutrient contents, yet the Queensland provenance was more productive. This points to the fact that either the original selection of the Queensland provenance at Mount Pine Ridge, or the natural and artificial selection under Queensland conditions, has produced a provenance more productive on red earths under Northern Territory conditions.

12.2 Soil Effect

Four red earths were studied in these trials. As has been discussed in the red earth review, *P. caribaea* appears to grow well on these soils, probably because they are deep, well drained and have physical properties suitable for the growth of species. All four soils appeared to be deficient in phosphorus, with lesser deficiencies of other nutrients.

In the Darwin trial, seedlings on the PBO-10 cm soil produced a larger dry weight than the seedlings on the two other soils in that trial. This was probably due to the higher total soil concentration of phosphorus, nitrogen and cations and the lower phosphorus adsorption capacity of this soil.

The greater dry weight production of the seedlings on the PB0-10 cm soil than on the PB10-25 cm soil is of interest, since it indicates the importance of the topsoil for the growth of *P. caribaea*, on red earths, in the field.

All four red earths had high phosphorus fixing capacities, with the Three Ways soil having the highest fixing capacity. Thus, it could be advisable to check regularly the phosphorus status of the trials on this site to find at what age the trees become deficient in phosphorus. Ways of overcoming the problem would be to apply an initial high application of phosphorus, to apply a slowly soluble source of phosphorus such as rock phosphate, or to apply phosphorus regularly (it has not been established if phosphorus fixation is a problem in the field at this stage).

12.3 Fertiliser Effect

The results obtained from both trials indicate that phosphorus is the most important nutrient for the growth of *P. caribaea* on all four soils, since it was the only nutrient that had a significant effect at the 0.001 level on total dry weight production in both trials. Nitrogen did not have a significant influence on total dry weight in either trial when an analysis of variance was conducted. However, in the Darwin trial nitrogen did result in an increase in total dry weight production when phosphorus, and either sulphur or the trace element mixture were added. Also, Richards (1961) and Richards and From (1965) have reported that nitrogen application had a negative influence on growth in the early stages of pot trial, but that the reverse occurred at later stages of the trials. Sulphur and trace elements both had a significant influence on total dry weight production in the Darwin trial.

Fertiliser interactions occurred in the Darwin trial but not in the Ainslie trial. It is possible that interaction(s) would have occurred in the Ainslie trial if the deficient nutrient other than phosphorus had been applied. In the Darwin trial, the significant interactions were S x N, P x N x S, P x T, T x S, N x T x S, P x S, P x T x S. The P x N interaction was not significant in terms of total dry weight, in both trials. This indicates that the P x N interaction can not be expected to occur unless other deficiencies are corrected at the same time.

12.4 Genotype x Environment Interaction

The Darwin trial evaluated interaction between soils, fertilisers and provenances. The information obtained from this trial and trials of this nature, can be taken into account when provenances are selected for different edaphic and fertiliser regimes.

The soil x phosphorus interaction was the only significant interaction (when the fertilisers were not pooled) for total dry weight production. The PB0-10 cm soil was most responsive to phosphorus application and the PB10-25 cm soil least responsive. The soil x provenance interaction was also significant for total dry weight production. This interaction was due to the fact that the Queensland provenance responded best on all soils and the Alamicamban provenance least.

The provenance x fertiliser interaction indicated that the three provenances exhibited differential deficiencies and sensitivities. The provenance x S, provenance x P, and provenance x PS interactions were the significant interactions of most interest. The Alamicamban provenance was most responsive to phosphorus in terms of total dry weight. This provenance was sensitive to sulphur, both with and without phosphorus. Although this trial was conducted with seedlings, it would be interesting to study this provenance under field conditions and see if it is sensitive to sulphur. Money could be saved by not applying this nutrient, and growth increased. Since phosphorus is the most important nutrient for plant growth on the four soils, selection of provenances responsive to this nutrient, such as the Alamicamban provenance, would increase the economic efficiency of fertilisation.

12.5 Mycorrhizae

The main mycorrhizal effect was significant for total dry weight. The provenances all responded to mycorrhizal inoculation at both levels of nutrition under study, except for three cases. There appeared to be good, if variable, responses to mycorrhizae with the PSNT treatment. This could have been due to unbalanced nutrition. There needs to be more research into mycorrhizal relationships with pine since *P. caribaea* is often planted on infertile soils without fertilisers. Inoculation with mycorrhizae could help reduce the increment lost without fertiliser application.

12.6 Implications and Recommendations

Fertilisers were undoubtedly of benefit to *P. caribaea* seedlings, in both trials. Indeed, the minimum increase in total dry weight production of the best treatment over the control of the three provenances on the three soils in the Darwin trial over the control was 90%.

Since seedlings on the PBO-10 cm soil were more responsive to fertilisers than seedlings on the Three Ways soil, and since *P. caribaea* trees are doing well on the Three Ways site (in the International Provenance trial), the Point Blaze site should be planted with a trial plot. A field trial is planned for this site in the next few years. Phosphorus and nitrogen have been shown to be the most important nutrients for *P. caribaea* in field trials on red earths. Taking this into account, the fertiliser regimes to be used in the trial should be PN, PNT, PNS and PNST, even though sulphur application has not given a response in field trials to date.

A minimum of four seed sources should be included in the field trial. These should be the Alamicamban provenance, routine collected seed from Queensland plantations (which is relatively easy to obtain), the Brus Lagoon provenance (which is growing best in the Three Ways International Provenance trial), and the Poptun provenance (which is growing best on the better drained, coastal plain site at Humpty Doo). The field fertiliser trial could be applied to only one of these provenances if area or time are limiting.

12.7 Further Research

A nutrient omission pot trial should be started to try and solve the nutritional problem at Three Ways. One suggestion is to design a pot trial similar to Bevege and Simpson (1973), since this design includes an omission trial as well as studying genotype x environmental interactions.

There appears to be little knowledge of the nutrition of the provenances in the field. One line of research could be to conduct foliar analyses of the provenances in International Provenance trials.

Lastly, it would be of interest to find the provenances that are most responsive to phosphorus (the most important nutrient for *P. caribaea* on Australian soils). It would be desirable to include a basal application of all nutrients other than phosphorus, and to apply the phosphorus at different rates.

APPENDIX I

Correlation coefficients relating 10 growth factors over 3 soil types, 16 fertiliser regimes, and 3 provenances.

	FOL	ST	RT	TOT	SR	SF	FT	H	BR	SH
FOL (FOLIAGE DRY WEIGHT)	-	-	-	-	-	-	-	-	-	-
ST (STEM DRY WEIGHT)	.95	-	-	-	-	-	-	-	-	-
RT (ROOT DRY WEIGHT)	.88	.86	-	-	-	-	-	-	-	-
TOT (TOTAL DRY WEIGHT)	.98	.96	.94	-	-	-	-	-	-	-
SR (SHOOT/ROOT RATIO)	.22	.21	-.19	.11	-	-	-	-	-	-
SF (STEM/FOLIAGE RATIO)	-.24	.03	-.16	-.17	.00	-	-	-	-	-
FT (FOLIAGE/TOTAL RATIO)	.31	.12	-.07	.17	.74	-.64	-	-	-	-
H (HEIGHT)	.82	.82	.79	.84	.12	-.14	.15	-	-	-
BR (BRANCHES)	.09	.08	.04	.08	.16	.00	.12	.28	-	-
SH (STEM HEIGHT)	.70	.73	.65	.71	.18	-.04	.14	.91	.56	-

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ABBREVIATIONS

QU	=	Queensland Provenance
M.P.R.	=	Mount Pine Ridge Provenance
ALA	=	Alamicamban Provenance
P. caribaea	=	*Pinus caribaea* var. *hondurensis*.