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SUBSEQUENT FERTILISER APPLICATION IN PINUS PINASTER STUDIES AT GNANGARA AND YANCHEP

by

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STUDIES AT GNANGARA AND YANCHEP

Introduction

Early studies at Gnangara established the need for fertiliser for successful pine establishment on the Bassendean sands of the Swan Coastal Plain (Hopkins 1960). This usually resulted in the application of approximately 60 gram of superphosphate on the seedling at time of planting, or soon after planting and before the end of winter. On the yellow and brown sands of the Spearwood dunes system fertiliser was not always beneficial at time of planting although it generally proved necessary to spray for zinc deficiencies within three years of establishment. In general practice 60 g of super, copper, zinc fertiliser was applied to the plant at time of planting. A follow up foliar spray of zinc sulphate was applied at age of 3 years when necessary.

A series of trials initiated by Stoate and Harding (Hopkins 1960) tested the possibility of the beneficial effects of subsequent fertiliser application to developing pine stands which lost vigour (degraded) after the age of 10 years. Further additions of at least 500 kg ha^{-1} of superphosphate were beneficial in restoring vigour to stands on many of the poorer sites at Gnangara. The residual effect lasted for at least 7 years. The few trials with nitrogen and phosphate (NP) addition (550 kg super + 240 kg ammonium sulphate ha^{-1}) improved performance over P addition alone (up to 1 tonne of superphosphate ha^{-1}) and were economical.

CSIRO - Extensive studies made by CSIRO at their Pinjar Research Station explored the efficacy of using nitrogenous fertilisers at time of establishment, either alone or in combination with phosphorus, to improve the initial growth. This work did not improve on the results obtained with superphosphate in general practice.

Diagnostic Strips - In the 1970's the response presented by the range of sites in developing stands at Gnangara was assessed imperically by applying superphosphate strips to traverse stands over all sites and at various stand ages. Strips were applied by a tractor drawn fertiliser spreader to about 15 m either side of the outrows selected for testing. Subsequent response was obtained on most sites from ages of three years onwards.

Cultivation - Hatch (pers comm.) further demonstrated that improved vigour of young pines, resulting from cultivation at age 2-3 years to remove all competing weeds between the rows of planted pines, was associated with increased foliar P levels, equivalent to those obtained by fertiliser addition in uncultivated stands. Dramatic responses by the trees bordering the outrows as compared to those within the unthinned stand also suggested the importance of reduced competition to the response of the dominant trees (final crop).

From 1968 a series of trials was established in plantations on both the Bassendean and Spearwood sands to evaluate the following aspects of subsequent fertiliser addition to assist the general use of fertiliser in practice.

1. The range of sites susceptible to response to subsequent fertiliser application.

2. The age or ages at which stands responded economically to fertiliser addition.

3. The best mix of nutrients and the optimum amounts of fertilisers to be added.

4. The relation between stand response and stand density, that is between thinning and fertiliser response.

The Basal Area series - The initial trials were in 17 year old stands at Gnangara (WP 20/65) and 14 year stands at Yanchep (WP 54/66) to investigate the fertiliser responses of a range of fixed stand densities (basal areas) following the required first commercial thinning at age 14-18 years of age. These trials, referred to as the basal area control trials, continued for 20 years.

An establishment report on the Gnangara trial (Hopkins 1971) detailed the early response in dendrometers installed on final crop trees in selected plots. Girth response was immediate following release and was three times greater in the lowest density class to that in the highest density class. Significant differences in seasonal growth between years was largely related to rainfall variability. The greatest response to heavy thinning was in the drier seasons. Response to thinning in all density classes was similar on both the best and poorest sites.

Butcher and Havel (1976) and Butcher (1977) reported on trial development up to 1975, particularly with respect to studies of soil hydrology and fertiliser effects carried out up to that period. At Yanchep the cessation of girth increment each year was associated with the exhaustion of soil moisture that occurred 4 months earlier in the dense than in the less dense stands (Butcher and Havel 1976). The differences in average diameter increment for all trees in stands of varying density were found to be quite consistent though subject to climatic influences and to fertiliser addition. Merchantable volume to a top stem diameter of 10 cm, calculated for the stand age period from 16.5 to 20.5 years, was found to be largely independent of stand density. The authors formed the hypothesis that on drought prone Yanchep sites, the water available at the beginning of the growing season determines the amount of wood that can be produced. It can be grown rapidly on a large number of smaller trees during the period August to November or slowly on a small number of trees during the extended period of August to March.

Subsequent measurements and analysi shas shown that the hypothesis was incorrect. Increment is reduced in severe drought in all density classes but over the 22 years of trial measurement increment significantly increased with increasing stand density within the density range of 7 to 25 m^2 ha^{-1}.

The situation on the Gnangara sites was considered to be somewhat different. Here the gradient of diameter increment corresponded to the gradient of decreasing stand density but merchantable volume production was positively related to stand density on the better site qualities. These sites are characterised by an extensive regional ground water table accessible to the trees at the moderate depth of 4 m. On the drier (poorer) sites the differences in volume production were smaller. This has been confirmed by subsequent measurement.

Table 1. Trials analysed for the current report showing location, stand type and treatment type.

Trial No.	Planted Year	Stand Age	Location	Havel Type	Site Index	Treat	Response
			Bassendean Dunes System				
WP29/71	1942	31	Gnangara	IJ	18	N+P	N+P
WP20/65A	1946	25	Gnangara	J	18	N+P	N+P
WP20/65B	1946	25	Gnangara	JK	17	N+P	N+P
WP20/65C	1946	25	Gnangara	HI	16	N+P	N+P
GnangE44	1957	20	Gnangara	IJ	17	N+P	Nil
WP 2/81A	1964	17	Gnangara	G	14	N+P	N+P
WP 8/72	1966	6	Gnangara	GH	14	N+P	P
WP17/67A	1967	0	Gnangara	G	11	P+O	P
WP17/67B	1967	15	Gnangara	G	11	P	P
YS35A	1971	2	Gnangara	J	17	N+P	P
YS35B	1971	12	Gnangara	J	17	N+P	P
YS36B	1971	12	Gnangara	GH	15	N+P	P
YS36A	1971	2	Gnangara	GH	15	N+P	P
WP 2/81B	1973	8	Gnangara	HI	16	N+P	N+P
WP20/76A	1973	3	Gnangara	H	12	N+P	P
WP20/76B	1973	11	Gnangara	H	12	N+P	P
WP22/76	1951	25	Gnangara	IJ	17	N+P	Nil
			Spearwood Dunes System				
WP54/66A	1952	19	Yanchep	BD	15	N+P	N+P
WP54/66B	1952	19	Yanchep	CD	14	N+P	N+P
WP54/66C	1952	19	Yanchep	D	13	P	N+P
WP23/73	1965	8	Yanchep	AC	16	N+P	N+P
WP48/66A	1967	6	Karakin	BD	15	N+P	P
WP 2/81C	1967	14	Yanchep	DF	14	N+P	N+P
WP48/66D	1967	13	Yanchep	AC	15	N+P	P
WP48/66C	1967	6	Haddrill	AC	15	N+P	P
WP48/66B	1967	6	Wabling	AC	14	N+P	P
WP 2/81D	1973	8	Yanchep	CD	18	N+P	N+P
WP21/76	1955	21	Pinjar	FH	12	N+P	N+P

Butcher and Havel (1976) also evaluated the interaction between stand density, moisture availability and response to fertiliser application in the Yanchep experiment. In heavily stocked stands the fertiliser response in girth increment of the select trees (the best 100 stems ha^{-1}) was minimal and completely overshadowed by the effect of stand density. They concluded that the chief limiting factor on the site was availability of moisture rather than nutrients.

Table 2. Details of trials established since 1968..

Trial No.	Start Year	Measure Years	Effect Years	Treat-ments	Replic-ation	Plots	Cont-rol	Design
WP29/71	1973	5	4	2	2	4	N	T
WP20/65A	1971	20	3	2	25	50	N	FRB
WP20/65B	1971	20	3	2	25	50	N	FRB
WP20/65C	1971	20	3	2	25	50	N	FRB
GnangE44	1978	11	0	5	3	15	Y	TRB
WP 2/81A	1981	5	5	11	4	64	Y	TFRB
WP 8/72	1972	16	4	9	4	36	Y	TFRB
WP17/67A	1967	15	4	13	6	75	Y	TFRB
WP17/67B	1982	7	4	9	6	75	Y	TFRB
YS35A	1973	17	4	6	4	24	N	SPFRB
YS35B	1983	9	4	6	4	24	N	SPFRB
YS36B	1983	9	4	6	3	18	N	SPFRB
YS36A	1973	14	4	6	3	18	N	SPFRB
WP 2/81B	1981	5	4	11	4	64	Y	TFBR
WP20/76A	1976	13	7	5	4	20	Y	TRB
WP20/76B	1984	5	6	5	4	20	Y	TRB
WP54/66A	1971	20	4	2	20	40	Y	FRB
WP54/66B	1971	20	4	2	20	40	Y	FRB
WP54/66C	1971	21	4	2	20	40	Y	FRB
WP23/73	1973	15	6	14	3	42	Y	TFBL
WP48/66A	1973	22	7	3	9	27	Y	FRB
WP 2/81C	1981	5	4	11	4	0	Y	TFBR
WP48/66D	1980	9	8	3	9	81	Y	FRB
WP48/66C	1973	22	7	3	9	27	Y	FRB
WP48/66B	1973	22	7	3	9	27	Y	FRB
WP 2/81D	1973	5	4	11	4	0	Y	TFRB
WP21/76	1976	11	4	7	3	30	Y	TRB
WP22/76	1976	13	6	8	4	16	Y	TRB

Butcher (1977) studied the hydrological relations of the stands in the Yanchep trial in detail, incorporating through-fall and stem-flow studies with measurement of soil water availability on certain plots. He concluded that the major factor determining *Pinus pinaster* growth on the drought prone, weakly leached coastal plain sands, within a Mediterranean type climate, is soil moisture availability. This in turn is governed by depth and moisture holding capacity of the porous sand, which limits the magnitude of moisture storage during winter, and by the density of stand, which controls the rate of exhaustion of the stored water during the spring and summer season. Manipulation of the stand density by thinning increases the through-fall and hence the recharge of the soil moisture system. Withdrawal over the long summer drought period is regulated by a lower density of trees. Thinning concentrates cambial growth on high value crop trees. The effectiveness of fertiliser application was considered to be dependent on the moisture condition of the soil profile. Subsequent measurement and analysis of the trials conclusively shows that there is no indication of fertiliser by stand density interaction or that the dominant stand is any more effective in fertiliser use than the dominated stand.

Pilot Plot studies - Site-vegetation surveys in the 1960's to assess the potential for planting *Pinus pinaster* on the northern Swan Coastal plain (Havel 1968) revealed a lack of information on pine establishment and growth on sites with a limestone influence. To rectify these needs a series of large pilot plots were planned to cover southern, central and northern sites within the range suggested as suited for commercial growth. Design of the plots anticipated that soil moisture would be limiting to tree growth in most years and planned to investigate the thinning and fertiliser requirements for commercial success.

A preliminary report on the study was published by Butcher in 1979. Growth for the initial 10 year period was similar over the range of the plots and comparable with that of the optimum sites at Gnangara where the pines were in contact with a ground water source. Differences present resulted from variations in initial growth. Growth was apparently independent of the climatic, soil and fertiliser factors involved for the three locations but was related to thinning treatment and hence to stand density (Butcher, 1979).

Fertiliser was not essential for establishment or early growth of *P. pinaster* to an age of 10 years on the yellow sands tested. Evidence from other areas, however, suggested that fertiliser applications would stimulate the growth of stands of intermediate ages on the sites concerned.

A greater susceptibility to drought death was evident at the northern, Karakin plot. This was not considered to be sufficient reason to eliminate such sites from the potential planting resource. Results from the extreme 1976-77 summer showed that all sites were susceptible to drought deaths, and the elimination of sites susceptible to summer drought deaths from the programme would lead to the virtual cessation of planting on the Coastal Plain. Butcher suggested that when assessing economic viability it was necessary to determine the level of stand density, in terms of basal area, at which there is a balance between the moisture recharge of the soil profile and moisture use by the pine stand.

Later testing - In 1972 and 1973 trials were established in stands planted in 1965 and 1966 to assess

i) The impact of different commercial stocking levels on stand and fertiliser response.
ii) The difference between low and high additions of a fertiliser.
iii) The difference between P, N and NP responses.
iv) The difference between frequent application and infrequent application.

Further trials investigating aspects of fertiliser addition were continued up to 1981. These and later results of the Basal area and Pilot trials have not previously been analysed and reported. This is the objective of this current paper. Tables 1 and 2

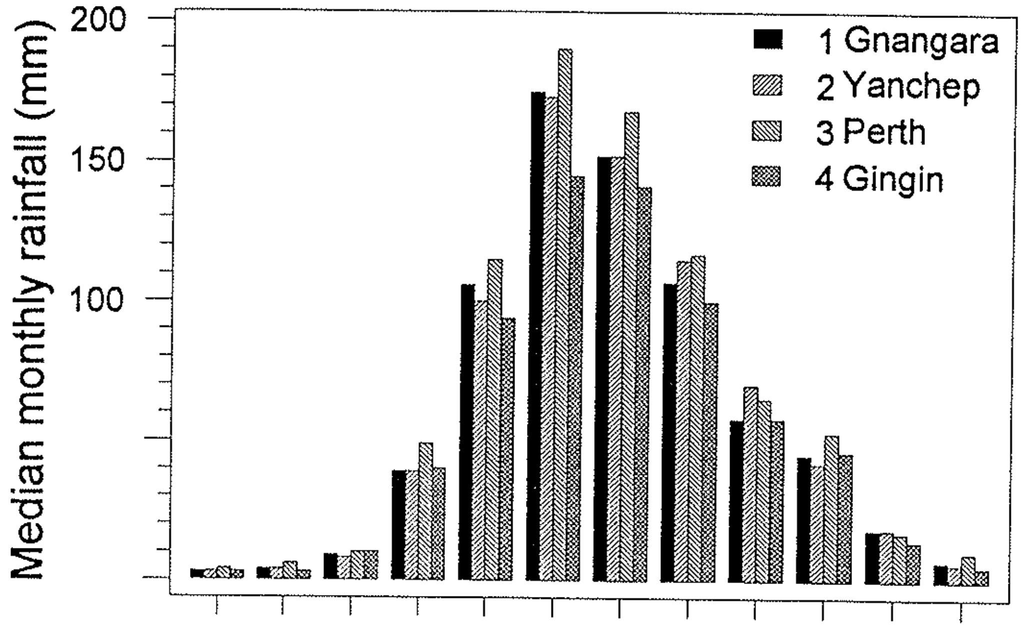

Figure 1. Bar diagrams showing the monthly rainfall variability for collection stations in the study area. All data are based on median values in a 39 year (1941-1979) period.

summarise fertiliser research activity in *P.pinaster* since 1968 and illustrate the range of designs, sites, fertilisers and age classes involved. General results for the study, presented in the remainder of this report, are separated for young, intermediate and mature age stands within the two major soil types.

Documentation for each trial including Summary and Conclusions, Procedure, Results and Discussion is attached as Appendix I.

Climate

The coastal plain area north of Perth experiences a temperate, Mediterranean climate with warm, dry summers and mild, wet winters.

Rainfall - The average rainfall for Perth, which has the longest records available for the area, is 870 mm with approximately 90 per cent falling between April and October (Table 1). Butcher (1986) collated results of rainfall sampling on sites in the area of interest for plantation development. He estimated average annual rainfall for the general plantation area to be 772 mm. The the year to year totals varied considerably but the annual pattern was similar for all stations (Fig. 1). Rainfall decreases northwards along the coastal plain and generally increases eastwards from the coast. The probability of a six month drought using Precipitation / Evaporation ratios is 41 years out of a 100 at Yanchep, but only 16 out of 100 for Perth (Havel 1968).

Table 3. Climate averages relevant to the study area (WAWA 1986). Rainfall and evaporation are in mm, temperature in ^{o}c and relative humidity in percentage units.

		Month											
	Source	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall	1	9	12	19	45	123	182	173	137	81	54	21	14
Raindays	1	3	3	4	8	14	17	18	17	14	11	6	4
Mean Temp.	2	25	26	23	20	16	14	12	13	14	16	19	22
Mean Max T	2	34	34	31	26	22	19	18	18	20	24	27	31
Mean Min T	2	16	17	15	12	10	9	8	7	8	9	11	14
Mean Daily Evaporation	3	11	9	7	5	3	3	2	3	3	5	7	8
Mean % RH	4	39	39	45	56	61	69	70	66	63	54	47	40

1. - For Perth station (1876-1985).
2. - For Gnangara Mound stations (1940-1984).
3. - For Swan Research Station (1973-1983).
4. - For Swan and Pearce stations at 0900 and 1500 hours (1937-1984).

Temperature - Temperatures for the study area are moderate (Table 3), with the highest mean monthly recorded in January and February (34^{o}C) and the lowest mean monthly minimum recorded in August (7^{o}C)

Evapo-transpiration - Evaporation exceeds rainfall in at least 4 months of the year and together with transpiration from plants is estimated to use about 70 per cent of the average annual rainfall (WAWA 1986).

Of the 70 per cent of the annual rainfall which falls during the coolest months of the year 25 per cent is required for evapotranspiration and the remainder is potentially available for redistribution and subsequent plant use during the period when evapotranspiration exceeds rainfall.

Landforms and Soils

Details of landforms, soils and associated vegetation for the plantation areas are provided by Havel (1968), McArthur (1991) and McArthur and Mattiske (1986).

Landforms - The study area on the northern part of the Swan Coastal Plain includes two major systems of dune materials. The furtherest inland and oldest is the Bassendean Dune System which is composed entirely of siliceous sand. This is the main setting for the Gnangara plantation. Further west is the Spearwood dunes System described by McArthur and Bettenay (1960) as consisting of a core of aeolianite, with a hard capping of secondary calcite overlain by varying depths of yellow brown sand. The parent material was calcareous sand to the surface, but continued leaching has removed the carbonate from the upper profile and precipitated it below to form a hard capping. The Yanchep plots sample the yellow sands of this system.

The Bassendean Dunes (Gnangara Sands) have low relief and the minor variations in topography are reflected by differences in depth to the water table which in turn influences the vegetation. There are hills and ridges with relief in excess of 5 m and commonly 10-15 m (Jandacot), level or gently undulating terrain (Gavin) and depressed areas which are swampy in winter (Joel).

The Jandakot soils occurring on the crests and upper slopes of ridges are quartz sands with a grey surface, an almost white sub-surface and a yellow sub-soil at 1-2 m. In some cases the bleached A2 horizon may be 2 m thick. The water table is at least 10 m below the surface.

The Gavin unit is generally of less than 5 m relief with free draining quartz sands with a dark grey surface, a grey sub-surface and a dark brown, sometimes cemented, sub soil; there may be iron concretions. These soils are iron-humus podsols and are very dry in summer.

The Joel unit occurs as small, separate, depressed areas within both the Jandacot and Gavin landscapes. The soils are humus podsols of quartz sand with a very dark grey surface of high organic content, a grey sub-surface and a dark brown, often cemented sub-soil at 1-2 m. The water table is usually within 2 m of the surface.

The Spearwood Dunes (Yanchep Soils) sites used for planting are mainly the Karrakatta sands comprising low hilly to gently undulating terrain with well drained yellow sands over limestone. On the western part of the Spearwood System a yellow phase of the Karrakatta sands consists of grey-brown surface sand which passes into bright yellow sand with limestone generally within 2 m of the surface. The soil tends to be shallow on the tops of rises becoming deeper in the hollows. A grey phase of the Karrakatta sands occurs mainly in the eastern part of the Spearwood dunes system. The soil is an iron podsol with a grey surface, an almost white subsurface and a yellow subsoil. Limestone is generally deeper than 2 m. The unit has affinities with the Jandakot Unit but is separated because of the limestone substrate (McArthur and Mattiske 1986).

The Spearwood sands are associated with karst depressions and emergent limestone outcrops, mainly on the western margins. They are well drained shallow brown sandy soils. A limestone unit of low hills and ridges with bare limestone or shallow siliceous or calcareous sand over limestone is also common towards the coast. The limestone unit is well drained with poor moisture storage.

Bassendean Sands

1. Young stands

(a) Establishment

Four trials, WP 17/76, WP 20/76, YS35 and YS36 investigated the effects of fertiliser at time of establishment or within a couple of years of establishment. The former contained a control, the latter two did not. Sites covered ranged from failed H types (WP 17/67) to the best I types (YS35 and YS36).

Trial WP 17/67 investigated effects of superphosphate and slow acting rock phosphate separately and in mixture, in single and double doses and with fertiliser repetition on poor quality, grey sands of the Bassendean Dunes System. Spot applications of 60 g per tree at time of planting, double dose of each fertiliser and a mixture, either applied in year 1 or split to apply half in year 1 and half in year 3 were compared. Best early response was obtained with the superphosphate which was significantly better than the rock phosphate alone. The double dose was no more effective than the single dose and in fact half the dose split over 3 years was adequate for the stimulus obtained.

Foliar analysis for per cent P at ages 2 and 4 years showed a rapid decrease in plant phosphate from the initial phosphate application, demonstrating the transitory response to superphosphate applications on such sites. The best treatments did not maintain height and volume growth at a level satisfactory for plantation practice.

WP 20/76 tested four different fertiliser applications against an unfertilised control on three year old plants on marginal sands of the Bassendean Dunes system. Significant height growth response was obtained in the 2 years following application and was highly significant for 5.5 years. There was no difference in response in N and N+P treatments and a dressing of 500 kg superphosphate ha^{-1} (46 kg P) was as good as any tested.

Trials YS35 and YS36 tested subsequent applications of P and N+P fertilisers to the establishing stand on more typical range of sites on the Bassendean Dunes system. For the best, moist sites (I type) a fertiliser regime applying 57 g of superphosphate to the plant at time of planting and a further 500 kg ha^{-1} at ages 6 and 8 years was favourable. There was no indication that broadcast dressings at an earlier age or N additions could improve on this performance. In the similar Trial YS36 there was evidence that a second spot application of superphosphate at age three and or broadcast applications at age 4 years were beneficial on drier sites (G and H).

The conclusion from these trials is that for pine planting on the Bassendean Dune sands a spot application of 60 g of superphosphate at time of planting and at least 500 kg ha^{-1} of superphosphate at age 3 and 6 years should provide optimum establishment and growth. There was no indication that N additions could be advantageous at this stage. Some evidence indicated that higher applications than those suggested would be wasted.

(b) Post establishment (6-15 years)

WP 17/67 extended fertiliser applications into developing stands. At age 15 the trial was thinned and superphosphate applied as a basic dressing of 250 kg ha^{-1}, as single or double dose and with applications single or split over 3 years. Fertiliser stimulated growth within a year of application and had a significant effect on increment for up to 4 years after application. The single application of 250 kg ha^{-1} at age 15 years was as good as double doses or split applications.

For WP 20/76 the treatments were fertilised a second time at stand age 11 years. Response was good to maintain increment of 8 m^3ha^{-1} up to age 15.5 years. A dressing of 500 kg ha^{-1} superphosphate was as good as any tested. There was no indication that N fertiliser addition could be favourable.

Applications of 500 kg superphosphate with and without 200 kg of ammonium sulphate ha^{-1} were applied at stand ages 6, 8 and 12 years in trials YS35 and YS36. The application at 8 years was favourable but there was no evidence that the further addition at age 12 years or the addition of N fertilisers was warranted.

WP 8/72 tested the effects of both P and N+P fertilisers on 6 year old stands on typical grey, leached sands of the Bassendean Dunes system. Two levels of superphosphate, 400 kg ha^{-1} and 800 kg ha^{-1}, and two levels of urea, 0 and 150 kg ha^{-1}, were compared at application intervals of 9 or 7 years. Unfertilised controls were available for comparison of treatment effects. Response was excellent but there was no evidence to suggest that use of double doses of superphosphate or the use of urea was warranted. A response to the application at age 6 years was maintained for up to 4 years. From the trial, fertilisation with 400 kg ha^{-1} superphosphate at the age of 6 years, repeated at least at 7 year intervals would appear to be satisfactory. It was possible that applications of less than 400 kg ha^{-1} superphosphate would suffice.

WP 2/81 also tested the effect of P and N+P fertiliser on 8 year old stands on the Bassendean Dunes sands. The effects of superphosphate at 500 kg ha^{-1} and 500 kg superphosphate plus 150 kg ha^{-1} urea were compared against unfertilised controls. Results were spectacular with the N+P and P treatments being 134 and 118 per cent of the control volume produced in the six years after application. The controls may not have been representative and the response may be inflated. The N+P response was 14 per cent better than that of the P response. Foliar levels of P responded immediately to treatment and remained high 5 years after the application.

For stands in the 7-15 year age span it appears that 500 kg ha^{-1} of superphosphate, applied at 5 to 7 year intervals will produce optimum response.

In one instance N+P application proved superior to P alone. In this case the improved response was only 14 per cent superior to the P alone treatment and the overall evidence would not warrant use of N at the levels tested.

2. Semi-mature stands (15-25 years)

WP 2/81 also included three 17 year old stands on the Bassendean Dunes system. To the first stand, an average to poor site, the N+P response was 26 per cent in volume for the five years following application. The P response was only 5 per cent. For the other two stands which were of good quality (CAI 9 m^3 ha^{-1}) there was no response to fertiliser application.

WP 21/76 aimed to increase growth on 20 year old stands on poor site quality at Pinjar Plantation. A control was tested against a base dressing of 500 kg ha^{-1} of superphosphate and increasing additions of urea up to 625 kg ha^{-1}. Response to fertiliser was significant for the first two years after application and increased in the third and fourth years. There was no detectable effect of fertiliser addition on increment in the fourth and fifth years after application. Treatments receiving more than 300 kg ha^{-1} urea were significantly better than the control in growth. The most effective treatment received 625 kg ha^{-1} urea and was superior to any treatment with less than 300 kg ha^{-1} urea. There was no advantage in increasing the base dressing from 500 to 1000 kg ha^{-1} superphosphate. A second fertiliser addition at age 28.5 years produced a highly significant response with 400 kg ha^{-1} superphosphate plus 600 kg ha^{-1} urea but none with superphosphate alone or super plus 150 kg ha^{-1} of urea. The average increase in current annual increment in total volume was 4 m^3 ha^{-1} on the 100 stems ha^{-1} of the select crop.

WP 20/65 was refertilised with 500 kg ha^{-1} superphosphate at age 16 years and set up as a thinning trial with two fertiliser levels. Treatment 1 of 500 kg ha^{-1} superphosphate and treatment 2 of 500 kg ha^{-1} super plus 500 kg ha^{-1} super, copper, zinc plus 250 kg ha^{-1} ammonium sulphate were applied at stand age 25 years.

Treatment 1 of 500 kg ha^{-1} super and treatment 2 of 500 kg ha^{-1} super plus 500 kg ha^{-1} Agras No 1 were applied at age 34 years. A significant response to treatment 2 over treatment 1 was recorded in CAI for two years after the first application and 3 years after the second application. Trial data indicated that the response of additional fertiliser was independent of stand density and site quality. The trial covered a comprehensive range of sites and stand densities. There were no controls to judge the impact of the base dressing of superphosphate but the luxury treatment 2 only increased growth by about 10 per cent above it.

For stands 20 years plus a base dressing of 500 kg ha^{-1} superphosphate appears to be effective. Increased response may be obtained by adding N fertilisers to the equivalent of 140 kg ha^{-1} N equivalent (300 kg urea, 650 kg ammonium sulphate, 800 kg DAP, 800 kg Agras No 1). Limited information indicates that a N equivalent of 70 kg ha^{-1} (150 kg urea, 330 kg ammonium sulphate, 400 kg Agras No 1, 400 kg DAP) may be beneficial in some stands. Replacement of a base dressing of 500 kg ha^{-1} of superphosphate by 200 kg of DAP to provide the same P equivalent would not meet this N requirement but at equal price with superphosphate, 400 kg ha^{-1} DAP could prove to be a better general fertiliser. The effectiveness of DAP in supplying P and N to pine stands was not tested in the current experiments.

Spearwood Sands

(a) Young Stands

No trials tested the applications of fertiliser other than the standard of 60 g of superphosphate, copper, zinc at time of planting. Trials WP 48/66 and WP 2/81 tested the effect of fertiliser additions to the young stand of 6 to 8 years.

WP 48/66 compared the effects of (1) 750 kg ha^{-1} super, copper, zinc with (2) 750 kg ha^{-1} super, copper, zinc plus 250 kg ha^{-1} urea and (3) unfertilised control applied at stand ages 6, 13 and 21 years at three different sites. For the northern Karakin site there was a significant effect of fertiliser at age 6 years on CAI basal area up to age 9 years. There was no difference in response in the P or the N+P applications. No effect of the early fertiliser was recorded at the Haddrill and Wabling sites.

WP 2/81 compared the effects of 500 kg ha^{-1} superphosphate with 500 kg ha^{-1} superphosphate plus 150 kg ha^{-1} urea and a control at age 8 years. Response in volume over the 5 years following application was 15 per cent better than the control for both the P and N+P treatments.

There was little effect of P or N+P treatments to stands 6 to 8 years old on the Spearwood Dunes system. Application of 500 kg ha^{-1} of super, copper, zinc fertiliser at age 6 years may produce a response of 15 per cent for about 3 years.

(b) Young to Medium aged stands (6-15 years).

WP 23/73 tested single and double doses of 375 kg ha^{-1} of superphosphate, 125 kg ha^{-1} urea and a mixture of 375 kg super plus 125 kg urea ha^{-1}. Each was compared when applied at 6 and 10 year intervals, commencing with an 8 year old stand. Fertiliser differences were only significant in the year following application and there were no important effects of either dose or application procedure. A Luxury treatment of 750 kg ha^{-1} super plus 250 kg ha^{-1} urea plus 125 kg ha^{-1} Minorels minor element mix was significantly superior to the control for the interval 8 to 18 years. It was however, equivalent to the maximum N+P dressing of the factorial treatments in the 14-18 year period of measurement. The maximum increment obtained was in the range 9 to 17 per cent.

The three Pilot plots in WP 48/66 were re-fertilised at age 13 years with no response to fertiliser to age 20 years.

WP 2/81 compared 500 kg super and 500 kg super plus 150 kg ha^{-1} urea with a control on a 13 year old stand on yellow sand of the Karrakatta series. Volume increment in the 5 years following application were 103 and 134 per cent respectively of the control

There is little evidence to support the application of superphosphate additions of up to 750 kg ha^{-1} and urea additions up to 250 kg ha^{-1} to young stands on Spearwood Dune sands. Response could be considerable on some deep yellow sands of the Karrakatta series.

(c) Medium to Mature Stands

The Pilot plots in WP 48/66 applied 500 kg ha^{-1} super, copper, zinc and 500 kg ha^{-1} super, copper, zinc plus 200 kg urea ha^{-1} at stand age 21 years. There was no observable effect at age 22 years to the whole stand but the select crop of 100 stems ha^{-1} showed improved increment from the superphosphate fertiliser at Karakin and Haddrill plots. The fertilised plots in the Pilot series showed 5 per cent improvement at Wabling, 14 per cent improvement at Haddrill and 10 per cent improvement at Karakin due to fertiliser application.

WP 54/66 compared applications of 500 kg ha^{-1} super, copper, zinc plus 250 kg ammonium sulphate at stand age 19 years to no fertiliser application. Response was immediate and remained for four years, Response to a further application of 500 kg super, copper, zinc plus 500 kg Agras No 1 at age 27 years was also of at least 4 years duration. Response was independent of stand density and appeared to be least on the best sites. The overall return in wood production to the fertiliser application was 6 per cent for the whole stand and 10 per cent for the 100 select crop stems.

Response to fertiliser on semi-mature to mature stands on the Spearwood Dunes sands is of the order of 6 to 10 per cent of the increment on unfertilised areas. This has been obtained with the equivalent of 500 kg ha^{-1} super, copper, zinc plus 50 to 90 kg ha^{-1} Nitrogen.

Timing of Fertiliser Applications

Apart from the effect of fertiliser applications at time of planting and to young, intermediate and mature stands explained above trials examined

i) the efficiency of fertiliser applications in different months in the Autumn to Spring season and

ii) fertiliser application associated with time of thinning.

WP 2/81 showed conclusively there was no growth advantage in applying P and N+P in any particular month from April to October. WP 21/76 and others found that fertilisers should be added as close to, or as soon after the thinning operation as possible. Significant losses in growth occurred when fertiliser application was delayed 3 or 4 years after thinning.

The effect of Stand Density

Knowledge of annual water stress on pines due to the dry summers of the region set up a hypothesis that fertiliser addition would be most effective in heavily thinned stands where water stress was less due to reduced stand density. This was studied in detail in the basal area thinning studies, WP 20/65 and WP 54/66, and the Pilot Plots in WP 48/66. There is no evidence that fertiliser effect and stand density interact with the reduction in basal area within the range from 37 m^2 ha^{-1} to 7 m^2 ha^{-1}. In fact fertiliser effect is best in stands with full stocking, response apparently being greatest on the smaller trees which do not make up the dominant or select crop.

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APPENDIX - DETAILS OF INDIVIDUAL TRIALS

List of Trials since 1970.

WP 20/65 - Basal area control thinning and fertiliser additions on grey sands at Gnangara.
WP 54/66 - Fertiliser responses following first thinning in *Pinus pinaster* stands on limestone soils at Yanchep.
WP 48/66 - Thinning and fertiliser trials at Karakin, Wabling and Haddrill on Spearwood Dune soils on the northern coastal plain.
WP 17/67 - Early application of phosphatic fertilisers on highly leached sands of the Bassendean dunes system.
WP 29/71 - Second rotation study on high quality sands at Gnangara.
Trials YS35 and YS36 (1971) - Interaction between fertiliser application and genotype on grey sands at Gnangara.
WP 8/72 - Post establishment fertiliser application to *Pinus pinaster* on the Bassendean sands.
WP 23/73 - Post establishment fertiliser application to *Pinus pinaster* on Spearwood sands.
WP 20/76 - Early applications of nitrogen and phosphate fertilisers to *Pinus pinaster* stands on Bassendean sands of low site quality.
WP 21/76 - Refertilisation of *Pinus pinaster* at Pinjar
WP 22/76 - Refertilisation of *Pinus pinaster* at Gnangara
GN E44 - Fertiliser application to 21 year old *Pinus pinaster* at Gnangara subject to water bore draw-down.
WP 2/81 - Seasonal timing for fertiliser application to *Pinus pinaster* stands on coastal plain sands.

WP 20/65 - Fertiliser responses in thinned *Pinus pinaster* on Bassendean Sands at Gnangara.

Summary and Conclusions

At Gnangara fertiliser was applied as a single dressing at stand age 25.2 years (September 1971) and as a two part application at ages 34.2 (September 1980) and 35.2 (September 1981) years. Treatment F1 applied 500 kg ha^{-1} superphosphate while F2 applied double this amount with 250 kg ha^{-1} of ammonium sulphate at age 25.2 and 500 kg ha^{-1} Agras at age 35.2.

For the whole stand CAI registered a significant response at ages 25.5, 26.5 and 27.5 to the first application. To the second application CAI response was highly significant at ages 34.5, 35.5, 37.5 (.053 level) and 38.5 years.

In the 100 stems ha^{-1} of the select stand a significant response to the first fertiliser addition was present in CAI at ages 26.5 and 27.5 years. Response to the second application occurred from age 34.5 to age 37.5 years. A significant Density by Fertiliser interaction, detected at age 36.5 years, resulted from excessive response to fertiliser in the 16 m^2 ha^{-1} treatment with minimal response in the extreme 7 and 37 m^2 ha^{-1} treatments. There is no obvious explanation why both the highest and lowest stand densities should have minimal response to fertiliser. The interaction was not present for the whole stand, it was relatively minor in extent and is not considered to be important.

MAI for the whole stand fertiliser response was highly significant from age 27.5 until the final measurement at age 38.5.

In the select crop the MAI response in BAob to the first fertiliser application was highly significant at age 27.5 years only. To the second application a significant response was obtained at ages 36.5, 37.5 and 38.5 years.

Trial data indicated that the degree of response to additional fertiliser did not interact with stand density or site quality.

The low level of response to the expensive, luxury fertiliser application obtained in the trial (approx. 10 per cent) probably would not warrant its use in practice. Results showing the transitory nature of the response indicate that repetition of the base fertiliser at a 5 instead of 10 year interval could be more economical and effective silviculturally.

Establishment

Location - The trial was located at Latitude 31°48'S, Longitude 116°55'E in compartments c69 and c70 in South Lane Poole Block, Gnangara. The stands concerned, planted at 1.8 m x 1.8 m square spacing in 1946 with seed imported from Portugal, represented the largest available area of plantation, of reasonable age, covering the range of sites and conditions typical of more recent planting. These heavily leached, sandy sites are deficient in nutrients and pines require added fertiliser for satisfactory growth (Perry 1939, Hopkins 1960). The stand received 57 g of superphosphate fertiliser per stem at time of planting and 500 kg ha^{-1} of superphosphate broadcast in May 1962 (age 16 years). Trees were low pruned to 2.5 m in 1958, to 5 m in 1959 and to 7 m in 1964.

Selection - Rectangular plots of 40 m x 20 m were selected to embrace areas of pine with apparent uniformity in stocking and tree height, with a buffer of at least 20 m between plots. Plots were divided into 4 consecutive subplots of 10 m x 20 m and in each subplot trees were counted and the heights and the diameter at breast height (DBH) of the 10 tallest (250 ha^{-1}) were measured. For each subplot the mean height and the total basal area over bark (BAob) were calculated.

Table 1. Plot allocation to site groups and randomisation into density and fertiliser treatments in the Gnangara trial. Plots marked with an asterisk were fitted with soil access tubes for soil moisture monitoring.

Treatment		Site (block)				
Thinning	Fertiliser	1	2	3	4	5
37 m^2 ha^{-1}	P	*32	43	*16	41	*39
	2P+N	9	15	56	1	18
25 m^2 ha^{-1}	P	25	*50	*21	23	*28
	2P+N	33	2	12	38	29
16 m^2 ha^{-1}	P	22	*40	36	*24	*27
	2P+N	3	8	10	13	6
11 m^2 ha^{-1}	P	*35	44	58	*46	*34
	2P+N	31	17	54	7	30
7 m^2 ha^{-1}	P	*4	53	49	52	*20
	2P+N	42	37	*48	51	19

Variation in height and diameter between subplots was often excessive and it was decided from the data that 20 m x 20 m plots, selected within each 40 m x 20 m temporary plot, would provide for both reasonable plot uniformity and a suitable total number of plots to satisfy a comprehensive trial. The two most similar, adjacent subplots in each plot were combined to represent a potential trial plot. Fifty eight of such were obtained.

The plots were ranked on the basis of mean height of the 10 predominant trees. Only the height range in which a reasonably uniform series of plots was available was considered. Fifty plots were selected into five site or uniformity blocks each containing 10 plots. Within each site block five density treatments at each of two fertiliser levels were randomly selected (Table 1).

Treatments - The maximum basal area which could be related to all of the plots was 37 m^2 ha^{-1}. Five stand density treatments were based on this by reducing each consecutively by one third to give treatments of 37, 25, 16, 11 and 7 m^2 ha^{-1}. Within each site group paired plots, selected on the basis of uniformity for both height and basal area, were assigned randomly to one of the five density types. One of each pair was assigned randomly to one of two fertiliser schedules.

Table 2. Measurement and thinning history for WP 20/65 at Gnangara plantation. For height measurement SC indicates that only the select crop trees were measured.

Date	Age	DBHOB	BarkT	Height	Ht.Cr.	Thin	Fert.
Aug. 1965	19.0	*	*	*	*		
Jan. 1967	20.6	*	*				
Apr. 1968	21.8	*				*	
Jan. 1970	23.8	*	*	*	*	*	
Sept.1971	25.2						*
Jan. 1972	25.5	*	*	*	*	*	
Dec. 1972	26.5	*		SC			
Jan. 1974	27.5	*	*	*	*	*	
Jan. 1976	29.5	*	*	*	*	*	
Dec. 1976	30.5	*					
Jan. 1978	31.5	*		*	*		
Jan. 1979	32.5	*				*	
Feb. 1980	33.6	*		SC			
Sept.1980	34.2						*
Feb. 1981	34.5	*					
Sept.1981	35.2						*
Feb. 1982	35.5	*		SC			
Jan. 1983	36.5	*		*			
Jan. 1984	37.5	*	*	SC			
Jan. 1985	38.5	*		SC			

Soil Moisture Monitoring - in 1968 two neutron probe access holes were randomly located in plots in the first, third and fifth site uniformity groups (Table 1).

Thinning - Stands were thinned to treatment specifications in 1965 to allow the first measurement in August 1965. All thinning volumes were recorded. Thereafter, to provide an average stand density over time as specified, plots exceeding the specified density due to ingrowth were thinned at approximately 2 yearly intervals to a value 5 per cent less than the treatment specification.

Fertiliser Application - In September 1971 at stand age 25.2 years the following treatment was applied:-

F1 - 500 kg ha^{-1} superphosphate.
F2 - 500 kg ha^{-1} superphosphate + 500 kg ha^{-1} Super, copper, zinc + 250 kg ha^{-1} Ammonium sulphate.

Table 3. Response in current annual increment to fertiliser within stand density classes. Data is summarised for both the whole stand and the select stands.

	Stand density (m^2 ha^{-1})									
Age	7		11		16		25		37	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
	Whole crop									
20.6	1.23	1.06	1.54	1.61	1.65	1.73	2.13	2.02	2.33	2.59
21.8	1.86	1.58	1.87	1.88	1.94	2.07	1.88	2.05	2.06	1.93
23.8	2.31	2.37	2.58	2.78	2.93	3.20	2.89	3.11	3.07	3.15
25.5	0.96	1.04	1.30	1.47	1.51	1.79	1.67	2.11	2.14	2.12
26.5	0.57	0.80	0.87	1.05	0.94	1.23	0.96	1.52	1.21	1.28
27.5	0.83	1.17	1.42	1.64	1.53	1.94	1.36	1.95	1.50	2.06
29.5	0.89	0.91	1.23	1.23	1.58	1.80	1.65	1.80	1.69	1.83
30.5	0.80	0.79	1.02	0.94	1.33	1.40	1.43	1.48	1.35	2.40
31.5	0.65	0.60	0.72	0.67	0.88	0.93	0.70	0.87	0.60	0.71
32.5	0.64	0.62	0.79	0.69	1.03	1.13	0.46	1.21	0.25	1.32
33.6	0.52	0.55	0.82	0.70	0.94	1.08	0.35	1.28	1.36	1.36
34.5	0.72	0.69	0.91	0.90	1.20	1.45	1.26	1.48	1.32	1.48
35.5	0.78	0.93	0.91	1.27	1.52	2.06	1.63	2.15	1.91	2.27
36.5	0.65	0.68	0.74	0.97	1.12	1.42	1.14	1.59	1.32	1.69
37.5	0.51	0.59	0.75	0.78	1.14	1.25	1.23	1.52	1.59	1.56
38.5	0.53	0.44	0.67	0.66	0.95	1.23	1.06	1.26	1.33	1.52
	Select crop									
20.6	0.54	0.44	0.39	0.42	0.37	0.29	0.26	0.25	0.28	0.26
21.8	0.79	0.72	0.51	0.55	0.36	0.39	0.24	0.26	0.24	0.18
23.8	0.61	0.64	0.45	0.49	0.30	0.33	0.22	0.24	0.17	0.17
25.5	0.83	0.92	0.65	0.73	0.45	0.54	0.29	0.38	0.31	0.29
26.5	0.54	0.64	0.58	0.63	0.33	0.47	0.19	0.34	0.22	0.19
27.5	0.75	1.11	0.79	1.03	0.52	0.73	0.25	0.40	0.29	0.29
29.5	0.89	0.91	0.90	1.03	1.00	0.77	0.36	0.44	0.31	0.31
30.5	0.80	0.79	0.91	0.90	0.70	0.72	0.34	0.44	0.33	0.29
31.5	0.65	0.60	0.63	0.64	0.46	0.51	0.20	0.25	0.13	0.15
32.5	0.64	0.62	0.69	0.65	0.54	0.58	0.32	0.37	0.27	0.23
33.6	0.62	0.55	0.79	0.70	0.60	0.76	0.38	0.48	0.38	0.31
34.5	0.64	0.62	0.79	0.81	0.77	0.94	0.33	0.51	0.28	0.27
35.5	0.78	0.93	0.88	1.27	0.96	1.36	0.50	0.83	0.48	0.51
36.5	0.65	0.68	0.72	0.97	0.69	1.08	0.36	0.59	0.35	0.35
37.5	0.51	0.59	0.72	0.78	0.72	0.86	0.38	0.59	0.36	0.36
38.5	0.53	0.44	0.65	0.66	0.59	0.89	0.34	0.45	0.37	0.35

Table 4. Response in current annual increment to fertiliser within treatment site groupings for the whole stand and select crop.

Age	Site class 1 F1	Site class 1 F2	Site class 2 F1	Site class 2 F2	Site class 3 F1	Site class 3 F2	Site class 4 F1	Site class 4 F2	Site class 5 F1	Site class 5 F2
					Whole crop					
20.6	1.97	1.90	1.83	1.88	1.87	1.82	1.67	1.60	1.62	1.82
21.8	2.12	2.12	2.01	1.95	1.94	1.94	1.89	1.63	1.64	1.87
23.8	1.50	1.60	1.44	1.58	1.38	1.48	1.35	1.33	1.21	1.30
25.5	1.57	1.80	1.56	1.81	1.56	1.68	1.41	1.66	1.47	1.57
26.5	0.95	1.23	1.02	1.18	1.04	1.19	0.94	0.98	0.60	1.09
27.5	1.49	1.84	1.37	1.82	1.31	3.36	1.55	2.03	0.92	1.48
29.5	1.55	1.58	1.46	1.62	1.58	0.85	1.37	1.39	1.08	1.34
30.5	1.22	1.32	1.29	1.31	1.20	1.26	1.14	1.96	1.08	1.16
31.5	0.73	0.69	0.74	0.77	0.77	0.82	0.70	0.71	0.60	0.79
32.5	0.92	1.04	1.05	0.97	0.03	0.92	0.35	1.09	0.83	0.96
33.6	0.37	1.21	1.01	1.04	1.15	0.86	0.67	1.01	0.78	0.85
34.5	1.10	1.29	1.24	1.26	1.09	1.16	1.07	1.28	0.90	1.02
35.5	1.30	1.84	1.44	1.66	1.48	1.70	1.34	1.77	1.19	1.71
36.5	1.04	1.37	1.07	1.36	1.05	1.18	1.03	1.32	0.79	1.12
37.5	1.11	1.14	0.95	1.15	1.12	0.97	1.04	1.21	0.99	1.24
38.5	0.89	1.03	1.01	0.96	0.96	1.02	0.88	1.07	0.78	1.02
					Select crop					
20.6	0.43	0.34	0.39	0.40	0.44	0.30	0.29	0.28	0.29	0.33
21.8	0.52	0.49	0.44	0.46	0.45	0.42	0.40	0.36	0.33	0.37
23.8	0.44	0.43	0.38	0.42	0.35	0.38	0.30	0.34	0.28	0.30
25.5	0.56	0.63	0.54	0.64	0.53	0.53	0.46	0.56	0.44	0.49
26.5	0.42	0.56	0.42	0.50	0.46	0.52	0.32	0.46	0.23	0.22
27.5	0.66	0.78	0.55	0.86	0.56	0.72	0.45	0.70	0.39	0.51
29.5	0.74	0.74	0.69	0.75	0.74	0.78	0.54	0.69	0.43	0.50
30.5	0.73	0.63	0.70	0.70	0.64	0.63	0.55	0.68	0.46	0.50
31.5	0.43	0.40	0.51	0.46	0.43	0.48	0.41	0.45	0.30	0.37
32.5	0.54	0.56	0.55	0.50	0.48	0.43	0.49	0.56	0.41	0.40
33.6	0.60	0.72	0.61	0.57	0.56	0.50	0.46	0.60	0.53	0.40
34.5	0.55	0.70	0.67	0.65	0.58	0.61	0.53	0.73	0.40	0.47
35.5	0.72	1.06	0.80	0.96	0.82	0.92	0.66	1.08	0.60	0.88
36.5	0.61	0.83	0.60	0.77	0.62	0.72	0.53	0.82	0.41	0.51
37.5	0.61	0.68	0.50	0.69	0.63	0.56	0.47	0.69	0.47	0.56
38.5	0.52	0.59	0.57	0.49	0.50	0.55	0.48	0.68	0.39	0.49

A second treatment was applied in September 1980 and 1981 at ages 34.2 and 35.2 years:-

F1 - 500 kg ha^{-1} superphosphate (1980).
F2 - 500 kg ha^{-1} Agras No. 1 (1980) + 500 kg ha^{-1} superphosphate (1981).

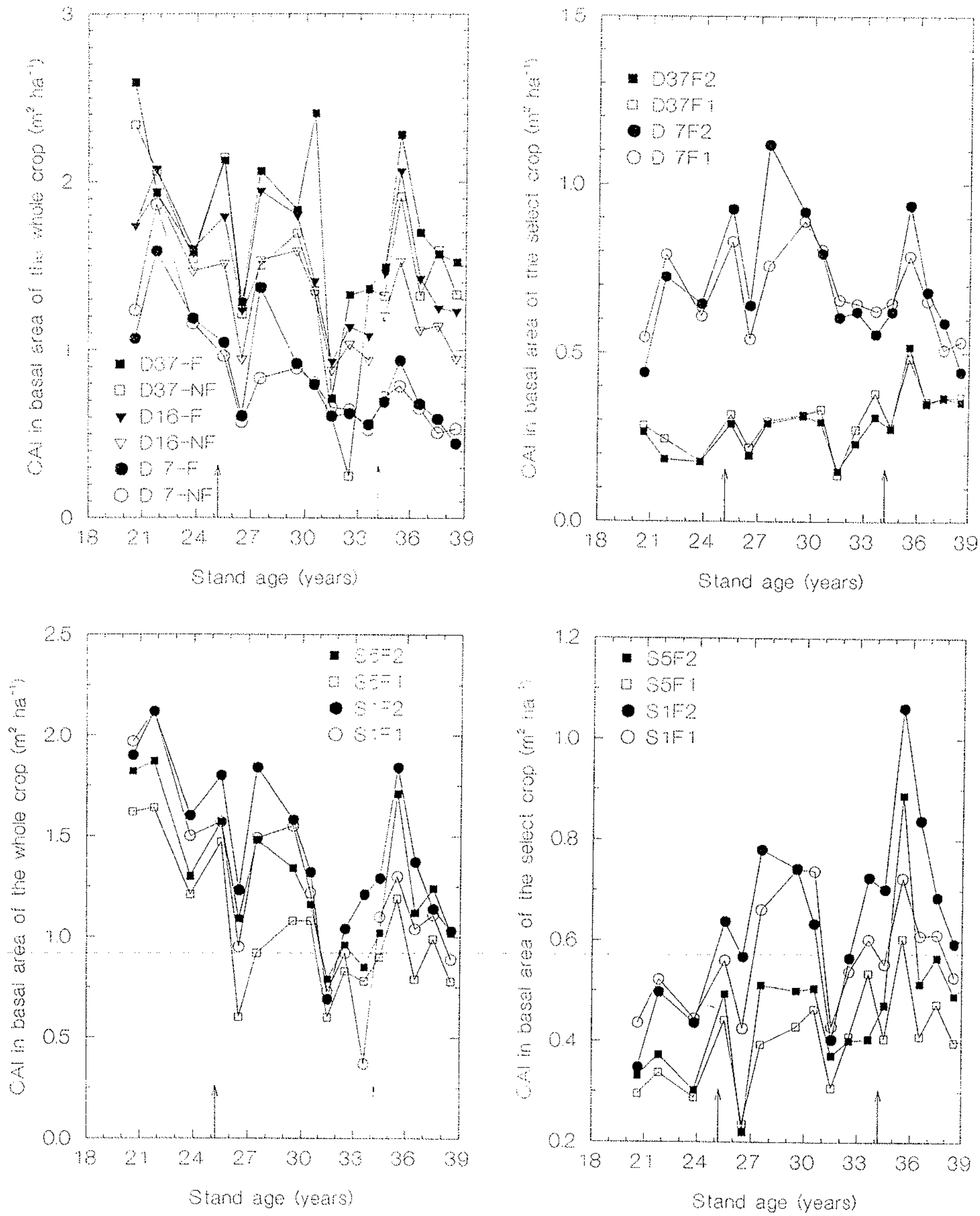

Figure 1. Trends in current annual increment in basal area for fertiliser response within stand density treatments (top) and site groups (lower) at Gnangara. Increment is shown for the whole stand (left) and the select crop (right). The timing of fertiliser additions is marked by vertical arrows in each plot.

Agras is a mixed fertiliser with 17.5 % N and 15.0 % P.

Measurement

Measurements - Diameter over bark at breast height (DBHob) was measured during the summer months in most years (Table 2). Full measurement for bark thickness, tree height and crown height were made whenever practical to do so. Trees removed as thinnings were fully measured together with diameter and bark thickness at 5 m stem height. With stand development height measurement became increasingly time consuming and in the later stages of the trial only marked select final crop trees (100 ha^{-1}) were measured for height.

Foliar Sampling - The 20 plots in site classes 1 and 5 were sampled for foliar nutrients in June 1973 at stand age 27 years. Six select crop trees were sampled in each plot, the samples pooled for each plot and analysed for per cent N, P and K and Zn and Mn content in ppm.

Results

Current Annual Increment in Basal Area

Progressive results for CAI in basal area for both the whole stand and the select stand are contained in Tables 3 and 4. Significance of the differences in means are presented in Table 5.

Stand Density - Increment in BAob for the whole stand increased with increasing stand density in the early years following the initial thinning, with the value for the 7 m^2 ha^{-1} treatment being in the order of one half that of the 37 m^2 ha^{-1} treatment (Table 4). This sequence continued with the regular maintenance of treatment stand densities throughout the life of the trial. Differences between mean CAI's for stand densities were highly significant at all stages. Actual increments varied greatly between years (Fig. 1) with climatic, fertiliser and stand aging effects. The pattern of variation was consistent between stand densities in any one year.

Annual increment for the Select Crop was the reverse of that for the whole stand, increasing with decreasing stand density as a result of releasing a similar number of the best trees (Table 4). The response pattern was consistent and highly significant for all density classes each year. Decreases in the increment of the selects in the lowest density classes in the later stages of the trial (Table 4, Fig. 1) were associated with a reduction in the number of select crop trees with thinning.

Site Classes - Current annual increments of whole stands for site classes graded downwards from the superior site 1 to the poorest site 5. The differences were slight and significant on only 3 occasions (Tables 4 and 5).

Site influences had highly significant effects on increment of the Select Crop stand (Tables 4 and 5) in most years.

Table 5. Significance of main effects and interactions of current annual increment of basal area over bark for WP 20/65 at Gnangara plantation. Results with stand development and treatment are recorded as the probability of the F value in an analysis of variance occurring by chance.

Date	Age	Whole Stand				Select Crop			
		Den	Site	Fert	DxF	Den	Site	Fert	DxF
1967	20.6	.000	.131	.727	.413	.000	.009	.107	.290
1968	21.8	.068	.007	.785	.222	.000	.001	.658	.403
1970	23.8	.000	.001	.071	.923	.000	.000	.165	.912
1972	25.5	.000	.423	.012	.305	.000	.010	.016	.503
1972	26.5	.000	.263	.017	.369	.000	.003	.077	.748
1974	27.5	.095	.301	.022	.363	.000	.001	.000	.069
1976	29.5	.000	.000	.037	.621	.000	.000	.085	.789
1976	30.5	.000	.460	.147	.108	.000	.010	.807	.863
1978	31.5	.003	.618	.331	.445	.000	.096	.676	.863
1979	32.5	.815	.611	.145	.453	.000	.009	.931	.682
1980	33.6	.039	.824	.238	.271	.000	.086	.901	.246
1981	34.5	.000	.009	.019	.251	.000	.010	.973	.457
1982	35.5	.000	.581	.000	.238	.000	.000	.108	.410
1983	36.5	.000	.042	.000	.197	.000	.000	.000	.031
1984	37.5	.000	.849	.128	.567	.000	.376	.000	.552
1985	38.5	.000	.823	039	.157	.000	.053	.013	.252

Fertiliser - Response to the initial fertiliser treatment was immediate, being detected in the measurement at age 25.5 years some 7 months after application, for both the whole stand and final crop (Table 3, Fig. 1). Differences between the F1 and F2 means were significant for three years after treatment for both the whole stand and the select crop (Table 5). Response to the second application which was split between ages 34.2 and 35.2 years was also immediate and significant for at least three years after the first part application.

A density by fertiliser interaction, significant at the 0.05 level, was recorded in 1983 (stand age 36.5 years) for the select crop (Table 5). This interaction was associated with excessive response to fertiliser in the 11 and 16 m^2 ha^{-1} treatments with minimal response in the 7 and 37 m^2 ha^{-1} treatments (Fig. 2). There is little reason for the significance difference in the results in which both the highest density and lowest stand density treatments showed little response to the F2 fertiliser treatment. The interaction is relatively minor over the whole period of measurement and the overall response of CAI to fertiliser addition is summarised in Figure 1.

Mean Annual Increment in Basal Area

Results for MAI in fertiliser main effects for both the whole and Select Stands and significance of the analysis of variance for all effects are set out in Tables 6, 7 and 8.

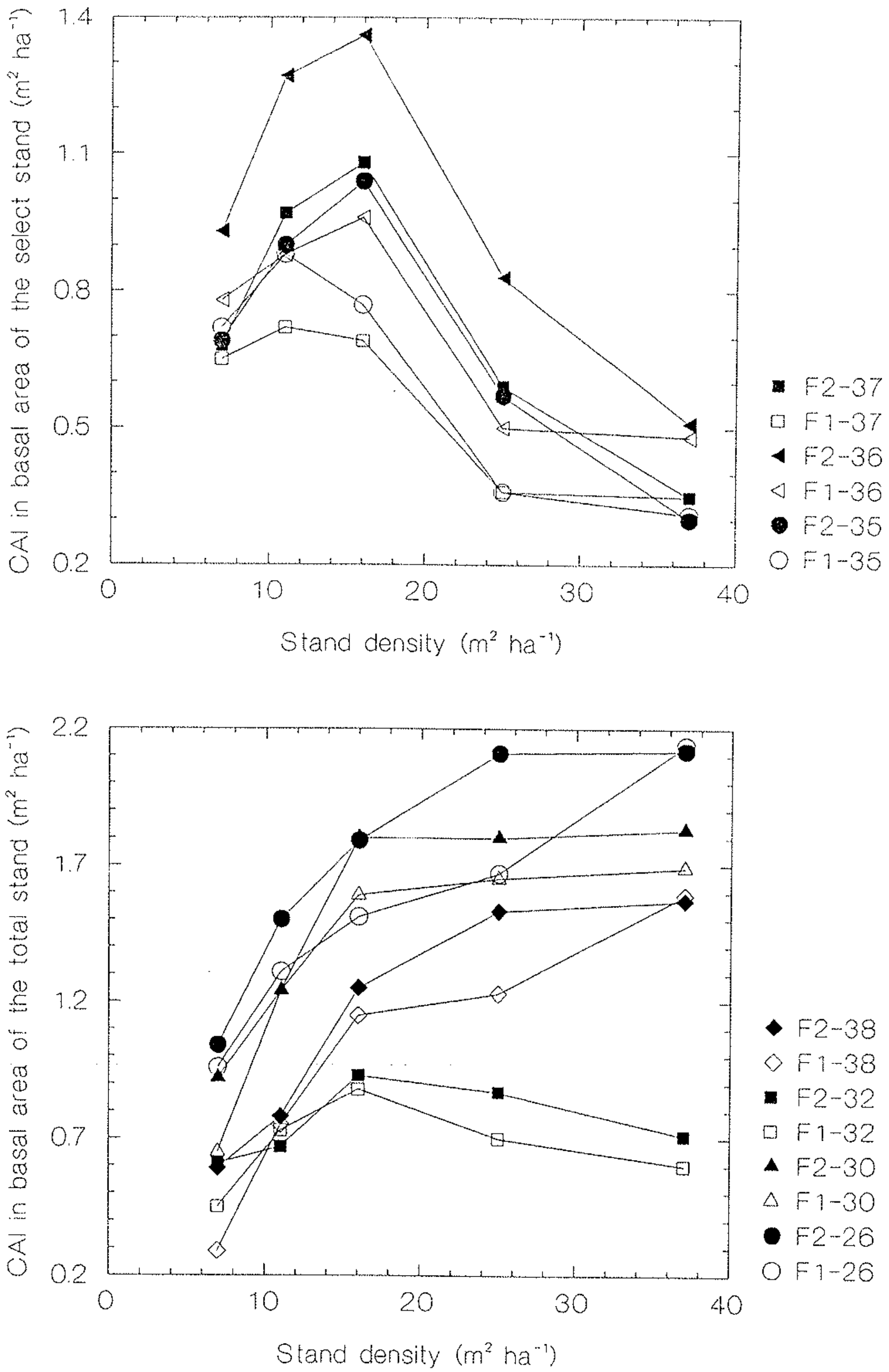

Figure 2. Trend lines for the significant interaction between stand density and fertiliser in 1983 in the select crop at Gnangara (Top). Trends for non significant data for the total stand (Lower) are included to suggest significance is due to a high fertiliser responses at medium stand densities with little response at the highest and lowest stand density.

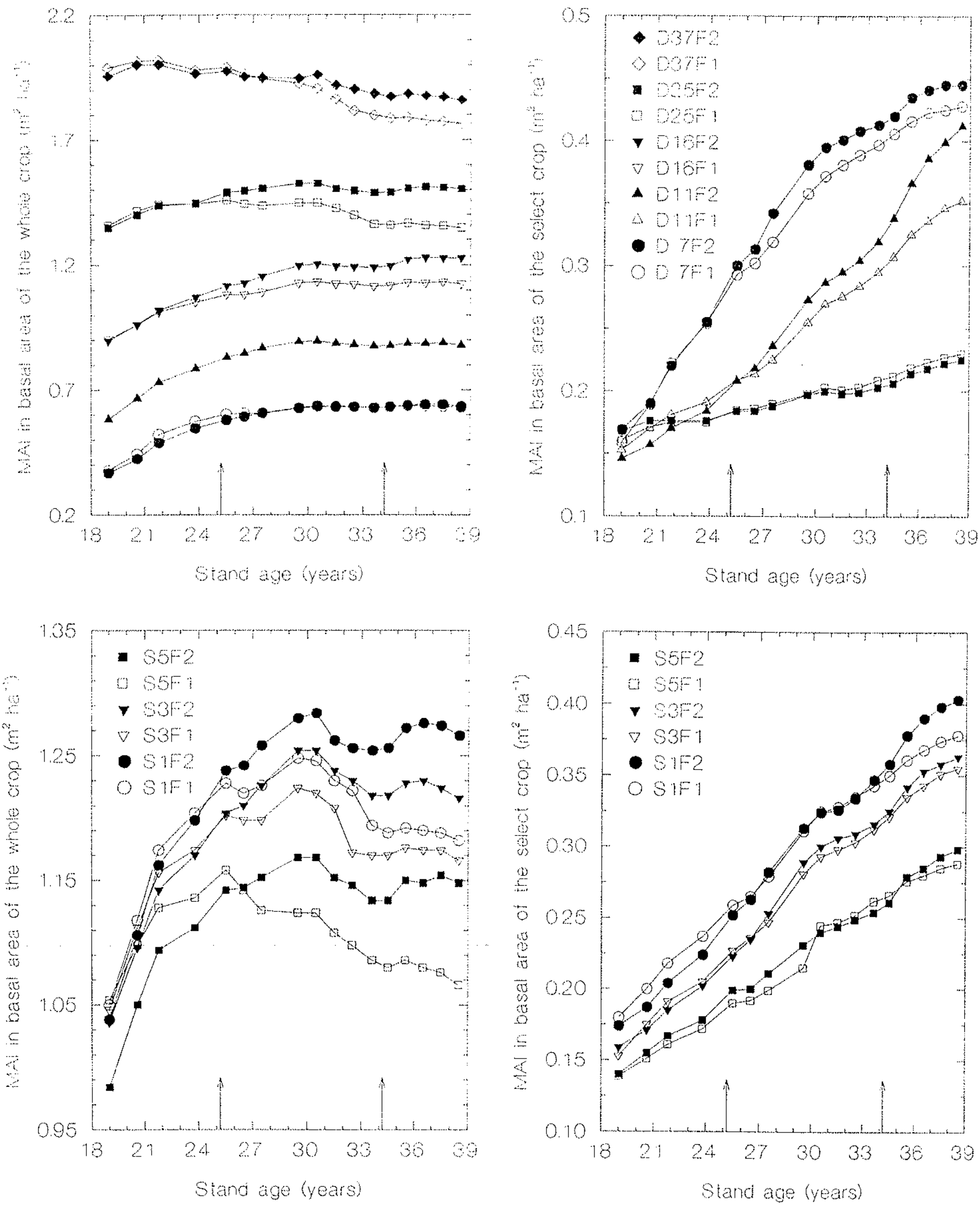

Figure 3. Trends for mean annual increment in basal area for fertiliser response within stand density treatments (top) and site groups (lower) at Gnangara. Increment is shown for the whole stand (left) and the select crop (right). The timing of fertiliser additions is marked by vertical arrows in each plot.

Table 6. Response in mean annual increment to fertiliser addition within treatment stand density classes for both the whole and select stands.

Age	Stand density (m^2 ha^{-1}) 7		11		16		25		37	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
	Whole stand									
19.0	0.37	0.36	0.57	0.58	0.90	0.89	1.35	1.34	1.99	1.95
20.6	0.44	0.42	0.65	0.66	0.96	0.96	1.41	1.40	2.01	2.00
21.8	0.52	0.48	0.72	0.73	1.01	1.02	1.44	1.43	2.02	2.00
23.8	0.57	0.54	0.76	0.78	1.05	1.07	1.44	1.44	1.98	1.96
25.5	0.60	0.57	0.80	0.83	1.08	1.11	1.45	1.49	1.99	1.97
26.5	0.60	0.59	0.81	0.84	1.08	1.12	1.44	1.49	1.96	1.95
27.5	0.60	0.60	0.82	0.86	1.09	1.15	1.43	1.50	1.94	1.95
29.5	0.62	0.62	0.85	0.89	1.12	1.19	1.44	1.52	1.92	1.94
30.5	0.63	0.63	0.86	0.89	1.13	1.20	1.44	1.52	1.90	1.96
31.5	0.63	0.63	0.85	0.88	1.12	1.19	1.42	1.50	1.86	1.91
32.5	0.63	0.63	0.85	0.88	1.12	1.19	1.39	1.49	1.81	1.90
33.6	0.62	0.62	0.85	0.87	1.11	1.18	1.36	1.48	1.79	1.88
34.5	0.63	0.63	0.85	0.87	1.11	1.19	1.35	1.49	1.78	1.87
35.5	0.63	0.63	0.85	0.88	1.13	1.22	1.36	1.50	1.79	1.88
36.5	0.63	0.64	0.85	0.88	1.12	1.22	1.35	1.51	1.77	1.87
37.5	0.63	0.64	0.85	0.88	1.13	1.22	1.35	1.51	1.77	1.87
38.5	0.63	0.63	0.84	0.87	1.12	1.22	1.34	1.50	1.76	1.86
	Select crop									
19.0	0.15	0.16	0.15	0.16	0.15	0.14	0.15	0.15	0.16	0.16
20.6	0.18	0.19	0.17	0.18	0.17	0.15	0.15	0.15	0.17	0.17
21.8	0.22	0.22	0.19	0.20	0.18	0.17	0.16	0.16	0.17	0.17
23.8	0.25	0.25	0.21	0.23	0.19	0.18	0.16	0.17	0.17	0.17
25.5	0.29	0.30	0.24	0.26	0.20	0.20	0.17	0.18	0.18	0.18
26.5	0.30	0.31	0.25	0.27	0.21	0.21	0.17	0.18	0.18	0.18
27.5	0.31	0.34	0.27	0.30	0.22	0.23	0.18	0.19	0.19	0.18
29.5	0.35	0.38	0.31	0.35	0.25	0.27	0.19	0.21	0.19	0.19
30.5	0.37	0.39	0.33	0.37	0.27	0.28	0.22	0.22	0.20	0.20
31.5	0.38	0.40	0.34	0.38	0.27	0.29	0.22	0.22	0.20	0.19
32.5	0.38	0.40	0.35	0.39	0.28	0.30	0.22	0.22	0.20	0.19
33.6	0.39	0.41	0.37	0.40	0.29	0.31	0.22	0.23	0.20	0.20
34.5	0.40	0.42	0.38	0.41	0.30	0.33	0.23	0.24	0.21	0.20
35.5	0.41	0.43	0.40	0.43	0.32	0.36	0.24	0.26	0.21	0.21
36.5	0.42	0.44	0.40	0.45	0.33	0.38	0.24	0.27	0.22	0.21
37.5	0.42	0.44	0.41	0.46	0.34	0.39	0.24	0.27	0.22	0.22
38.5	0.42	0.44	0.42	0.46	0.35	0.41	0.25	0.28	0.23	0.22

Table 7. Response in mean annual increment to fertiliser addition within treatment site groupings for both the whole and select crops.

	Site group									
	1		2		3		4		5	
Age	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
19.0	1.05	1.03	1.06	1.04	1.04	1.03	0.99	1.05	1.04	1.05
20.6	1.11	1.10	1.11	1.10	1.11	1.09	1.04	1.09	1.09	1.05
21.8	1.17	1.16	1.16	1.15	1.15	1.14	1.09	1.12	1.12	1.09
23.8	1.20	1.19	1.18	1.19	1.17	1.17	1.11	1.14	1.13	1.11
25.5	1.22	1.23	1.21	1.22	1.20	1.20	1.13	1.17	1.15	1.14
26.5	1.22	1.24	1.21	1.23	1.19	1.21	1.13	1.18	1.14	1.14
27.5	1.22	1.25	1.21	1.25	1.19	1.22	1.14	1.20	1.12	1.15
29.5	1.24	1.28	1.22	1.27	1.22	1.25	1.16	1.21	1.12	1.16
30.5	1.24	1.28	1.23	1.27	1.22	1.25	1.15	1.23	1.12	1.16
31.5	1.23	1.26	1.21	1.26	1.20	1.23	1.14	1.22	1.10	1.15
32.5	1.22	1.25	1.21	1.25	1.17	1.23	1.12	1.21	1.09	1.14
33.6	1.19	1.25	1.20	1.24	1.17	1.21	1.10	1.21	1.08	1.13
34.5	1.18	1.25	1.20	1.24	1.17	1.21	1.10	1.21	1.08	1.13
35.5	1.19	1.27	1.21	1.25	1.17	1.22	1.11	1.22	1.08	1.15
36.5	1.19	1.27	1.20	1.26	1.17	1.23	1.10	1.23	1.08	1.14
37.5	1.18	1.27	1.20	1.25	1.17	1.22	1.10	1.23	1.07	1.15
38.5	1.18	1.26	1.19	1.24	1.16	1.21	1.10	1.22	1.06	1.14
	Select crop									
19.0	0.18	0.17	0.16	0.17	0.15	0.15	0.14	0.15	0.13	0.14
20.6	0.20	0.18	0.17	0.19	0.17	0.17	0.15	0.16	0.15	0.15
21.8	0.21	0.20	0.19	0.20	0.19	0.18	0.17	0.17	0.16	0.16
23.8	0.23	0.22	0.21	0.22	0.20	0.20	0.18	0.18	0.17	0.17
25.5	0.25	0.25	0.23	0.25	0.22	0.22	0.20	0.21	0.19	0.19
26.5	0.26	0.26	0.24	0.26	0.23	0.23	0.20	0.22	0.19	0.20
27.5	0.27	0.28	0.25	0.28	0.24	0.25	0.21	0.24	0.19	0.21
29.5	0.31	0.31	0.28	0.31	0.28	0.28	0.23	0.27	0.21	0.23
30.5	0.32	0.32	0.29	0.32	0.29	0.30	0.24	0.28	0.24	0.24
31.5	0.32	0.32	0.30	0.33	0.29	0.30	0.25	0.29	0.24	0.24
32.5	0.33	0.33	0.30	0.33	0.30	0.30	0.25	0.29	0.25	0.24
33.6	0.34	0.34	0.31	0.34	0.31	0.31	0.26	0.30	0.26	0.25
34.5	0.35	0.35	0.33	0.35	0.32	0.32	0.27	0.32	0.26	0.26
35.5	0.36	0.37	0.34	0.37	0.33	0.34	0.28	0.34	0.27	0.27
36.5	0.36	0.39	0.35	0.38	0.34	0.35	0.29	0.35	0.28	0.28
37.5	0.37	0.39	0.35	0.39	0.35	0.35	0.29	0.36	0.28	0.29
38.5	0.37	0.40	0.36	0.39	0.35	0.36	0.30	0.37	0.28	0.29

Stand Density - For the first five years mean increment increased with age for all density classes (Table 6, Fig. 3). With further development, increment flattened to provide a small increase with time for the 7, 11, and 16 m^2 ha^{-1} treatments and a gradual decrease in the two higher density classes (Table 6). The 16 m^2 ha^{-1} class was the maximum at which mean increment could be maintained over the whole trial period (Fig. 3).

For the select section of the stand mean increment continued to increase with stand age for the duration of the trial (Table 7, Fig. 3). The value of reduced competition with decreasing stand density class was considerable and at the termination of the trial the mean increment in the 7 m^2 ha^{-1} class doubled that of the 37 m^2 ha^{-1} least thinned treatment.

Site - Following the initial thinning mean increment increased for the whole stand on all sites to a maximum at age 30 years (Table 7, Fig. 3). A slight decline in increment was then associated with increasing stand age. Analysis of variance (Table 8) showed that mean increment for the whole stand was strongly associated with site class at Gnangara from age 24 years onwards.

Table 8. Significance of main effects and interactions of mean annual increment of basal area over bark for WP 20/65 at Gnangara plantation. Results for stand density, site class and fertiliser addition and interaction are expressed as the probability of the F value obtained in the ANOVA being obtained by chance.

Date	Age	Whole Stand				Select Crop			
		Den	Site	Fert	DxF	Den	Site	Fert	DxF
1965	19.0	.000	.743	.526	.976	.154	.000	.429	.745
1967	20.6	.000	.337	.676	.964	.005	.000	.862	.665
1968	21.8	.000	.104	.642	.918	.000	.000	.949	.747
1970	23.8	.000	.014	.980	.842	.000	.000	.706	.818
1972	25.5	.000	.009	.528	.693	.000	.000	.345	.845
1972	26.5	.000	.006	.227	.601	.000	.000	.212	.888
1974	27.5	.000	.012	.035	.857	.000	.000	.026	.594
1976	29.5	.000	.001	.024	.618	.000	.000	.202	.740
1976	30.5	.000	.001	.014	.722	.000	.002	.437	.820
1978	31.5	.000	.001	.016	.637	.000	.001	.427	.855
1979	32.5	.000	.002	.007	.449	.000	.003	.320	.801
1980	33.6	.000	.007	.006	.335	.000	.001	.310	.829
1981	34.5	.000	.005	.004	.307	.000	.001	.242	.907
1982	35.5	.000	.006	.002	.275	.000	.001	.094	.905
1983	36.5	.000	.005	.001	.205	.000	.001	.053	.899
1984	37.5	.000	.007	.001	.233	.000	.001	.042	.913
1985	38.5	.000	.006	.001	.187	.000	.001	.040	.910

For the select crop mean increment was also closely associated with site class (Table 9). It increased at a steady rate, independent of site class, over the course of the trial (Table 8, Fig. 3).

There was no indication of interaction between density and fertiliser treatments.

Increment in Height

Increment data for select crop height (Table 9) showed significant increments to be associated with high values for the

7 m^2 ha^{-1} treatment at Gnangara from age 27.5 to 34.5 years. This was associated with reduction in the number of stems in the select crop for this treatment and was significant only at age 29.5 and 36.5 years (Table 9).

Table 9 Probabilities that mean values for density class, site class and fertiliser response obtained for mean annual increment in height of the select crop and current annual increment in select crop height at Gnangara occurred by chance. The density x fertiliser interaction was not significant at any measurement.

	Select stand height			CAI select stand height		
Age	Density	Site	Fert.	Density	Site	Fert.
19.0	0.795	0.000	0.482	-	--	
23.8	0.547	0.000	0.475	0.008	0.068	0.006
25.5	0.658	0.000	0.112	0.952	0.272	0.046
26.5	0.738	0.000	0.106	0.300	0.424	0.819
27.5	0.966	0.000	0.236	0.675	0.648	0.488
29.5	0.476	0.000	0.068	0.002	0.102	0.192
30.5	0.153	0.000	0.038	0.733	0.964	0.784
31.5	0.126	0.000	0.085	0.285	0.556	0.935
32.5	0.080	0.000	0.026	0.958	0.457	0.012
33.6	0.134	0.000	0.093	0.994	0.922	0.337
34.5	0.101	0.000	0.010	0.946	0.969	0.015
35.5	0.083	0.000	0.024	0.192	0.642	0.362
36.5	0.102	0.000	0.005	0.054	0.570	0.011
38.5	0.103	0.000	0.005	0.931	0.145	0.052
DF	4	4	1	4	4	1

Top height was measured as the mean of the tallest 75 trees ha^{-1} and generally was not influenced by thinning within the Select Crop (100 s ha^{-1}). There was no trend for top height to increase with decreasing stand density in the Gnangara trial.

Fertiliser application. - A progressive improvement in select crop height was observed in the N+P (F2) plots at Gnangara following application at age 25.2 years (Table 9). Significant differences between the two treatments were present at the 30.5, 32.5 and 34.5 to 38.5 year measurements (Table 17). For current annual increment, the periods 15 to 24 years, 32.5, 34.5 and 35.5 years onwards registered significant fertiliser effects (Table 9).

Foliar Nutrients

Mean values for main effects of Sites 1 and 5 sampled at Gnangara in April 1973 are summarised in Table 10. The increase in per cent N and P from fertiliser added in September 1971 was highly significant and significant (.03 level) for Mn (Table 11). Per cent foliar K was significantly greater (.000 level) on the better site while content of Mn was significantly higher on the poorer site.

Table 10. Mean values for foliar nutrients sampled at Gnangara in April 1973. Interactions were not significant.

Effect	N(%)	P(%)	K(%)	Zn(ppm)	Mn(ppm)
Density					
7	0.777	0.102	0.567	9.2	16.7
11	0.772	0.103	0.540	8.5	21.0
16	0.792	0.100	0.552	8.7	21.2
25	0.747	0.103	0.567	11.5	26.5
37	0.770	0.111	0.562	10.5	24.7
Site					
1	0.770	0.106	0.615	9.7	17.5
5	0.774	0.102	0.501	9.7	26.6
Fertiliser					
P	0.726	0.089	0.573	10.0	18.5
N+P	0.818	0.119	0.543	9.4	25.6

Table 11. Analysis of variance of foliar nutrients sampled in site blocks 1 and 5 in June 1973, two years after fertiliser addition. Results, apart from the error term, are probabilities that the f value obtained would be obtained by chance.

Source	DF	%N	%P	%K	%Zn	%Mn
Density	4	0.877	0.889	0.937	0.275	0.283
Site	1	0.885	0.639	0.000	1.000	0.009
Fertiliser	1	0.008	0.002	0.245	0.530	0.030
Density*Fert	4	0.687	0.973	0.312	0.651	0.880
Error	9	0.004	0.000	0.003	4.222	38.160
Total	19					

Discussion

Fertiliser was applied as a single dressing at age 25.2 and as a split application at 34.2 and 35.2 years of age. Treatment F1 applied 500 kg of superphosphate ha^{-1} while F2 was double this amount plus 250 kg of ammonium sulphate at age 25.2 and 500 kg Agras at age 35.2 years. F2, which incorporated nitrogenous fertiliser, was considered as possibly desirable for latter stages of the rotation.

The base fertiliser F1 applied as 500 kg ha^{-1} was regarded as necessary for continued, healthy growth on the phosphate deficient soils. A control was not available to assess the value of this application which experience suggested was reasonable that stage of stand development. Foliar analysis (Table 11) revealed that the base fertiliser maintained foliar P levels at .09 per cent 18 months after application. Unfertilised stands usually have foliar P levels of .06-.04 per cent. The base treatment is thus associated with non limiting P values. The trial cannot be used to assess this base effect but only the further effect of a luxury application consisting of twice the superphosphate and 500 kg ha^{-1} of a nitrogenous fertiliser.

Table 12. Percentage improvement in CAI of F2 over F1 for total basal area produced over the 19.5 years of the trial. Values are provided for the whole stand and the select stand and result from the increased fertiliser applications.

Density	Stand Baob (m^2 ha^{-1})		Site	Site Class	
	Whole	Select		Whole	Select
7	9.6	7.7	1	18.5	9.4
11	10.3	11.1	2	13.8	10.0
16	21.7	15.9	3	10.6	2.9
25	32.9	10.5	4	20.0	29.5
37	13.3	3.6	5	27.3	4.3
All	17.2	10.0	All	17.2	10.0

Response to the F2 application was immediate and quite pronounced for three years. Four years after application the CAI values for both levels of fertiliser were again identical. To achieve continuing stimulus from fertiliser on such sites it is obviously necessary to re-fertilise at 4 to 5 yearly intervals

The record for mean annual increment commenced for the stands after the initial thinning at age 19.5 years at Gnangara. The mean annual increment to any stand age includes the standing basal area at that age plus all basal area removed by thinning from the plot since the commencement of the trial. Values for the 37 m^2 ha^{-1} treatment at Gnangara approximate the increment from unthinned stands.

The added fertiliser and greater increment in F2 was associated with significantly higher foliar levels for N and P and Mn content (Table 11.). A separate trial with Mn fertiliser on stands in the area failed to reveal any improvement in growth. The response of the Luxury treatment is believed to result from improved N levels in the presence of luxury foliar P. An excellent response to similar high levels of ammonium sulphate and superphosphate was also obtained in Trial 29/71 in older thinned stands with almost identical site conditions.

The average improvement in CAI to the F2 fertiliser treatment increased with stand density (Table 12). The actual fall off in the progressive rate of increasing response with increased stand density for the 37 m^2 ha^{-1} density in Table 12 was associated with losses to tree mortality at the highest densities. To some extent this progression is surprising as previous concerns with lack of water availability for tree growth on the sites had indicated that the most efficient fertiliser response could have been the reverse i.e. associated with the less dense stands with the most water available to the remaining trees in droughty periods. In such a situation it would be expected that fertiliser applied to the low density treatments would have a greater influence on the select stand than on stands with higher densities. Table 12 shows that this was not so, except perhaps for the 37 m^2 ha^{-1} extreme. Water availability can be discounted as a possible limiting factor to fertiliser use on the sites tested.

It was also desirable to know whether fertiliser is more efficient on the better or poorer sites. In the present trial the blocks were a decreasing set of site qualities as assessed by Top height and basal area at the establishment of the trial. A general assumption was that site quality was also largely associated with depth to the underground water horizon and hence to available water. The design using the site groupings as randomised blocks precluded the examination of interactions of site and stand density or site and fertiliser effects. Results in Table 11 for means for the site blocks suggest there is no difference in the degree of response on any of the range of sites tested. This is also the impression obtained from increment trends plotted in Figures 1 and 2.

WP 54/66 - Fertiliser responses following the first thinning in *Pinus pinaster* stands on limestone soils at Yanchep

Summary and Conclusions

The objective of the trial was to determine the response of thinned maturing stands to fertiliser additions. The trial was incorporated as part of the Basal Control thinning series which enabled response to fertiliser to be examined over a range of four stand densities (7, 11, 16 and 25 m^2 ha^{-1}) and within five uniformity blocks representing a gradation of site potentials.

Response to 500 kg ha^{-1} super, copper, zinc fertiliser plus 250 kg ha^{-1} ammonium sulphate at age 19 years was immediate and remained for four years. Response to a further application of 500 kg ha^{-1} of the NP fertiliser Agras at age 27 years was also immediate and of at least 4 years duration. Response for the whole stand was independent of stand density and appeared to be minimal for the best site blocks. For the 100 stems ha^{-1} select crop a tendency for the fertiliser to be most effective at the lower densities was only important in several years and for the heavily thinned 7 m^2 ha^{-1} treatment. Dominant trees did not use fertiliser more effectively than the remainder of the stand over the period of the trial.

The overall response in wood production due to fertiliser addition was 6 per cent for the whole stand and 10 per cent for the select crop. This offers little scope to increase production of wood on the better sites on the limestone sands of the Spearwood Dunes System through fertiliser addition. Some indications in the trial suggest that fertiliser additions may be more effective on the generally poorer sites at Yanchep. Similarity in foliar nutrient values with similar stands at Gnangara indicate that water relations rather than nutrition cause the poorer growth at Yanchep.

Establishment

Location - The Yanchep trial was established in Section A, compartments 1, 3 and 4 of the " Hundred Acre Block", of the Yanchep Plantation complex, at Longitude 115°42'E and Latitude 31°29'S. This is approximately 55 km north of Perth and 10 km from the ocean. Elevation is 45 m and depth to the ground water table is approximately 16 m.

The "Hundred Acre Block" was planted to *Pinus pinaster* of Portuguese origin in 1952 at a spacing of 2.1 m x 2.1 m. The stand was low pruned in 1962. Seedlings received 57 g of superphosphate at time of planting and a 2.5 per cent zinc sulphate spray at age 4 years.

Selection - Within the stands rectangular plots of 40 m x 20 m were selected to embrace areas of pine with uniformity in stocking and tree height, with a buffer of at least 20 m between plots. Plots were divided into 4 consecutive subplots of 10 m x 20 m and in each subplot trees were counted and the heights and the diameter at breast height (DBH) of the 10 tallest (250 ha^{-1}) were measured. For each subplot the mean height and the total basal area over bark (BAob) were calculated.

Variation in height and diameter between subplots was often excessive and it was decided from the data that 20 m x 20 m plots, selected within each 40 m x 20 m temporary plot, would provide for both reasonable plot uniformity and a suitable total number of plots to satisfy a comprehensive trial. The two most similar, adjacent subplots in each plot were combined to represent a potential trial plot.

Table 1. Plot allocation to site groups and randomisation into density and fertiliser treatments in the Yanchep trial. Plots marked with an asterisk were fitted with soil access tubes for soil moisture monitoring.

Treatment		Site (block)				
Thinning	Fertiliser	1	2	3	4	5
25 m^2 ha^{-1}	Nil	14	37	*10	*41	*47
	N+P	5	*6	*53	21	22
16 m^2 ha^{-1}	Nil	*1	12	13	39	45
	N+P	4	30	*24	34	*46
11 m^2 ha^{-1}	Nil	54	11	17	20	*29
	N+P	*2	*16	51	55	43
7 m^2 ha^{-1}	Nil	52	*7	28	19	*23
	N+P	3	*9	8	*48	*42

The plots were ranked on the basis of mean height of the 10 predominant trees. Only the height range in which a reasonably uniform series of plots was available was considered. Forty plots were selected into five site or uniformity blocks each containing 8 plots. Within each site block four density treatments at each of two fertiliser levels were randomly selected (Table 1).

Treatments - The selection process was similar to that of the initial trial (WP 20/65) at Gnangara. The younger stand, limited area and more drought prone sites set the maximum treatment density at 25 m^2 ha^{-1} and the total plot number was restricted to forty plots.

Stand density levels were maintained throughout the trial by thinning adjustment following annual measurement of stand basal area. Treatments for site groups were also fitted with access tubes (Table 1) to allow for soil moisture monitoring.

Fertiliser Application - The following treatment was applied in August 1971:-

F0 - Nil fertiliser.

F1 - 500 kg ha^{-1} super, copper, zinc + 250 kg ha^{-1} Ammonium sulphate.

A second application was applied in August 1979:-

F0 - Nil fertiliser
F1 - 500 kg ha^{-1} Agras No 1 (17.5 % N, 15 % P)

Table 2. Measurement and thinning history for WP 54/66 at Yanchep plantation. For height measurement SC indicates that only the select crop trees were measured.

Date	Age	DBHOB	BT	Hght	Ht.Cr.	Thin	Fert
Dec. 1966	14.5	*	*	*	*	*	
Jan. 1968	15.5	*	*	*	*	*	
Jan. 1969	16.5	*	*	*	*	*	
Apr. 1970	17.7	*					
Jan. 1971	18.5	*	*	*	*	*	
Aug. 1971	19.0						*
Jan. 1973	20.5	*	*	*	*	*	
Mar. 1974	21.7	*					
Dec. 1974	22.5	*	*	*	*	*	
Dec. 1975	23.5	*					
Dec. 1976	24.5	*		*	*	*	
Jan. 1978	25.5	*					
Jan. 1979	26.5	*		SC		*	
Aug. 1979	27.0						*
Jan. 1980	27.5	*		SC			
Feb. 1981	28.5	*					
Feb. 1982	29.5	*		SC			
Jan. 1983	30.5	*		*			
Jan. 1984	31.5	*	*	SC			
Jan. 1985	32.5	*		SC			
Jan. 1986	33.7	*		SC			

Measurement and Analysis

Measurements - Diameter over bark at breast height (DBHOB) was measured during the summer months in most years (Table 2). Full measurements for bark thickness, tree height and crown height were made whenever practical to do so. For trees removed as thinnings all measurements were made together with diameter and bark thickness at 5 m stem height. With stand development height measurement became increasingly time consuming and in the later stages of the trial only marked select final crop trees (100 ha^{-1}) were subject to height measurement (Table 2).

Foliar Sampling - Foliar samples were selected from 6 of the final crop trees in each plot during the late summer of 1967, 1969, 1971, 1973 and 1976. These samples were analysed for a range of foliar nutrients by standard analytical techniques.

Table 3. Fertiliser response as current annual increment within stand density classes for each measurement at Yanchep. Fertiliser was added (F1) at ages 19 and 27 years.

	Stand density (m^2 ha^{-1})									
	7		11		16		25		All	
	F0	F1	F0	F1	F0	F1	F0	F1	F0	F1
	Whole stand									
16.5	1.39	1.42	1.75	1.72	2.03	2.21	2.36	2.36	1.88	1.93
17.7	1.27	1.28	1.31	1.31	1.33	1.34	1.37	1.46	1.32	1.35
18.5	1.10	1.07	1.48	1.30	1.62	1.70	2.01	1.98	1.55	1.51
20.5	1.01	1.23	1.23	1.27	1.32	1.57	1.53	1.68	1.27	1.44
21.7	0.86	1.17	1.10	1.28	1.20	1.67	1.30	1.65	1.12	1.44
22.5	1.12	1.38	1.54	1.62	1.67	2.22	1.83	2.81	1.54	2.01
23.5	0.58	0.61	0.94	0.82	1.17	1.30	1.35	1.41	1.01	1.04
24.5	0.60	0.55	0.96	0.82	1.05	1.02	1.17	1.22	0.94	0.90
25.5	0.54	0.45	0.80	0.62	0.94	0.84	1.03	0.86	0.83	0.69
26.5	0.57	0.65	1.04	0.95	1.32	1.27	1.53	1.48	1.11	1.09
27.5	0.47	0.66	0.77	0.84	1.06	1.28	1.29	1.14	0.90	0.98
28.5	0.49	0.64	0.67	0.83	0.93	1.25	0.95	1.15	0.76	0.97
29.5	0.56	0.70	0.91	1.00	1.22	1.49	1.63	1.73	1.08	1.23
30.5	0.56	0.56	0.81	0.83	1.09	1.17	1.27	1.30	0.93	0.96
31.5	0.56	0.61	0.95	0.90	1.17	1.27	1.33	1.46	1.00	1.06
32.5	0.62	0.63	1.00	0.80	1.18	0.80	1.28	1.37	1.02	0.90
33.7	0.63	0.61	0.96	0.86	1.23	1.19	1.43	1.50	1.06	1.04
	Select crop									
16.5	0.36	0.37	0.36	0.32	0.24	0.25	0.19	0.19	0.29	0.28
17.7	0.36	0.36	0.25	0.23	0.16	0.17	0.13	0.12	0.22	0.22
18.5	0.48	0.48	0.43	0.40	0.06	0.30	0.19	0.21	0.29	0.35
20.5	0.51	0.66	0.43	0.38	0.33	0.29	0.18	0.19	0.36	0.38
21.7	0.43	0.64	0.36	0.39	0.22	0.33	0.15	0.20	0.29	0.39
22.5	0.57	0.72	0.53	0.48	0.31	0.43	0.21	0.30	0.40	0.48
23.5	0.47	0.54	0.43	0.37	0.27	0.33	0.18	0.18	0.33	0.35
24.5	0.49	0.49	0.44	0.36	0.24	0.27	0.15	0.17	0.33	0.32
25.5	0.43	0.40	0.39	0.28	0.21	0.22	0.14	0.12	0.29	0.26
26.5	0.48	0.58	0.50	0.47	0.32	0.35	0.21	0.22	0.37	0.40
27.5	0.47	0.66	0.55	0.56	0.34	0.49	0.24	0.24	0.40	0.49
28.5	0.49	0.64	0.49	0.56	0.31	0.44	0.21	0.23	0.37	0.47
29.5	0.56	0.70	0.65	0.68	0.41	0.59	0.27	0.33	0.47	0.57
30.5	0.56	0.56	0.59	0.55	0.35	0.46	0.25	0.25	0.44	0.46
31.5	0.56	0.61	0.68	0.58	0.39	0.57	0.25	0.29	0.47	0.51
32.5	0.62	0.63	0.74	0.56	0.39	0.46	0.25	0.25	0.50	0.47
33.7	0.63	0.61	0.70	0.56	0.42	0.49	0.27	0.29	0.50	0.49

Table 4. Fertiliser response in current annual increment for basal area within site classes at Yanchep. Fertiliser was added (F1) at ages 19 and 27 years.

	Site class									
	1		2		3		4		5	
	F0	F1	F0	F1	F0	F1	F0	F1	F0	F1
	Whole stand									
16.5	2.06	2.09	1.88	1.96	1.82	1.97	1.83	1.90	1.83	1.72
17.7	1.40	1.42	1.36	1.33	1.21	1.41	1.28	1.35	1.34	1.24
18.5	1.49	1.40	1.72	1.54	1.42	1.70	1.54	1.48	1.60	1.43
20.5	1.29	1.35	1.32	1.42	1.18	1.63	1.26	1.46	1.31	1.33
21.7	1.13	1.25	1.16	1.36	1.06	1.54	1.12	1.43	1.11	1.63
22.5	1.57	1.71	1.61	1.76	1.38	2.28	1.52	1.97	1.62	2.32
23.5	1.04	0.98	1.03	1.03	0.95	1.04	1.02	0.98	1.01	1.15
24.5	0.96	0.87	0.97	0.85	0.82	0.97	0.95	0.82	1.02	1.02
25.5	0.83	0.63	0.78	0.65	0.81	0.73	0.81	0.78	0.91	0.69
26.5	1.12	1.00	1.13	1.09	1.07	1.16	1.09	1.05	1.17	1.15
27.5	0.90	0.90	0.90	0.92	0.92	1.14	0.87	0.87	0.90	1.08
28.5	0.87	0.91	0.60	0.93	0.80	0.88	0.73	1.04	0.81	1.08
29.5	1.16	1.11	1.24	1.25	1.03	1.22	0.96	1.28	1.01	1.30
30.5	1.06	0.78	0.94	0.97	0.90	0.94	0.85	1.06	0.93	1.06
31.5	1.02	0.76	1.04	1.22	0.96	1.09	0.93	1.17	1.05	1.06
32.5	1.16	0.90	0.99	0.99	0.96	0.69	0.88	0.95	1.12	0.97
33.7	1.10	0.92	1.02	1.02	1.00	1.07	1.00	1.12	1.20	1.06
	Select crop									
16.5	0.37	0.35	0.28	0.32	0.28	0.29	0.27	0.24	0.23	0.21
17.7	0.30	0.27	0.24	0.25	0.17	0.25	0.21	0.18	0.20	0.16
18.5	0.40	0.41	0.13	0.38	0.34	0.40	0.29	0.28	0.29	0.26
20.5	0.40	0.39	0.48	0.43	0.32	0.45	0.29	0.35	0.32	0.27
21.7	0.35	0.37	0.33	0.40	0.29	0.44	0.25	0.37	0.23	0.35
22.5	0.49	0.49	0.43	0.46	0.37	0.55	0.34	0.46	0.39	0.45
23.5	0.41	0.41	0.39	0.38	0.31	0.39	0.28	0.31	0.29	0.28
24.5	0.43	0.38	0.36	0.31	0.29	0.36	0.27	0.28	0.31	0.27
25.5	0.34	0.29	0.31	0.24	0.30	0.27	0.23	0.28	0.27	0.21
26.5	0.45	0.46	0.41	0.42	0.37	0.44	0.32	0.37	0.33	0.34
27.5	0.48	0.50	0.45	0.51	0.39	0.48	0.32	0.48	0.36	0.47
28.5	0.45	0.47	0.45	0.45	0.33	0.46	0.29	0.49	0.35	0.47
29.5	0.59	0.60	0.48	0.57	0.46	0.55	0.38	0.59	0.44	0.56
30.5	0.58	0.43	0.52	0.48	0.39	0.44	0.33	0.49	0.39	0.46
31.5	0.53	0.42	0.53	0.57	0.45	0.56	0.36	0.54	0.48	0.46
32.5	0.64	0.48	0.56	0.46	0.44	0.53	0.36	0.49	0.51	0.42
33.7	0.59	0.50	0.53	0.48	0.45	0.50	0.41	0.50	0.52	0.46

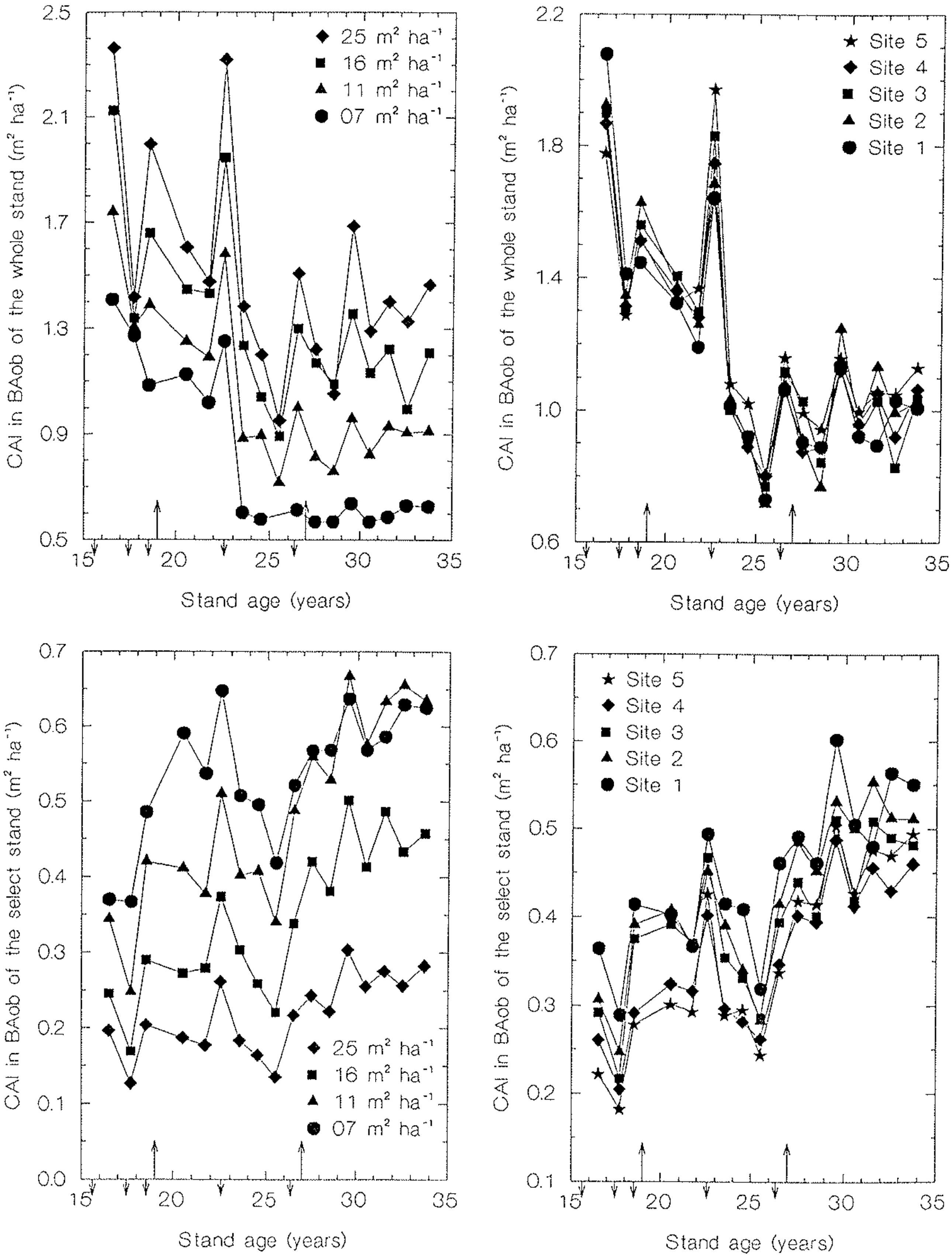

Figure 1. Variation in current annual increment in basal area of the whole stand and select stand with stand density treatments and site classes at Yanchep. The small downwards pointing arrows on the horizontal axis show major thinning events and the upward pointing arrows show fertiliser events.

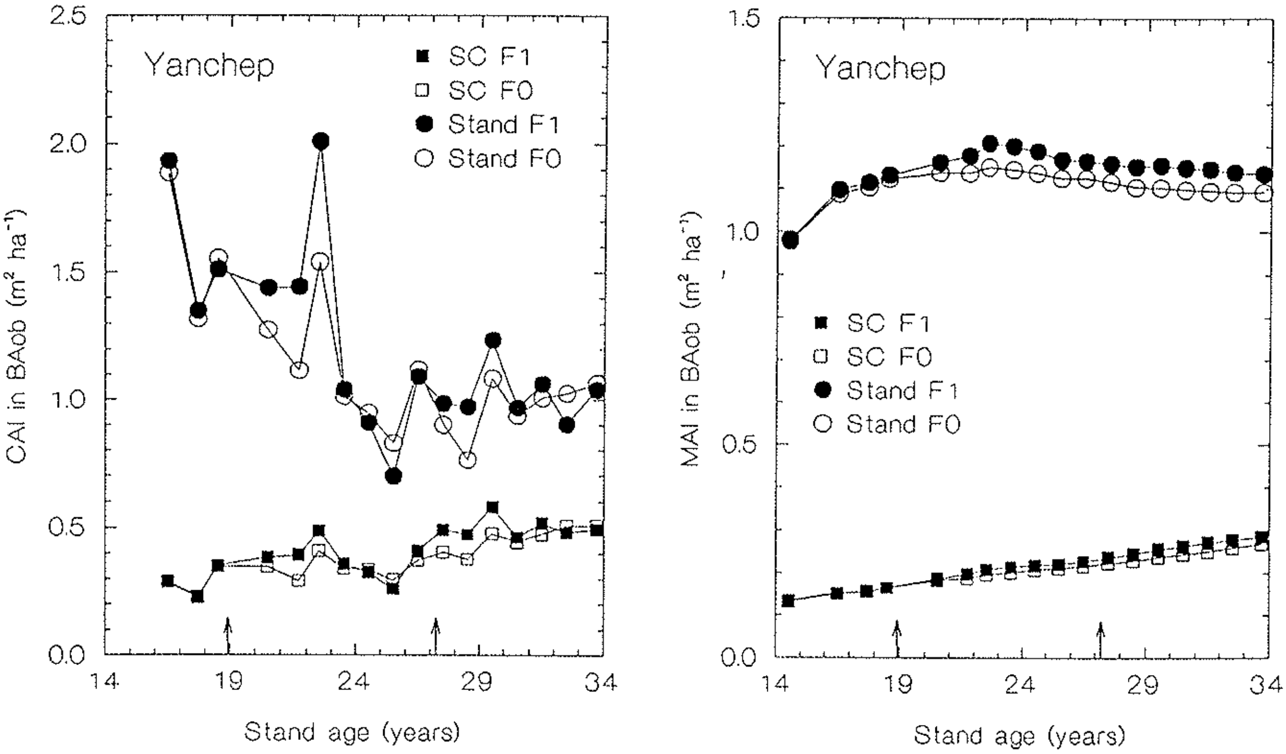

Figure 2. Response in the current annual increment and mean annual increment in basal area to fertiliser for both the whole stand and the select crop. The arrows on the horizontal axis mark fertiliser events.

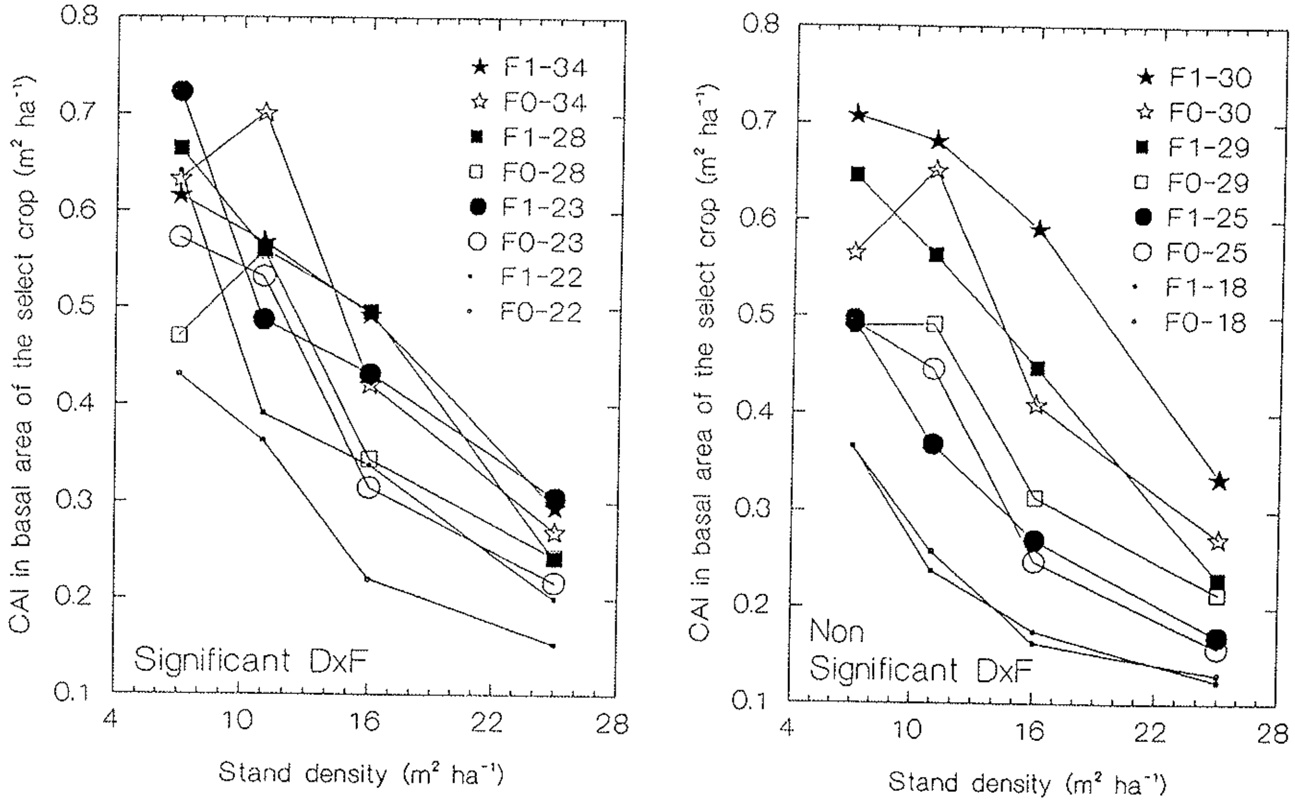

Figure 3. Trend lines for the interaction between stand density and fertiliser in the select crop at Yanchep. Trends for non significant interactions (right) are compared with the significant interactions (left) to indicate abnormal response in the 11 m^2 ha^{-1} treatment.

The trial was designed as a 4x2 factorial within 5 uniformity blocks which represented different site groupings. All measurement data were subject to analysis of variance for CAI and MAI for basal areas and volumes of both the whole stand and the select stand (marked for the best 100 stems ha^{-1}).

Results

For the fertiliser factor in the design level 1 (F0) was no added fertiliser and level 2 (F1) was a heavy dressing of superphosphate + nitrogen + zinc in September at ages 19.0 and 27.0 years.

Current Annual Increment - Means for CAI for both the whole stand and the select stand for the F0 control and F1 added fertiliser treatments are grouped in density classes for each measurement in Table 3 and within Site classes in Table 4. Table 5 contains the probabilities of achieving F values from analysis of variance to exceed by chance the values obtained by the data set.

Table 5. Significance of the main effects and interaction of means for current annual increment of basal area over bark for WP 54/66 at Yanchep plantation. Results with stand development are recorded as the probability of the F value occurring by chance. Fertiliser was added at ages 19 and 27 years.

Date	Age	Whole Stand				Select Crop			
		Den	Site	Fert	DxF	Den	Site	Fert	DxF
1969	16.5	.000	.014	.380	.497	.000	.000	.706	.459
1970	17.7	.124	.391	.462	.828	.000	.009	.803	.934
1971	18.5	.000	.409	.462	.475	.000	.000	.862	.627
1973	20.5	.000	.795	.002	.467	.000	.009	.189	.177
1974	21.7	.000	.322	.000	.269	.000	.063	.000	.087
1974	22.5	.000	.298	.000	.079	.000	.243	.005	.058
1975	23.5	.000	.538	.431	.072	.000	.001	.366	.073
1976	24.5	.000	.415	.415	.577	.000	.007	.623	.337
1978	25.5	.000	.313	.000	.676	.000	.130	.064	.169
1979	26.5	.000	.370	.434	.273	.000	.006	.113	.123
1980	27.5	.000	.391	.155	.111	.000	.087	.008	.025
1981	28.5	.000	.409	.001	.719	.000	.383	.001	.246
1982	29.5	.000	.675	.020	.701	.000	.232	.004	.353
1983	30.5	.000	.840	.527	.953	.000	.272	.602	.501
1984	31.5	.000	.147	.336	.743	.000	.508	.103	.103
1985	32.5	.001	.664	.253	.392	.000	.323	.500	.183
1986	33.7	.000	.165	.442	.323	.000	.228	.597	.043

In both the whole stand and select stand the density treatments had a highly significant impact on CAI for all except the first few years after establishment, (Table 5, Fig. 1). For the whole stand CAI increased with increasing stand density. For the select stand the CAI increased with decreasing stand density as more space was afforded the dominant stems. No separate impact of the five blocks representing site classes was detected for the whole stand (Table 5. Fig. 1). Site differences did have a significant impact on CAI of the select stand in most years between ages 16.5 and 26.5 years (Table 5, Fig. 1).

Following fertiliser application at age 19.0 years (1971) a highly significant main effect was recorded for CAI for the stands at ages 20.5, 21.7, 22.5 and 25.5 years (Tables 3, 4 and 5, Fig. 2). Response was not recorded in CAI's for the intervening ages 23.5, and 24.5 and it is suspected this is due to the low stand increment associated with the prevailing drought (Fig. 1). Following the second application of F1 at age 27.0 years highly significant main effects were obtained in the 28.5 and 29.5 CAI's but not afterwards (Table 5, Fig. 2).

Highly significant main effects of fertiliser were detected for CAI of the select stand at ages 21.7 and 22.5 years (Table 5). With the second application of fertiliser at age 27.0 years highly significant main effects were detected at ages 27.5, 28.5 and 29.5 years. A Density by Fertiliser interaction (.025 level) at ages 27.5 and 33.7 years was associated with little response in the 11 and 25 m^2 ha^{-1} treatments while the 7 and 16 m^2 ha^{-1} treatments showed considerable response (Fig. 3). In all cases the interactions were minor parts of the variation compared to the significant main effects.

Mean Annual Increment - Trends for MAI of main effects for basal area are illustrated in Figures 2 and 4. Means of MAI in stand BAob for fertiliser treatments are set out for both the whole and select stands in Tables 6 and 7. The significance of results for analysis of variance for each measurement is shown in Table 8.

The main effects for stand density were highly significant for MAI of both the whole and select stands for most of the trial period. The site effect was significant at the .05 level only for ages 16.5 to 20.5 for the whole stand. It was, however, highly significant for the whole trial period in MAI for the select crop.

Significant responses to the fertiliser addition at age 19 years were obtained for the whole stand at ages 21.7 to 26.5, i.e. for five years after application. For the application at age 27.0 years a significant response was recorded continuously from age 27.5 to the last measurement at age 33.7 years. The DxF interactions were not significant.

Interactions for the select crop were not significant. A significant fertiliser effect was detected only after the second application in measurements at ages 29.5, 30.5 and 31.5 years (Fig. 2, Tables 6, 7 and 8).

Height and volume - Density by fertiliser interactions for mean select crop height were not significant for either CAI or MAI data. No significant fertiliser effect on MAI height data was detected. The CAI for height difference between F0 and F1 was significant (.026 level) only in the 30.5 to 31.5 age interval.

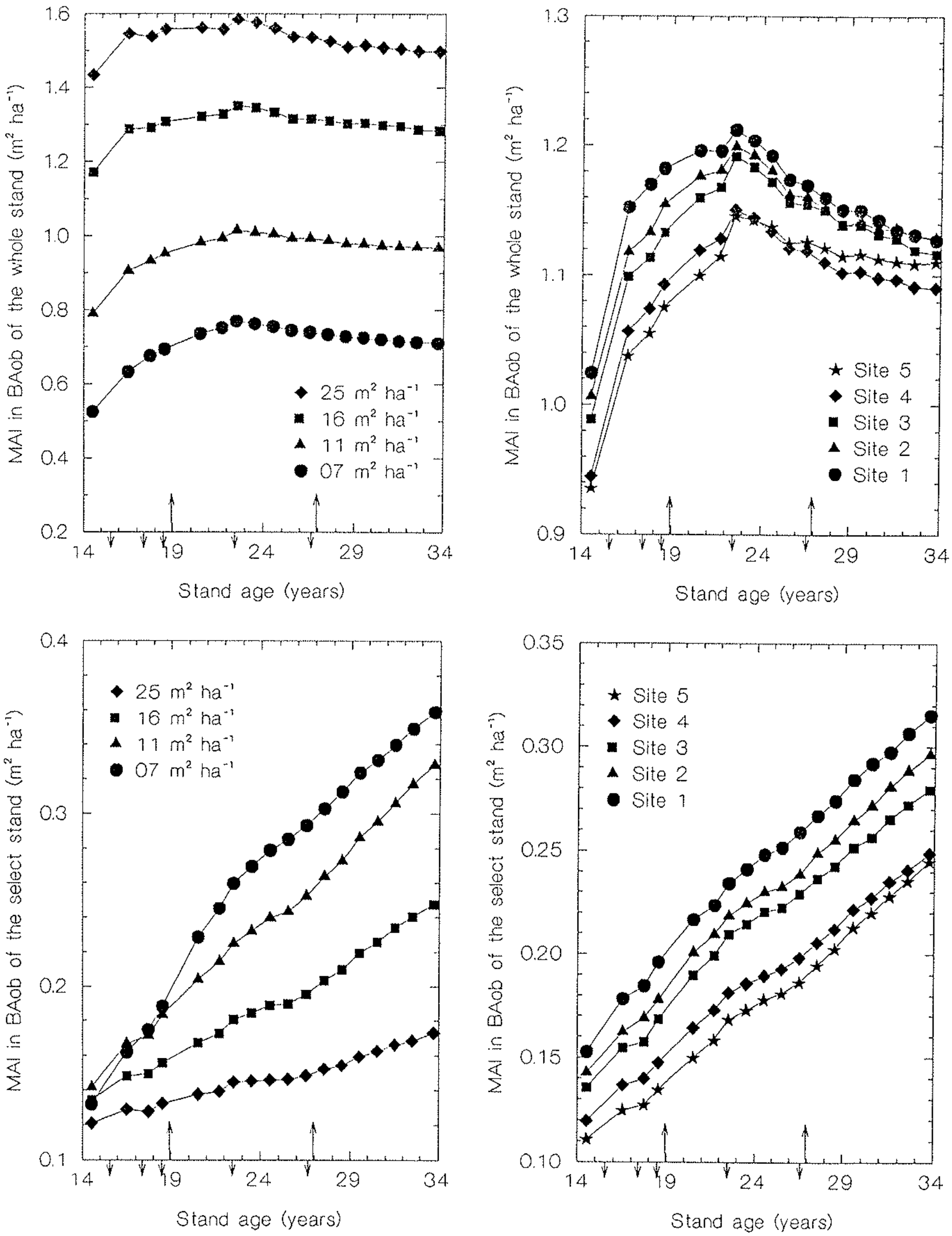

Figure 4. Variation in the mean annual increment in basal area with stand density and site class for the whole stand and select stand at Yanchep. The small downwards pointing arrows on the horizontal axis show major thinning events and the upward pointing arrows show fertiliser events.

Table 6. Mean annual fertiliser response for basal area within stand density classes for each measurement at Yanchep. Fertiliser was added at ages 19 and 27 years.

	Stand density (m^2 ha^{-1})									
Age	7		11		16		25		All	
	F0	F1	F0	F1	F0	F1	F0	F1	F0	F1
	Whole stand									
14.5	0.52	0.52	0.79	0.79	1.17	1.17	1.42	1.44	0.97	0.98
16.5	0.63	0.63	0.90	0.90	1.27	1.29	1.54	1.55	1.09	1.10
17.7	0.67	0.67	0.93	0.93	1.28	1.30	1.52	1.54	1.10	1.11
18.5	0.69	0.69	0.95	0.94	1.29	1.32	1.54	1.56	1.12	1.13
20.5	0.72	0.74	0.98	0.98	1.29	1.34	1.54	1.57	1.13	1.16
21.7	0.73	0.77	0.99	0.99	1.29	1.36	1.53	1.58	1.13	1.17
22.5	0.74	0.79	1.01	1.01	1.30	1.39	1.54	1.62	1.15	1.20
23.5	0.73	0.78	1.00	1.01	1.30	1.38	1.53	1.61	1.14	1.20
24.5	0.73	0.77	1.00	1.00	1.29	1.37	1.52	1.60	1.13	1.18
25.5	0.72	0.76	0.99	0.98	1.27	1.35	1.50	1.57	1.12	1.16
26.5	0.72	0.75	1.00	0.98	1.27	1.35	1.50	1.56	1.12	1.16
27.5	0.71	0.75	0.99	0.98	1.27	1.34	1.49	1.55	1.11	1.16
28.5	0.66	0.71	0.92	0.90	1.25	1.34	1.47	1.53	1.08	1.12
29.5	0.66	0.71	0.92	0.91	1.25	1.35	1.48	1.54	1.08	1.13
30.5	0.65	0.71	0.91	0.91	1.25	1.34	1.47	1.53	1.07	1.12
31.5	0.65	0.71	0.92	0.91	1.24	1.34	1.47	1.53	1.07	1.12
32.5	0.65	0.70	0.92	0.90	1.24	1.32	1.46	1.53	1.07	1.11
33.7	0.65	0.70	0.92	0.90	1.24	1.32	1.46	1.52	1.07	1.11
	Select stand									
14.5	0.12	0.13	0.13	0.14	0.13	0.13	0.12	0.11	0.13	0.13
16.5	0.15	0.16	0.16	0.16	0.15	0.14	0.13	0.12	0.15	0.15
17.7	0.17	0.17	0.17	0.17	0.15	0.14	0.12	0.12	0.15	0.15
18.5	0.18	0.19	0.18	0.18	0.15	0.15	0.13	0.13	0.16	0.16
20.5	0.21	0.23	0.20	0.20	0.16	0.16	0.13	0.13	0.18	0.18
21.7	0.23	0.25	0.21	0.21	0.16	0.17	0.13	0.14	0.18	0.19
22.5	0.24	0.27	0.22	0.22	0.17	0.18	0.14	0.14	0.19	0.20
23.5	0.25	0.28	0.23	0.22	0.17	0.19	0.14	0.14	0.20	0.21
24.5	0.26	0.29	0.24	0.23	0.18	0.19	0.14	0.14	0.20	0.21
25.5	0.26	0.30	0.24	0.23	0.18	0.19	0.14	0.14	0.21	0.22
26.5	0.27	0.31	0.25	0.24	0.18	0.20	0.14	0.15	0.21	0.22
27.5	0.28	0.32	0.27	0.25	0.19	0.21	0.14	0.15	0.22	0.23
28.5	0.29	0.33	0.27	0.26	0.19	0.22	0.15	0.15	0.22	0.24
29.5	0.30	0.34	0.28	0.28	0.20	0.23	0.15	0.16	0.23	0.25
30.5	0.30	0.35	0.30	0.29	0.20	0.24	0.15	0.16	0.24	0.26
31.5	0.31	0.36	0.31	0.30	0.21	0.25	0.16	0.17	0.25	0.27
32.5	0.32	0.37	0.32	0.30	0.22	0.25	0.16	0.17	0.25	0.27
33.7	0.33	0.38	0.33	0.31	0.22	0.26	0.16	0.17	0.26	0.28

Table 7. Mean annual fertiliser response for basal area within site classes for each measurement at Yanchep. Fertiliser was added at ages 19 and 27 years.

Age	Site class 1 F0	1 F1	2 F0	2 F1	3 F0	3 F1	4 F0	4 F1	5 F0	5 F1
Whole stand										
14.5	1.02	1.02	1.02	0.98	1.00	0.97	0.93	0.96	0.90	0.96
16.5	1.14	1.15	1.13	1.10	1.10	1.09	1.03	1.07	1.02	1.05
17.7	1.16	1.17	1.14	1.11	1.10	1.12	1.05	1.09	1.04	1.06
18.5	1.18	1.18	1.17	1.13	1.12	1.14	1.07	1.11	1.06	1.08
20.5	1.19	1.20	1.18	1.16	1.12	1.19	1.09	1.14	1.09	1.10
21.7	1.18	1.20	1.18	1.17	1.12	1.21	1.09	1.16	1.09	1.13
22.5	1.20	1.22	1.20	1.19	1.13	1.25	1.11	1.18	1.11	1.18
23.5	1.19	1.21	1.19	1.19	1.12	1.24	1.10	1.18	1.10	1.17
24.5	1.18	1.19	1.18	1.17	1.11	1.23	1.10	1.16	1.10	1.17
25.5	1.17	1.17	1.17	1.15	1.10	1.21	1.09	1.15	1.09	1.15
26.5	1.17	1.16	1.16	1.15	1.10	1.21	1.09	1.14	1.09	1.15
27.5	1.16	1.15	1.15	1.14	1.09	1.20	1.08	1.13	1.09	1.15
28.5	1.11	1.15	1.13	1.13	1.06	1.16	1.07	1.08	1.01	1.10
29.5	1.11	1.14	1.14	1.14	1.06	1.17	1.06	1.08	1.01	1.10
30.5	1.11	1.13	1.13	1.13	1.06	1.16	1.06	1.08	1.01	1.10
31.5	1.10	1.12	1.13	1.13	1.05	1.16	1.05	1.09	1.01	1.10
32.5	1.11	1.11	1.12	1.13	1.05	1.14	1.05	1.08	1.01	1.10
33.7	1.11	1.11	1.12	1.13	1.05	1.14	1.04	1.08	1.02	1.10
Select stand										
14.5	0.14	0.16	0.14	0.14	0.13	0.13	0.12	0.11	0.11	0.11
16.5	0.16	0.18	0.16	0.16	0.15	0.15	0.14	0.12	0.12	0.12
17.7	0.17	0.19	0.16	0.17	0.15	0.15	0.14	0.13	0.13	0.12
18.5	0.18	0.20	0.17	0.17	0.16	0.17	0.15	0.13	0.13	0.13
20.5	0.21	0.22	0.19	0.20	0.18	0.19	0.16	0.16	0.15	0.14
21.7	0.21	0.23	0.20	0.21	0.18	0.21	0.17	0.17	0.15	0.15
22.5	0.22	0.24	0.21	0.22	0.19	0.22	0.18	0.18	0.16	0.16
23.5	0.23	0.24	0.21	0.23	0.19	0.23	0.18	0.18	0.17	0.17
24.5	0.24	0.25	0.22	0.23	0.20	0.23	0.18	0.19	0.18	0.17
25.5	0.24	0.25	0.22	0.23	0.20	0.23	0.18	0.19	0.18	0.17
26.5	0.25	0.26	0.23	0.24	0.21	0.24	0.19	0.20	0.18	0.18
27.5	0.26	0.27	0.24	0.25	0.21	0.25	0.19	0.21	0.19	0.19
28.5	0.26	0.27	0.25	0.25	0.22	0.26	0.20	0.22	0.20	0.20
29.5	0.28	0.28	0.25	0.26	0.23	0.27	0.20	0.23	0.20	0.21
30.5	0.29	0.29	0.26	0.27	0.23	0.27	0.21	0.24	0.21	0.22
31.5	0.29	0.29	0.27	0.28	0.24	0.28	0.21	0.25	0.22	0.23
32.5	0.30	0.30	0.28	0.29	0.24	0.29	0.22	0.25	0.23	0.23
33.7	0.31	0.31	0.29	0.29	0.25	0.30	0.22	0.26	0.24	0.24

Table 8. Significance of main effects and interactions of mean annual increment of basal area over bark for WP 54/66 at Yanchep plantation. Results for stand density, site class , fertiliser addition and interaction are recorded as the probabilities of the F value in the analysis being obtained by chance. Fertiliser was added at ages 19 and 27 years.

Date	Age	Whole Stand				Select Crop			
		Den	Site	Fert	DxF	Den	Site	Fert	DxF
1966	14.5	.000	.173	.876	.998	.052	.000	.784	.558
1969	16.5	.000	.023	.689	.978	.000	.000	.926	.871
1970	17.7	.000	.017	.628	.973	.000	.000	.826	.927
1971	18.5	.000	.018	.694	.934	.000	.000	.987	.955
1973	20.5	.000	.031	.254	.838	.000	.000	.560	.649
1974	21.7	.000	.081	.056	.725	.000	.000	.158	.478
1974	22.5	.000	.200	.000	.532	.000	.000	.129	.405
1975	23.5	.000	.246	.014	.458	.000	.000	.116	.300
1976	24.5	.000	.318	.023	.438	.000	.000	.207	.320
1978	25.5	.000	.386	.041	.431	.000	.000	.227	.307
1979	26.5	.000	.456	.056	.458	.000	.000	.199	.258
1980	27.5	.000	.502	.052	.500	.000	.000	.115	.151
1981	28.5	.000	.086	.032	.394	.000	.000	.062	.116
1982	29.5	.000	.083	.020	.366	.000	.000	.029	.130
1983	30.5	.000	.102	.019	.367	.000	.000	.041	.112
1984	31.5	.000	.113	.017	.334	.000	.000	.031	.099
1985	32.5	.000	.130	.029	.356	.000	.000	.075	.103
1986	33.7	.000	.181	.036	.334	.000	.000	.097	.087

Results for stand volume were similar to those depicted for stand basal area except that site classes were more distinct for total stand volume than for total stand basal area. As some volumes were obtained from estimates of height, the basal area data presented is considered most accurate and volume data are not repeated.

Foliar Nutrients

Mean values for the main effects for foliar nutrients sampled at Yanchep in 1971, 1973 and 1976 are summarised in Table 9.

A significant effect of site for P in 1971 (Table 10) was associated with a progressive decrease in P values from the best Site 1 to the poorest Site 5. The significant effect for density treatments resulted from a high value in the 11 m^2 treatment. This is associated with a density by fertiliser interaction significant at the .067 level. The significant K effect in 1971 (Table 10) was associated with a progressive decrease in K content with increasing stand density.

Sampling in 1973, 1.4 years after fertiliser application in August 1971, detected significant effects for increased levels of foliar P, Mg, Mn and Zn in the fertilised treatment. Magnesium and Mn increased significantly with increasing stand density and Mn also increased with increasing site quality (Table 9).

By summer 1976 the only significant effect detectable for treatment differences was a decrease in foliar N in the fertilised plots (Table 10).

To estimate the effect of sampling years N, K, P, Mn and Zn data were analysed as a repeated measures trial with site blocks nested within sampling years (Table 11). Differences between years were highly significant for the 5 nutrients. Foliar P was the only nutrient to show an increase in value with fertiliser addition and the interaction for the increase in 1973 was highly significant .

Discussion

Stand Density - The imposed stand densities effectively partitioned growth for both CAI (Figs. 1 and 2) and MAI (Figs. 2 and 4) data. In establishing the trial which was based on a similar trial at Gnangara it was intended to have the top density class set at 37 m^2 ha^{-1} to match the range at Gnangara. Stands of such density did not exist at age 14 years at Yanchep, any stand density over approximately 25 m^2 ha^{-1} being subject to drought effects with mortality each summer. The plantation area is hence drought prone and one would expect stand density to have an influence on soil moisture availability, individual tree growth and perhaps availability of applied fertiliser.

Butcher and Havel (1976) and Butcher (1977) reported on the development of the trial up to 1975, particularly with respect to intense studies of soil hydrology and fertiliser effects carried out up to that period. Cessation of girth increment each year was associated with the exhaustion of soil moisture which occurred 4 months earlier in the dense than in the less dense stands (Butcher and Havel 1976). The differences in average diameter increment for all trees in stands of varying density were found to be consistent though subject to climatic influences and to fertiliser addition. Merchantable volume (to a top stem diameter of 10 cm), calculated for the period from stand age 16.5 to 20.5 years, was found to be largely independent of stand density. The authors formed the hypothesis from this early assessment that on the drought prone Yanchep sites the amount of soil water available at the beginning of the growing season is limiting. It is this that determines the amount of wood that can be produced. It can either be put rapidly on a larger number of smaller trees during the period August to November or slowly on a small number of trees during the extended period of August to March.

This was not the general case, even though the trial embraced the worst drought in the history of the region in 1977-1980. Significant differences between MAI for the density treatments

Table 9. Mean values for foliar nutrients of the final crop at Yanchep for density, site and fertiliser treatments in 1971, 1973 and 1976.

Year		Per cent					ppm	
	Den	N	K	P	Ca	Mg	Mn	Zn
1971	7	.724	0.856	0.065	0.154	0.180	12.2	30.1
	11	.734	0.807	0.076	0.170	0.196	14.2	30.8
	16	.756	0.778	0.067	0.160	0.192	15.4	28.7
	25	.758	0.734	0.066	0.139	0.195	15.8	28.8
1973	7	0.759	0.430	0.071	0.138	0.160	16.1	19.4
	11	0.768	0.440	0.066	0.124	0.149	20.5	19.6
	16	0.840	0.409	0.066	0.118	0.126	20.1	18.4
	25	0.849	0.401	0.064	0.120	0.158	22.9	18.1
1976	7	0.807	0.709	0.050	-	-	17.8	21.4
	11	0.872	0.669	0.040	-	-	19.2	20.4
	16	0.842	0.768	0.048	-	-	19.8	25.6
	25	0.780	0.738	0.039	-	-	19.8	21.5
Year	Site	N	K	P	Ca	Mg	Mn	Zn
1971	1	.765	0.752	0.088	0.150	0.196	16.8	31.3
	2	.741	0.808	0.072	0.149	0.200	14.1	29.6
	3	.726	0.837	0.063	0.158	0.193	14.5	28.8
	4	.745	0.756	0.064	0.163	0.179	14.1	29.1
	5	.738	0.815	0.056	0.158	0.185	12.3	29.0
1973	1	0.840	0.417	0.076	0.135	0.169	23.8	17.3
	2	0.807	0.448	0.063	0.122	0.148	19.8	18.8
	3	0.747	0.426	0.068	0.130	0.149	20.5	19.1
	4	0.748	0.380	0.059	0.122	0.133	16.8	18.1
	5	0.876	0.427	0.067	0.117	0.141	18.3	20.8
1976	1	0.746	0.761	0.039	-	-	15.6	20.7
	2	0.803	0.760	0.041	-	-	21.0	24.1
	3	0.873	0.663	0.047	-	-	17.8	19.5
	4	0.875	0.653	0.041	-	-	21.1	19.8
	5	0.827	0.766	0.053	-	-	20.1	26.8
Year	Fert	N	K	P	Ca	Mg	Mn	Zn
1971	1	.744	0.801	0.069	0.157	0.188	14.8	29.0
	2	.742	0.787	0.068	0.154	0.194	13.9	30.2
1973	1	0.787	0.409	0.048	0.123	0.140	18.6	17.6
	2	0.820	0.430	0.086	0.127	0.156	21.2	20.1
1976	1	0.886	0.702	0.043	-	-	18.5	21.9
	2	0.764	0.739	0.045	-	-	19.7	22.5

Table 10. Significance of treatment differences in foliar nutrient concentrations for sampling of the dominant trees in late summer 1971, 1973, and 1976. Values for treatments are the probabilities that the F value in variance analysis would be obtained by chance. An NP fertiliser was added in August 1971.

Year	Nutrient	Density	Site	Fertiliser	DxF	MS Error
1971	N	.454	.703	.903	.533	.003
	P	.029	.000	.584	.067	.0001
	K	.018	.182	.614	.396	.007
	Ca	.039	.689	.745	.177	.0005
	Mg	.346	.303	.410	.816	.0005
	Mn	.058	.091	.359	.649	9.30
	Zn	.541	.667	.324	.584	14.27
1973	N	.201	.138	.376	.330	.013
	P	.515	.087	.000	.141	.0001
	K	.531	.350	.323	.103	.004
	Ca	.137	.429	.580	.118	.0004
	Mg	.018	.080	.042	.742	.0006
	Mn	.007	.021	.050	.838	16.10
	Zn	.503	.117	.006	.701	6.76
1976	N	.682	.585	.041	.314	.032
	P	.169	.271	.709	.421	.0002
	K	.310	.152	.335	.931	.014
	Mn	.856	.298	.524	.564	34.62
	Zn	.274	.111	.782	.665	38.93

Table 11. Repeated measures analysis of variance of foliar nutrient levels for 1971, 1973 and 1976 with site blocks nested within sampling years.

Source	DF	N	K	P	Zn	Mn
		p	p	p	p	p
Years	2	0.016	0.000	0.000	0.000	0.000
Site(Years)	12	0.459	0.086	0.000	0.070	0.028
Density	3	0.530	0.360	0.212	0.665	0.004
Fertiliser	1	0.205	0.375	0.000	0.087	0.234
Years*D	6	0.537	0.044	0.098	0.191	0.756
Years*F	2	0.024	0.461	0.000	0.624	0.210
D*F	3	0.815	0.871	0.054	0.942	0.735
Error	90					
Total	119					

showed the 16 and 25 m^2 ha^{-1} treatments to be the highest basal area and volume producers (Fig. 4) while not significantly different in themselves. The average CAI's for volume of the whole stand for the 7, 11 and 16 m^2 density treatments were 57,

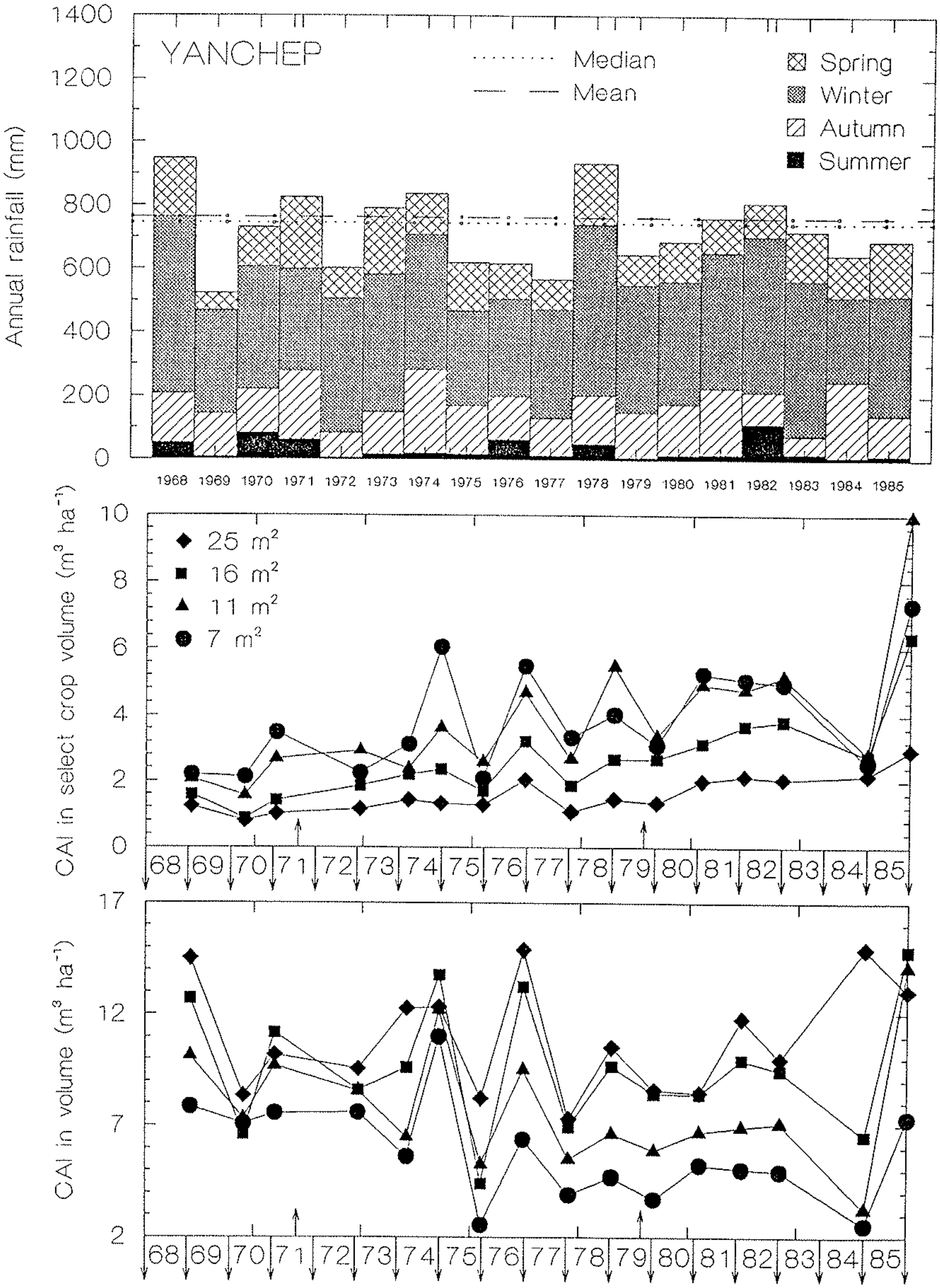

Figure 5. Seasonal and annual rainfall at Yanchep and current annual increments of stand density classes for total volume of the whole stand and select crop over the period of the trial. Fertiliser events are marked by arrows on the horizontal axis for current annual increments.

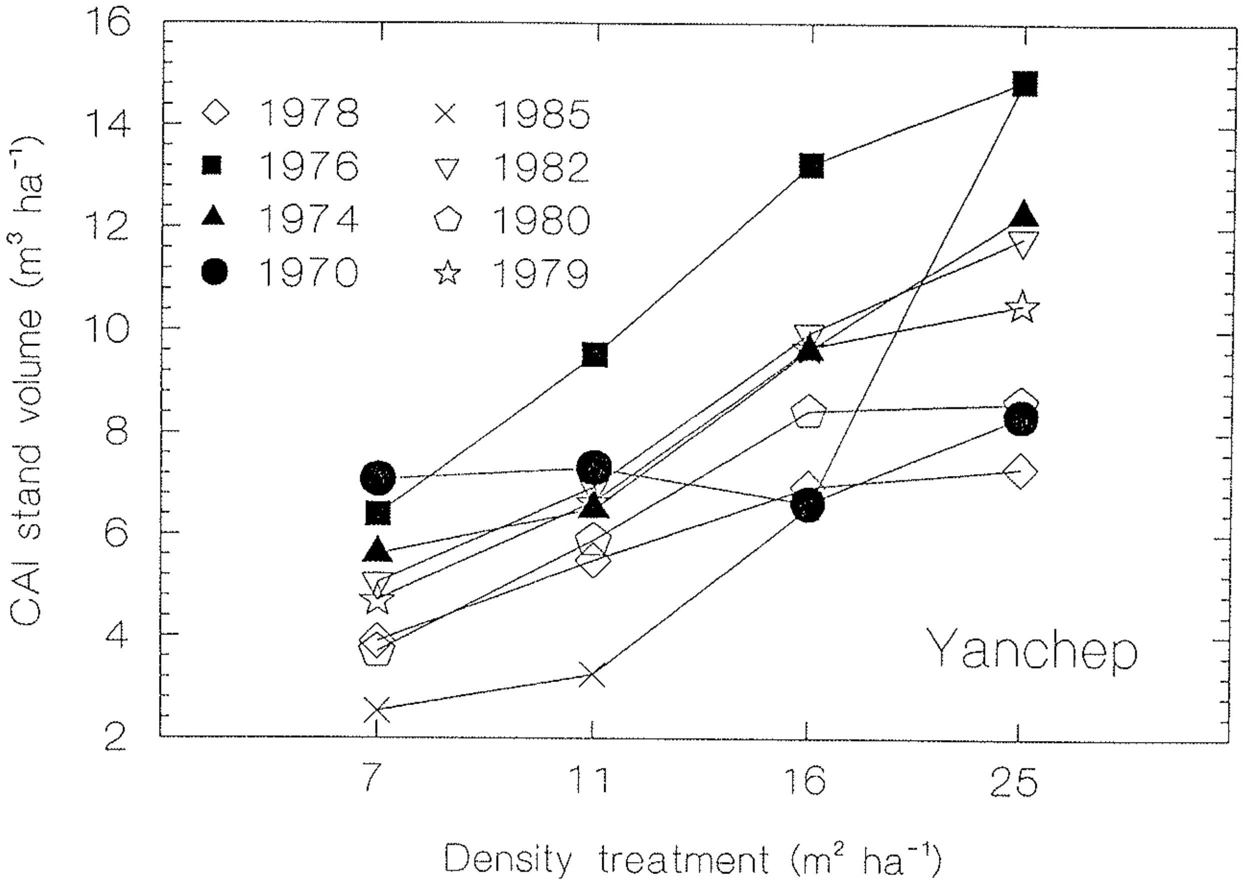

Figure 6. Average stand volume of density classes within different increment periods to indicate the relative response of different classes during drought and normal increment periods.

75 and 91 per cent of the densest 25 m^2 treatment (Fig. 5). The CAI associated with low rainfalls in 1969 and 1970 were not significantly different (Table 3, Figs. 5, 6). The densest 25 m^2 ha^{-1} treatment also declined in growth during the 1978 and 1980 drought years and recovered after the drought (Figs. 5, 6). The 16 m^2 treatment appeared to weather the drought with little increment loss relative to the other less dense treatments.

It was largely on the basis of the lack of difference of volumes between densities in the 1969-70 increment period (age 16.5-17.7, Table 5) that Butcher (1977) concluded that, under soil water stress, as much wood was produced on heavily thinned as unthinned stands. This was an abnormal result and the only measurement at Yanchep with non significant differences between density classes in the whole period of study (Table 5). It was not duplicated even in the sustained, severe drought from stand age 24.5 to 27.5 years (Figs. 5, 6). For both BAob and total volume, increments of the higher density classes were significantly better over this drought period which was due to the lowest annual rainfall throughout the study period (Fig. 5).

Hence, although drought may limit basal area and volume increment with increasing stand density, it does so in exceptional years only and influences all density classes studied to some extent. The effect over the stand rotation for volume production is not important on these sites or in sites at Gnangara studied by a similar trial.

Fertiliser interactions. There was not the continuing DxF interaction which one would expect if greater water availability at the lower stand density was more important to stand basal area growth and volume production. For basal area of the select stand significant interactions were recorded on two occasions only (Table 3, Fig. 3) and these could not be explained by increased growth with decreasing stand density. For volume increment no DxF interactions were significant during the trial and volume production of the whole stand increased directly with stand density (Fig. 7, 8). There is hence no support for the suggestion by Butcher and Havel (1976) that application of fertilisers must be preceded by reduction in stand density to be effective.

Site - The use of randomised blocks to separate site classes was only partly effective. The trial is relatively uniform and represents the higher end of the productivity of the Yanchep Plantation Group. MAI volume means for the best block 1 to the poorest 5 were 8.0, 7.8, 7.3, 6.6 and 6.3 m^3 ha^{-1} total volume, respectively. These differences were either too small or the plot allocation to uniform blocks was inadequate to produce significantly different increments in the total stand (Tables 5 and 8). The select crop from which the Top height was largely responsible for allocation to the five site classes, was very responsive in MAI to site classes. The CAI response was not consistent but significant for 7 of the 17 periods of CAI calculation.

The possibility that stand density and or fertiliser effects interacted significantly with site class could not be tested statistically within the trial design. There was no indication that any density treatment was more favourable on any individual site block (Fig. 8, left). However, the plot of total volume increment with fertiliser addition with site class shows little response to fertiliser on sites 1 and 2 and considerable, responses on the other 3 sites (Fig. 8, right). At Yanchep there is little possibility of significance of density by site interaction but the fertiliser addition was probably most effective on the poorest sites in the area.

Fertiliser - Response to fertiliser addition in spring was immediate and significant in the summer, four months after application. It persisted in the annual increment for no more than four years after application. By year five increments for F0 and F1 did not differ (Tables 5 and 8, Fig. 2).

Table 12. Percentage improvement in CAI for basal area produced through increased fertiliser applications over the 18.5 years of the trial. Values are provided for both the whole stand and the select stand.

Density	Stand density (m^2 ha^{-1})		Site	Site class	
	Whole	Select		Whole	Select
7	9.6	14.4	1	-4.8	-7.0
11	0.0	-10.0	2	2.5	1.5
16	6.4	26.9	3	15.2	24.0
25	7.6	5.8	4	3.1	26.1
			5	7.0	2.0
All	6.2	9.8	All	6.2	9.8

The duration and extent of the increment from fertilisation was disappointing. The application of 500 kg ha^{-1} super, copper, zinc plus 250 kg ha^{-1} ammonium sulphate at age 19.0 years and 500 kg ha^{-1} Agras at age 27.0 years is considered to be reasonably high for plantations of the species. In Table 12 the percentage increments for F1 over F0 for the 11 m^2 ha^{-1} treatment are zero for the whole stand and negative for the select crop. The increment per cent for the site classes also shows no clear pattern and has negative or little impact of fertiliser on the best site blocks. It must be concluded that the blocking was not very effective in the design and offers little scope for interpreting site differences which were supposedly associated with them.

Dominant use of fertiliser. - The argument that dominant trees use applied fertiliser most effectively has been put to favour thinning in association with fertiliser addition (Turner and Lambert, 1996). In fact throughout the trial it appeared that the non dominant portion of the stand responded best to fertiliser addition. In Figure 9 the ratio of the volume increment of the select crop divided by the volume increment of the whole stand is plotted for stand density treatments for the non fertilised (F0) and fertilised (F1) main effects. There is

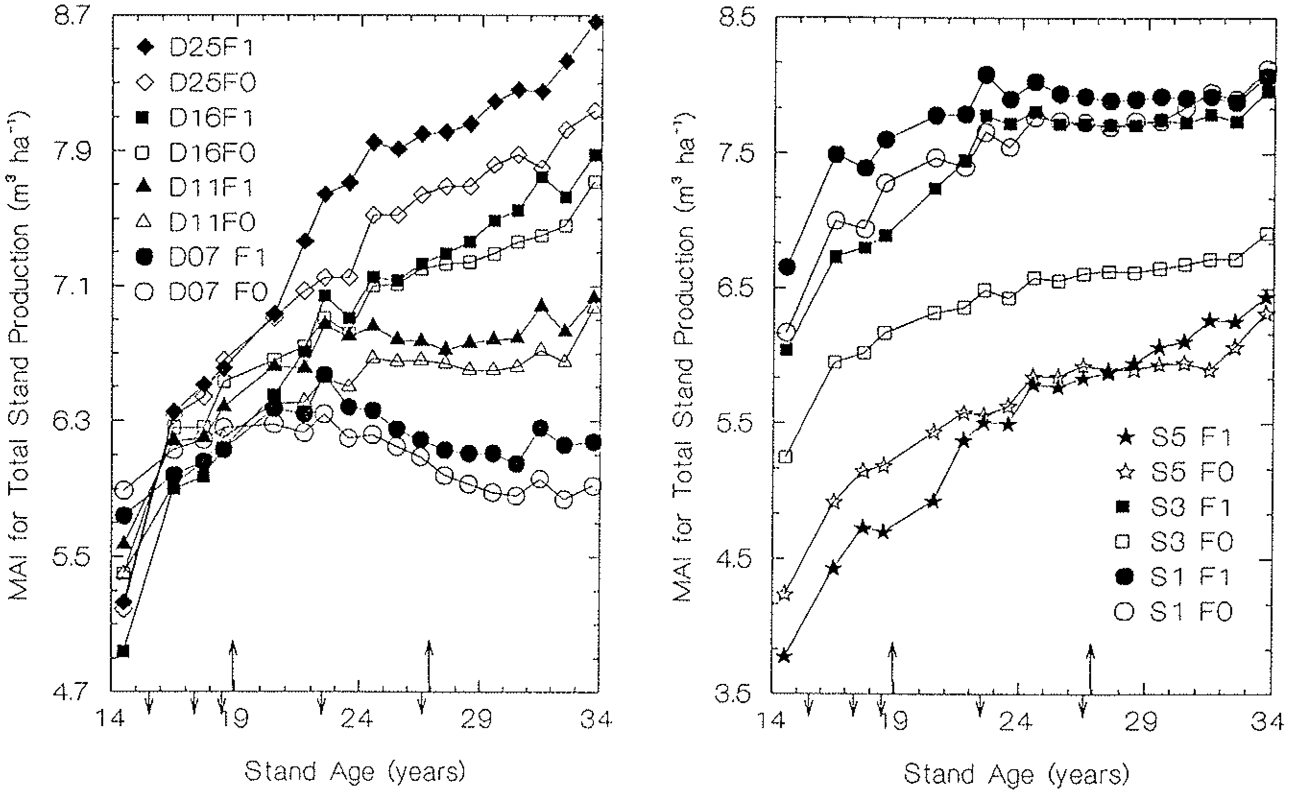

Figure 7. Mean annual increment in volume for the fertiliser effect of the extreme density and site classes. Fertiliser events are marked by arrows on the horizontal axis.

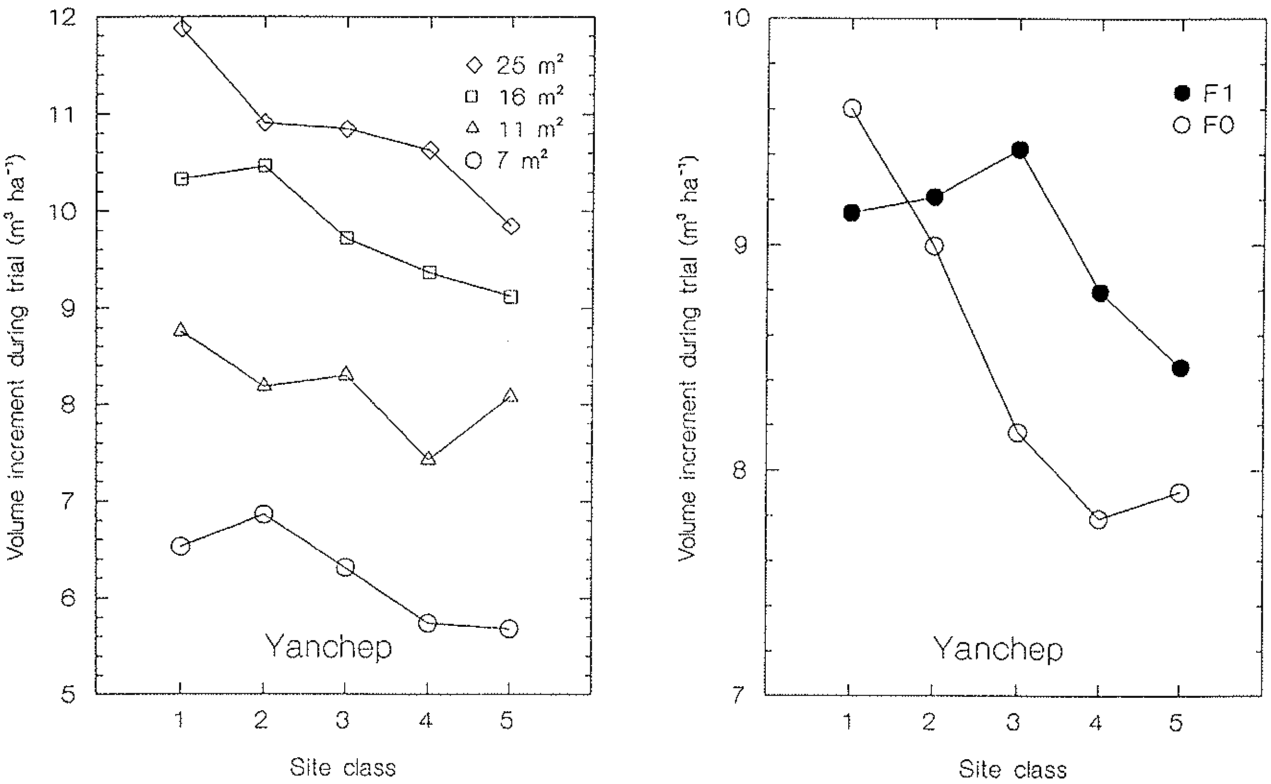

Figure 8. Volume increment for density and fertiliser treatments within the range of site classes over the trial period.

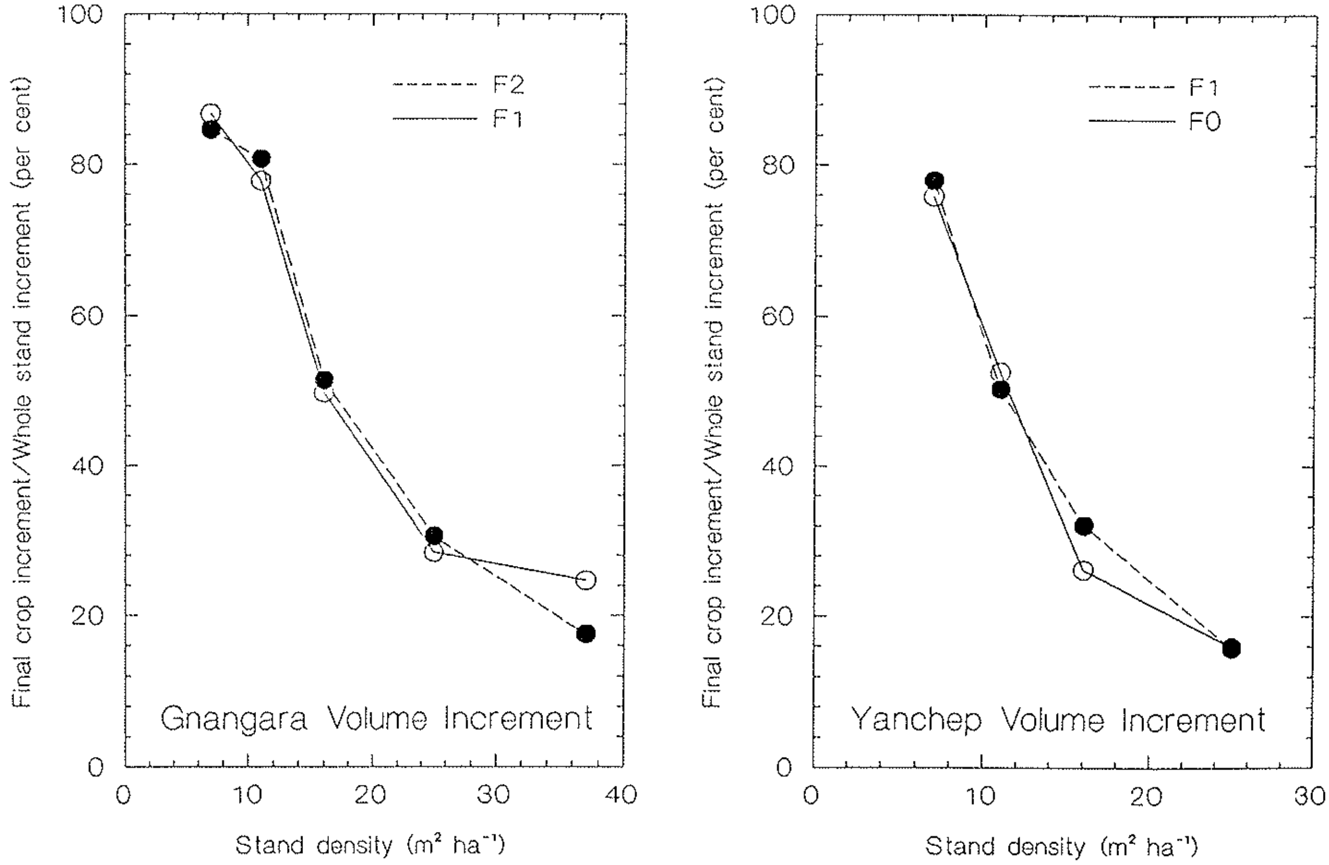

Figure 9. Comparisons of the ratio of Select crop/Whole crop volume increment during the trial with stand density. Plots are provided for the non fertilised (F0) and fertilised (F1) main effects to show that fertiliser use by the dominant trees is no different to that of the whole stand. The Gnangara data is included to show the effect on different soil types and over a larger density range.

no indication that the dominant stand is more efficient in fertiliser uptake either at Yanchep or Gnangara, where the same trial was conducted on a different soil type.

Nutrition

The five site blocks were selected to represent decreasing plot growth and hence, decreasing site potential. Response in volume growth to fertiliser addition at Yanchep was minimal for sites 1 and 2 but appreciable for sites 3, 4 and 5 (Figs. 7, 8). This could result from differences in the physical nature of the soil (i. e. soil depth) and, or different soil chemistry for the five site blocks.

Table 13. Mean values of foliar nutrient content for the fertiliser x site class interaction obtained from the 1973 sampling.

Site	Fert	N73	P73	K73	Mn73	Zn73	Ca73	Mg73
1	0	.798	.057	.393	23.5	16.0	.136	.156
	1	.883	.097	.443	24.3	18.8	.134	.182
2	0	.790	.052	.435	18.5	19.3	.125	.144
	1	.825	.076	.463	21.3	18.5	.121	.154
3	0	.718	.050	.423	21.0	17.8	.137	.151
	1	.778	.087	.430	20.0	20.5	.125	.148
4	0	.713	.038	.350	14.8	16.3	.117	.113
	1	.785	.081	.410	19.0	20.0	.128	.154
5	0	.920	.044	.448	15.3	19.0	.105	.138
	1	.833	.090	.408	19.9	18.9	.126	.148

Foliar nutrition, reported by Hatch and Mitchell (1971) for the early years of the Yanchep trial in 1967, 1969 and 1971, prior to fertiliser addition, generally did not differ significantly within the density and site blocks. The exception was foliar K per cent which significantly decreased with increasing stand density (Tables 9, 10). Their analysis was for a split plot, repeated measures design for the 1967, 1969 and 1971 measurements, having 10 random plots for each site block. Hatch and Mitchell did not detect significant P effects for site and density treatments. These were present in 1971, using the factorial arrangement for fertiliser and density treatments within each site block. This effect mainly resulted from foliar P falling off with decreasing site potential and could at least partly explain that decreasing volume increment over the site range was associated with decreasing availability of P. The data, however, indicated significance in the density x fertiliser interaction (p=.067), resulting mainly from high P values in the F1 portion of the plots (Table 13). These high values were consistent in all six of the separate trees sampled for each plot mean and cannot be adjusted by missing values or transformation. It is believed that the P effect results from flaws in randomising plots to provide for F0 and F1 treatments within each density treatment within each site block. As mentioned this separation was not available to the analysis of Hatch and Mitchell.

Hatch and Mitchell (1971) assumed that the foliar values measured for N, P, K, Ca, Mg, Mn, and Zn were above the values required for satisfactory growth.

Performance of treatment means for Years, Density, Site and Fertiliser main effects for repeated measures analysis (Table 11) for N, P, K, Mn and Zn are summarised in Figure 10. The 1973 measurement, following fertiliser addition, revealed a highly significant response to added fertiliser. The response restored homogeneity in P levels for density and site treatments which did not differ significantly in either 1973 or 1976. Foliar Zn also gave a highly significant response to fertiliser addition with increased values in the fertilised plots. These had returned to even values for F0 and F1 in the 1976 sampling. Magnesium and Mn approached significance with fertiliser addition, Mg increasing in fertilised plots and decreasing significantly with decreasing site class. Mn decreased in fertilised plots, decreased significantly with decreasing site class and increased with increasing stand density (Table 9). By 1976 foliar values were not significantly related to treatments except for foliar N which showed a significant decrease (.041 level) in the fertilised treatment in 1976 (Table 9, 11).

Fertiliser by site data for the 1973 sampling are presented in Table 13 to test the assumption that variable response to fertiliser could be due to different nutrient capacities of blocks over the site range (Fig. 8, right). The F0 treatments for P73, Mn and Ca show a decrease in foliar P in the crop with decreased site potential. There is no other consistent pattern for either F0 or F1 for the other nutrients analysed. Much of the variation with density is perhaps due to dilution effects as only final crop trees were sampled within each stand density treatment.

The P values with fertiliser double dose (F2) at Gnangara were above 0.1 per cent and the single dressing also produced foliar P values considerably higher than any measured with fertiliser addition in the Yanchep trial. Foliar N values were similar at both Gnangara and Yanchep and the foliar K measured at Gnangara was similar to the lowest value measured at Yanchep in 1973. Foliar Zn values at Gnangara were about half those measured in 1973 at Yanchep while Mn contents were similar at both trial sites.

The foliar values are reasonably similar in both trials and it would not appear that the considerable growth differences were associated with variable soil nutrient levels. Mn additions have been tried on similar sites and apart from a temporary improvement in foliage colour did not promote tree growth. Water is apparently the main limiting factor to satisfactory growth at Yanchep.

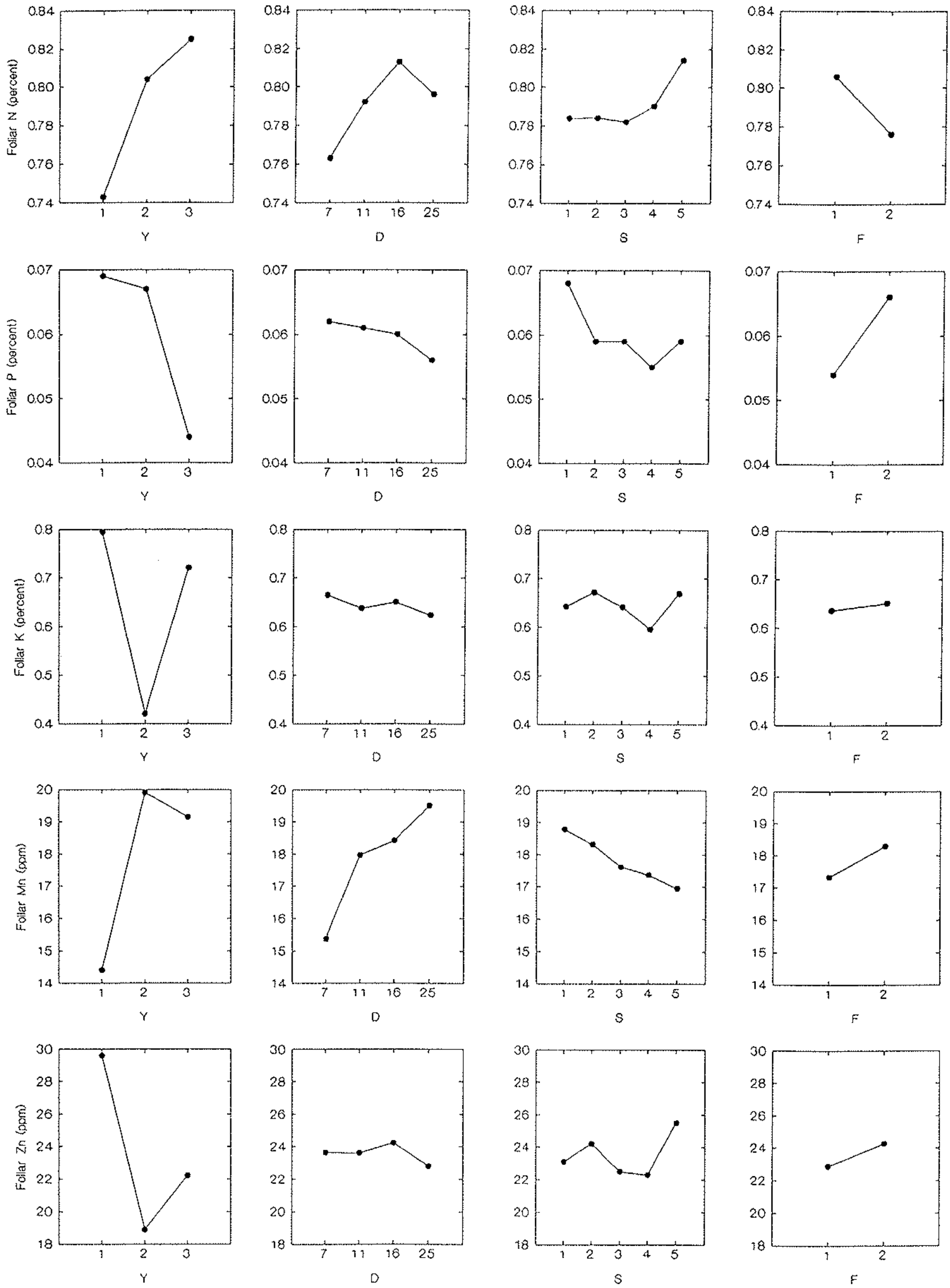

Figure 10. Main effects plots for Years, Density, Site and Fertiliser treatments for foliar sampling in 1971, 1973 and 1976 at Yanchep.

WP 48/66 - Fertiliser and thinning requirements for *Pinus pinaster* plantations on soils of the Spearwood Dunes on the northern Swan Coastal Plain.

Summary and Conclusions.

The effects of superphosphate and superphosphate plus urea fertiliser on pine stands over a range of sites on the Spearwood Dunes sands north of Perth were studied up to stand age 22 years. The trial was designed to compare growth under unthinned, medium and low stand densities. Fertiliser was applied at ages 6, 13 and 21 years and compared 500 kg ha^{-1} superphosphate, 500 kg ha^{-1} superphosphate plus 200 kg ha^{-1} urea and an unfertilised control in each case. There was little response to fertiliser applications at any site and no evidence that nitrogen at the level added had any effect on growth. Average growth improvement associated with the added fertiliser was approximately 5 per cent. There was no indication that fertiliser was more effective in stands maintained at low densities to reduce soil moisture stress during the growing season. Pine growth over the range of sites tested was remarkably uniform, considering the high drought incidence of the northern site. Growth was however, at the best average for the species and generally of a low commercial potential compared to the better sites on the Bassendean Dunes system at Gnangara and the Spearwood dunes system south of Perth.

Introduction.

Site - vegetation surveys in the 1960's to assess the potential for planting *Pinus pinaster* on the northern Swan Coastal plain (Havel 1968) revealed a lack of information on pine establishment and growth on sites with a limestone influence from Yanchep north. To rectify these needs a series of large pilot plots were planned to cover the southern, central and northern sites within the range suggested as suitable for commercial growth. Plot design anticipated that soil moisture would be limiting to tree growth in most years and planned to investigate the thinning and fertiliser requirements for commercial success.

A preliminary report on the study was published by Butcher (1979). Increment for the initial 10 year period was similar over the range of the plots and comparable to that of the optimum sites at Gnangara where the pines were in contact with a ground water source. Differences which existed were largely the result of differences in initial growth. Growth was apparently independent of the climatic, soil and fertiliser factors involved for the three locations but was related to thinning treatment and hence to stand density (Butcher, 1979).

Fertiliser was not essential for establishment or early growth of *P. pinaster* to an age of 10 years on the yellow sands tested. Evidence from other areas, however, suggested that fertiliser applications would stimulate the growth of stands of intermediate ages on the sites concerned.

A greater susceptibility to drought death was evident at the northern, Karakin plot. This alone was not considered to be sufficient reason to eliminate such sites from the potential planting resource. Results from the extreme 1976-77 summer showed that all sites were susceptible to drought deaths, such that the elimination of sites susceptible to summer drought deaths would lead to the virtual cessation of planting on the Coastal Plain. Butcher (1979) suggested that when assessing economic viability it was necessary to determine the level of stand density, in terms of basal area, at which there is a balance between the moisture recharge of the soil profile and moisture depletion by the pine stand.

The current report summarises fertiliser use on the pine crop at the three locations.

Location

North block - The Karakin plot was planted on deep yellow sands of the Spearwood Dunes system at latitude 31°08', longitude 115°30' in June 1967. The site is within 10 km of the ocean, adjacent to Ledge Point and some 100 km NNW of Perth.

Central block - The Wabling plot is at latitude 31°24', longitude 115°38', between Yanchep and Moore River.

Southern block - The Haddrill plot is at latitude 31°33', longitude 115°44', between Pinjar and Yanchep

Procedure

Establishment

Woodlands were cleared in December 1966 and burnt in March 1967. Sites were ploughed and furrow-lined preparatory to planting in June 1967. Blocks were machine planted at 2.4 m x 1.8 m spacing. All seedlings received 60 g of superphosphate, zinc oxide at planting and the area between rows was cultivated for scrub control in the first and second years after planting. The seed source originated from an open stand of superior phenotypes located in the native Leirian forest in Portugal.

The study was designed as a 3 x 3 factorial at the 3 locations with 3 thinning intensities and 3 fertiliser regimes randomised within 3 site types at each location. Each pilot plot is 400 m x 120 m, with the long axis across the contour in approximately an East-west direction. It was separated into a lower slope depression, a middle slope and an upper slope as sites 1, 2 and 3, respectively. Nine sample plots were selected in each of these three site types. The sample plot was 0.04 ha within a buffer plot of 0.16 ha. Plots were marked, measured and stratified on the basis of tree height in 1971 for random allocation of fertiliser and thinning treatments. There were 81 plots in the study. Plot allocation to treatments at locations is shown in Table 1.

Thinning Prescription

Three levels of thinning were studied.

1. **Unthinned Control**- Planted at 2285 stems ha^{-1} in 1967.

2 **Routine Thinning** - Thinned to 500 stems ha^{-1} (20 trees per plot) in 1977 at age 10 years.
Thinned to 250 stems ha^{-1} in 1985 at age 18 years.

3. **Heavy Thinning** - Thinned to 750 stems ha^{-1} in 1973 at age 6.
Thinned to 250 stems ha^{-1} in 1980 at age 12 years.
Thinned to 100 stems ha^{-1} in 1987 at age 18 years.

Table 1. Allocation of treatments to plots within the factorial design for thinning and fertiliser treatments with replication in the three site types.

Slope (Block)	Thinning	Fertiliser N+P	Fertiliser P	Fertiliser Nil
1. - Lower	1. - Unthinned	3,34,57	5,31,55	7,29,60
	2. - Routine	4,30,56	2,32,63	9,28,61
	3. - Heavy	6,35,59	1,36,62	8,33,58
2. - Middle	1. - Unthinned	15,42,71	11,39,67	16,41,68
	2. - Routine	10,44,69	18,40,64	13,37,70
	3. - Heavy	14,45,66	17,38,65	12,43,72
3 - Upper	1. - Unthinned	22,51,74	25,50,78	21,46,81
	2. - Routine	26,54,73	20,49,77	24,48,76
	3. - Heavy	23,53,79	19,47,80	27,52,75

Fertiliser Prescription

Seedlings received 60 g Superphosphate, copper, zinc at planting in August 1967. Three levels of fertiliser were compared.

Applied in September 1973
1. 750 kg superphosphate, copper, zinc + 250 kg urea ha^{-1}.
2. 750 kg superphosphate, copper, zinc ha^{-1}.
3. Nil

Applied in August 1980
1. 500 kg superphosphate, copper, zinc + 200 kg urea ha^{-1}.
2. 500 kg superphosphate, copper, zinc ha^{-1}.
3. Nil.

Applied in September 1988
1. 500 kg superphosphate, copper, zinc + 200 kg urea ha^{-1}.
2. 500 kg superphosphate, copper, zinc ha^{-1}.
3. Nil.

Measurement.

The following measurements were made -

February	1974.	Dbhob (diameter at breast height over bark) and height.
January	1975.	Dbhob and heights.
January	1976.	Dbhob and heights of crop trees (250 ha^{-1}).
January	1977.	Dbhob and heights of crop trees (250 ha^{-1}).
January	1978.	Dbhob and heights of crop trees (250 ha^{-1}).
March	1980.	Dbhob and heights of select trees (100 ha^{-1}).

February	1981.	Dbhob and heights of select crop trees.
January	1982.	Dbhob and heights of select crop trees.
January	1983.	Dbhob and heights of select crop trees.
January	1985.	Dbhob, all heights and bark thickness.
January	1986.	Dbhob and heights of select crop trees.
January	1987.	Dbhob and heights of select crop trees.
January	1988.	Dbhob and heights of select crop trees.
February	1989.	Dbhob and heights of select crop trees.
March	1993.	Partial measurement of Dbhob and heights of select crop trees at Karakin only.

Foliar Analysis - Foliar samples were taken from 6 trees of the select crop in all plots in March 1975 and analysed for per cent P and K and for Zn and Mn content in ppm. In April 1977 the northern plots at Karakin were sampled again and analysed for per cent N.

Table 2. Stem numbers (ha^{-1}) for thinning treatment classes at each location. Locations are Karakin (1), Wabling (2) and Haddrill (3), thinnings are Control, Routine and Heavy.

Loc	Thin	Measurement year								
		1974	1976	1977	1978	1980	1982	1985	1987	1989
	Contr	1700	1700	1700	1536	1483	1483	1461	1350	1308
1	Rout	1805	1802	1802	497	497	497	497	488	250
	Heavy	750	747	747	722	722	250	247	244	97
	Contr	1969	1966	1966	1916	1641	1641	1641	1641	1636
2	Rout	1988	1988	1988	497	497	497	497	497	250
	Heavy	750	750	750	741	705	250	250	250	100
	Contr	1972	1972	1969	1969	1538	1527	1527	1505	1505
3	Rout	1997	1997	1997	491	491	491	491	488	250
	Heavy	750	750	750	750	722	250	250	250	100

Analysis - The plots at each location were initially analysed as separate trials largely to validate measurement data. The Sites were then nested within Locations and all plots compared within a single analysis of variance for each measurement. These combined results are reported initially and supported by results from the separate Locations only where interactions were prominent or detailed explanation was considered to be warranted.

Results

Stocking - The initial stocking at Haddrill and Wabling was similar at approximately 1970 s ha^{-1} (Table 2). Initial survival at the northern site, Karakin, was poorer with approximately 1700 s ha^{-1} resulting from 13 per cent mortality. These mortalities increased slightly with site position with mean stockings of 1458, 1427 and 1367 s ha^{-1} for the lower, mid and upper slope sites. Stocking at the other locations was similar for sites. The Heavy thinning treatment was reduced from 1970 to 750 s ha^{-1} at age 6 years, to 250 s ha^{-1} in 1980 at age 12.7 years and to

100 s ha^{-1} in 1987 at age 19.5 years (Table 2). The Routine treatment reduced to 500 s ha^{-1} at age 9.5 and to 250 s ha^{-1} at age 19.7 years. Mortality following establishment in the unthinned control was 21 per cent for all plots over the trial period with 23 per cent at Karakin and Haddrill and 17 per cent at Wabling. The deaths at the three Locations were detected mainly from age 10 to 13 years (1978-1980) but continued progressively to age 22 years at the northern site, Karakin.

Table 3. Mean heights (m) of the select (250 s ha^{-1} to 1977) and final crop (100 s ha^{-1}) for treatment classes at each Location. Locations are Karakin (1), Wabling (2) and Haddrill (3), Sites are Lower slope, Middle slope and Upper slope and Fertiliser treatments are Nitrogen + Phosphorus, Phosphorus and the non fertilised Control.

		Measurement year							
Loc	Site	1974	1976	1977	1978	1980	1985	1987	1989
	Lower	6.12	8.24	9.20	9.81	11.74	14.84	15.95	17.37
1	Mid	5.48	7.49	8.27	9.01	10.99	14.84	16.31	17.28
	Upper	5.20	7.32	8.23	9.05	11.17	14.99	15.95	17.57
	Lower	5.62	7.58	8.31	9.01	10.64	14.37	15.56	16.72
2	Mid	5.72	7.72	8.41	9.06	10.90	14.56	15.81	17.04
	Upper	5.76	7.80	8.52	9.22	11.04	14.43	15.99	17.02
	Lower	70	9.03	9.81	10.45	12.24	15.74	17.00	18.39
3	Mid	6.34	8.42	9.28	9.96	11.66	14.98	16.16	17.47
	Upper	5.96	8.12	9.01	9.71	11.49	15.04	16.28	17.61
Loc	Fert	1974	1976	1977	1978	1980	1985	1987	1989
	N+P	5.58	7.67	8.54	9.27	11.31	14.51	15.66	17.16
1	P	5.67	7.73	8.62	9.31	11.66	15.10	16.15	17.68
	Cont	5.56	7.65	8.55	9.29	10.92	15.07	16.40	17.39
	N+P	5.63	7.58	8.34	8.94	10.84	14.43	15.82	16.91
2	P	5.73	7.72	8.43	9.15	10.82	14.36	15.72	16.90
	Cont	5.73	7.80	8.47	9.20	10.92	14.57	15.82	16.96
	N+P	6.45	8.62	9.46	10.11	11.75	15.19	16.38	17.74
3	P	6.27	8.42	9.30	9.99	11.87	15.26	16.37	17.71
	Cont	6.28	8.54	9.33	10.03	11.76	15.31	16.69	18.02
ALL		5.88	7.97	8.78	9.48	11.32	14.87	16.11	17.39

There was a trend for mortality to be greatest in the N+P treatment and least in the P treatment, particularly at Karakin and Haddrill sites, but this was not significant. A trend for mortality to be greater with site position upslope was also not found to be significant.

Height - Mean heights of the dominant crop for Site and Fertiliser treatments are set out in Table 3 and plotted for

Thinning treatments in Figure 1. Up to age 10 years the means refer to the select crop of 250 s ha^{-1}, from 12 to 22 years mean heights are for the select 100 s ha^{-1}.

Table 4. Significance of the differences in means for select crop height for treatment combinations. Sites are nested within Locations for analysis and the probabilities are that the F value obtained in analysis would be obtained by chance. The error mean square is included.

		Stand age (years)								
Source	DF	7	8	9	10	11	13	18	21	22
Location	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Site(Loc)	6	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00
Thin	2	0.40	0.62	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Fert	2	0.91	0.91	0.88	0.99	0.72	0.13	0.62	0.65	0.77
Loc*Thin	4	0.91	0.91	0.62	0.51	0.61	0.93	0.64	0.41	0.33
Loc*Fert	4	0.60	0.53	0.36	0.58	0.47	0.06	0.05	0.10	0.07
Thin*Fert	4	0.57	0.67	0.66	0.60	0.78	0.81	0.94	0.53	0.63
L*T*F	8	0.98	0.98	0.97	0.93	0.84	0.84	0.54	0.54	0.24
Error	48	.098	.106	.095	.087	.097	.130	.199	.359	.187
Total	80									

Table 5. Significance of the differences in increment of select crop height for treatment combinations. Sites are nested within Locations for analysis and the probabilities are that the F value obtained in analysis would be obtained by chance. The error mean square is included.

		Increment period (years)						
Source	DF	7-8	8-9	9-10	10-11	11-13	13-18	18-20	20-22
Location	2	0.00	0.25	0.00	0.41	0.00	0.15	0.54	0.22
Site(Loc)	6	0.48	0.00	0.00	0.04	0.48	0.00	0.30	0.19
Thin	2	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.11
Fert	2	0.00	0.98	0.46	0.23	0.18	0.53	0.66	0.28
Loc*Thin	4	0.92	0.48	0.74	0.31	0.76	0.54	0.63	0.15
Loc*Fert	4	0.02	0.56	0.31	0.49	0.00	0.80	0.70	0.37
Thin*Fert	4	0.08	0.03	0.00	0.10	0.47	0.97	0.57	0.35
L*T*F	8	0.08	0.99	0.29	0.88	0.86	0.72	0.60	0.54
Error	48	.007	.011	.011	.017	.023	.005	.066	.061
Total	80								

Mean final crop height differed significantly for Locations (Table 4) being 17.8 m for Haddrill and 17.4 m and 16.9 m for Karakin and Wabling, respectively at age 22 years. Site differences were also significant, heights tending to decrease upslope. This was mainly evident at Haddrill and, for the early development, at Karakin. Slope had no significant effect on

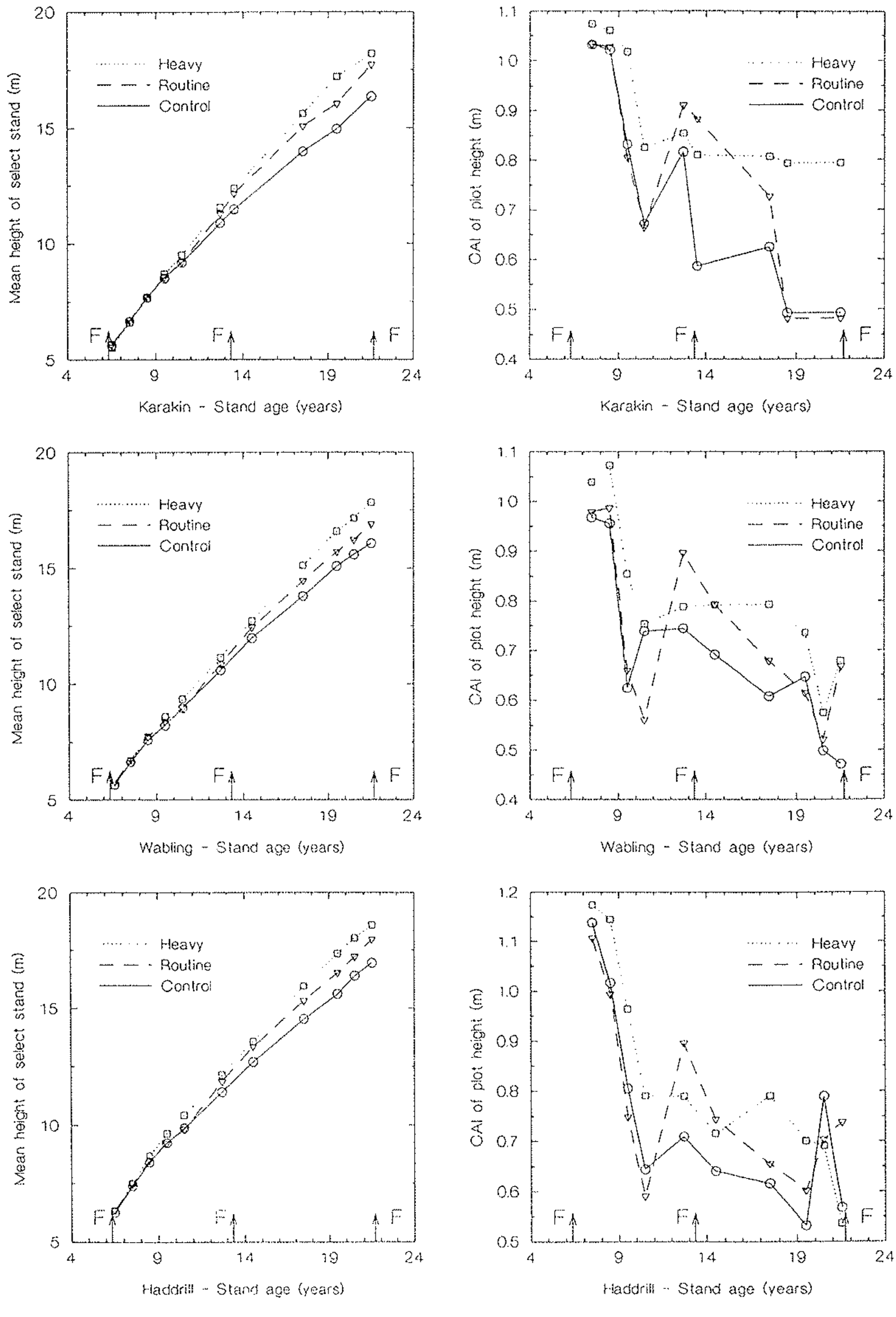

Figure 1. Mean heights and current annual increment in height of the select stand at each Location showing the impact of thinning treatments. The F and Arrow on the x axis mark fertiliser applications.

least at Wabling, after which the three Locations were similar (Fig. 2). Site differences due to the lower slope were also significantly better at Haddrill up to age 11 years. Thinning differences (Fig. 2 left) were highly significant with the Control production being superior and the Routine and Heavy treatments fluctuating following treatment. A significant Location by Thinning interaction recorded for the measurement at age 11 years (Table 6) was due to the BAob of the Routine treatment being similar at all 3 Locations and is not considered to be important. Fertiliser addition at age 6.2 years produced a response at each location with the N+P effect being highest (Fig. 2 right, Table 6). This effect was significant in the combined stand data for ages 8, 9 and 10 years (Table 6) but was not detected in the separate analyses for each Location. Except at ages 9 and 10 years of age the differences due to fertiliser treatments in whole plot BAob were not significant at the .05 level (Table 6), data analysis for each Location individually completely isolated the positive fertiliser effect to Karakin (.001 level).

BAob Increment - BAob increment (Fig. 3, Table 7) for the whole stand differed significantly with Location in all but the 18-22 year measurement interval (Table 7). It was not consistently superior at any one Location being greatest at Haddrill up to 11 years and best at Wabling from 17-22 years (Fig. 3). Site differences in whole stand BAob were superior for the Lower slope situation up to age 10 after which they evened out. Growth on the Control was the best of the thinning treatments to age 18 years after which it was not significantly different (Fig. 3 left, Table 7). With fertiliser, BAob growth (Fig. 3 right) was superior for the N+P addition for 4 years after the initial application (as for standing BAob). In separate analyses for Locations this result was not significant at Haddrill, significant for the first year only at Wabling and highly significant (.001 level) up to age 18 years at Karakin. Significant interactions of Location with Fertiliser were obtained for whole stand increment for the 9-10, 11-13, 13-18 and 18-20 year increment periods. Examination of data at separate Locations showed a highly significant effect of added fertilisers at Karakin for 9-10, 11-13 and 13-18 years but none at either Wabling or Haddrill for these periods. For the 11-13 year period at Haddrill stem mortalities in the fertiliser treatments led to a decrease in increment for the period in these treatments (Fig. 3 right).

Means for the select stand of 250 s ha^{-1} and final crop stand of 100 s ha^{-1} (Fig. 4 and 5, Tables 6 and 7) depict treatment effects on the dominant crop without variation in stem numbers associated with removals by thinning treatments. Effects of Location and Site were as reported above for whole stand BAob. Growth of the dominants increased greatly with release from thinning at all Locations (Fig. 4, Tables 6 and 7). Fertiliser treatments had a significant effect for all except the 6.5 and 21.5 year measurement for standing BAob of the select crop (Table 6, Fig 5 left) and, except for the 10-11 and 18-22 year intervals, for BAob increment (Table 7. Fig. 5 right). This effect, apart for the initial 7-8 year period, was restricted to stands at the Karakin Location. Location by Fertiliser height development at Wabling and at Karakin after age 10 years. Heights of thinning treatments were significantly different (Table 4, Fig. 1) from age 10 years onwards at all sites. Mean heights, except for Karakin in 1980, were not influenced by fertiliser addition (Tables 3 and 4).

Height growth to age 12.5 years was significantly different between Locations being best at Haddrill, second best at Karakin and poorest at Wabling (Fig. 1). Differences in height increment due to site effects were mainly during the early stand development from 8 to 11 years of age (Table 5). Significant effects of fertiliser on height increment were recorded only for the initial 7 to 8 year measurement period while the impact of thinning was strong over all but the 20 to 22 year measurement period (Table 5, Fig. 1).

Table 6. Results of analysis of variance for mean annual increment in basal area (m^2 ha^{-1}) of the total stand and the select stand, for treatment combinations. The data are probabilities that the F value obtained would be exceeded by chance. the error mean square is included.

		Stand age (years)								
Source	DF	7	8	9	10	11	13	18	20	22
Total stand										
Location	2	0.00	0.00	0.00	0.00	0.00	0.25	0.43	0.39	0.93
Block(Loc)	6	0.00	0.00	0.00	0.00	0.04	0.30	0.90	0.42	0.90
Thinning	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Fert.	2	0.83	0.07	0.05	0.05	0.23	0.55	0.42	0.35	0.25
Loc*Thin	4	0.09	0.30	0.59	0.76	0.00	0.64	0.84	0.37	0.78
Loc*Fert.	4	0.90	0.73	0.80	0.66	0.79	0.22	0.24	0.33	0.06
Thin*Fert.	4	0.94	0.96	0.96	0.93	0.73	0.17	0.26	0.38	0.51
L*T*F	8	0.97	0.95	0.94	0.93	0.82	0.40	0.53	0.46	0.33
Error	48	.025	.034	.034	.031	.025	.032	.025	.025	.021
Total	80									
Select crop										
Location	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Block(Loc)	6	0.00	0.00	0.02	0.11	0.27	0.84	0.89	0.78	0.43
Thinning	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fert.	2	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06
Loc*Thin	4	0.23	0.02	0.00	0.00	0.00	0.68	0.61	0.74	0.79
Loc*Fert.	4	0.77	0.30	0.33	0.34	0.13	0.59	0.29	0.49	0.57
Thin*Fert.	4	0.50	0.27	0.26	0.05	0.11	0.72	0.62	0.34	0.38
L*T*F	8	0.58	0.50	0.63	0.38	0.50	0.06	0.09	0.27	0.27
Error	48	.001	.001	.001	.001	.001	.001	.001	.001	.002
Total	80									

Standing Basal Area - Up to age 11 years basal area production for the whole stand was best at Haddrill, lower at Karakin and

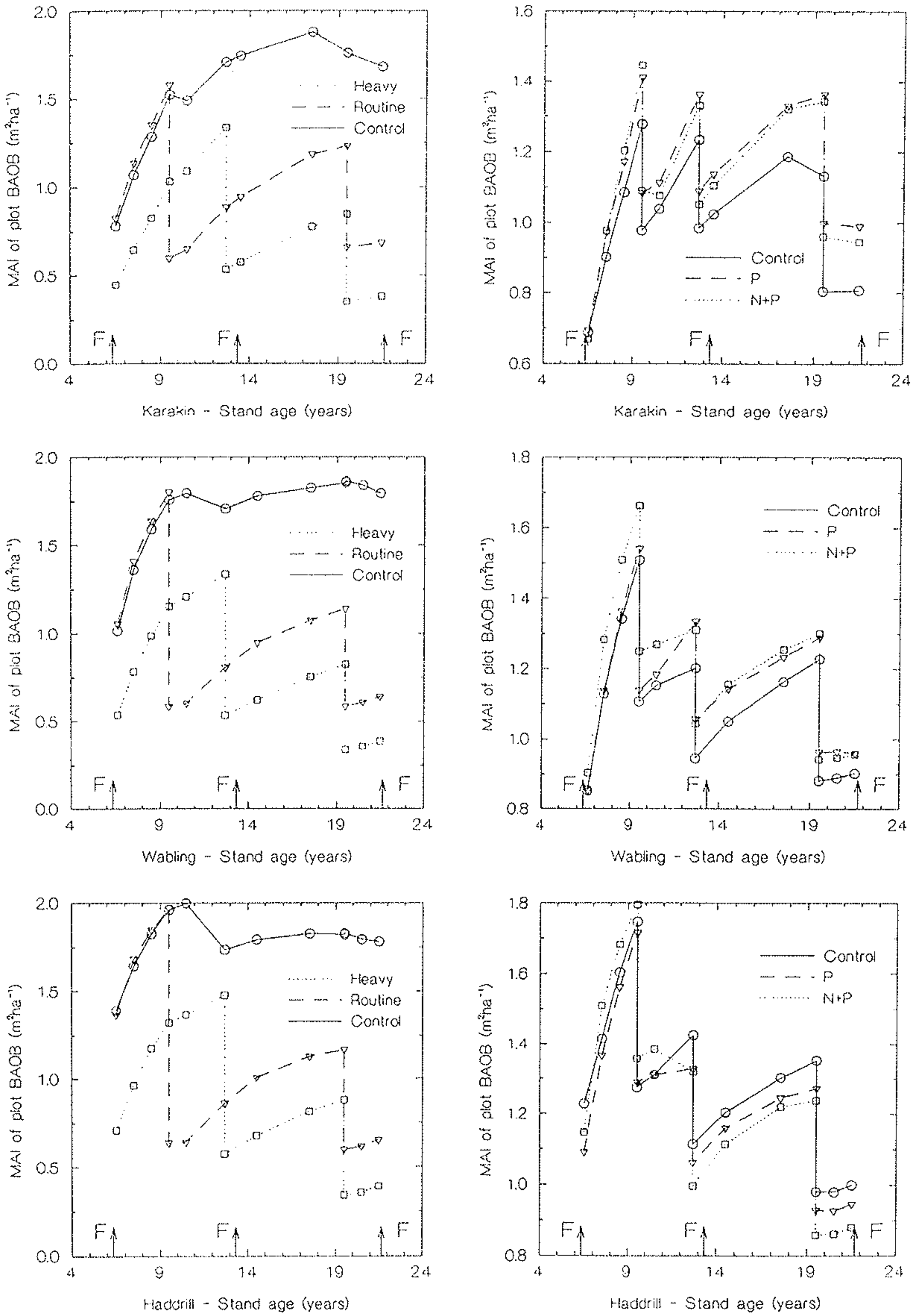

Figure 2. Plot of mean annual increment for standing basal area (m^2 ha^{-1}) at each location for thinning (left) and fertiliser (right) treatments. The F and arrow on the x axis mark fertiliser applications.

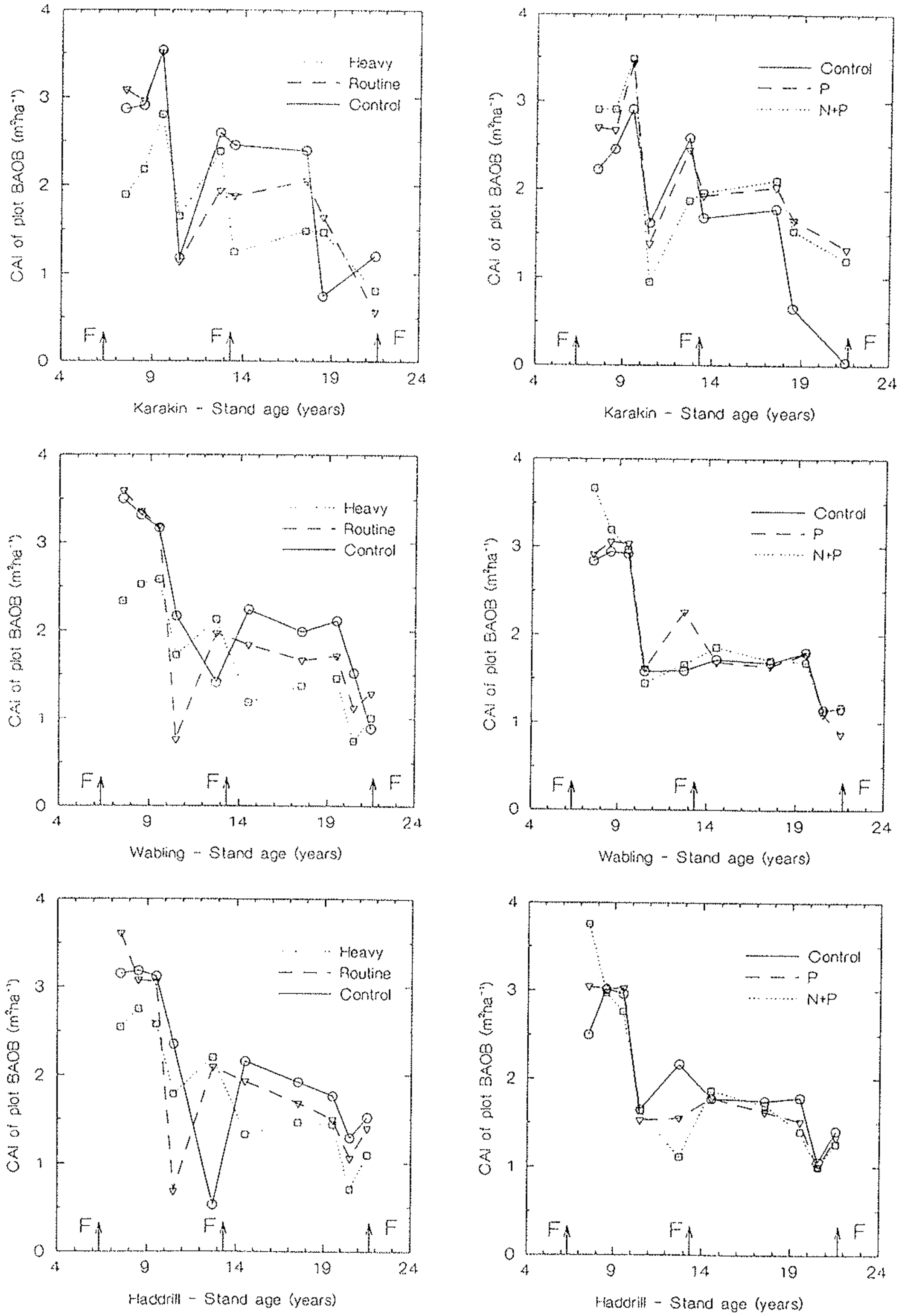

Figure 3. Plot of current annual increments for basal area (m^2 ha^{-1}) of the whole stand at each location for thinning (left) and fertiliser (right) treatments. The F and arrow on the x axis mark fertiliser applications.

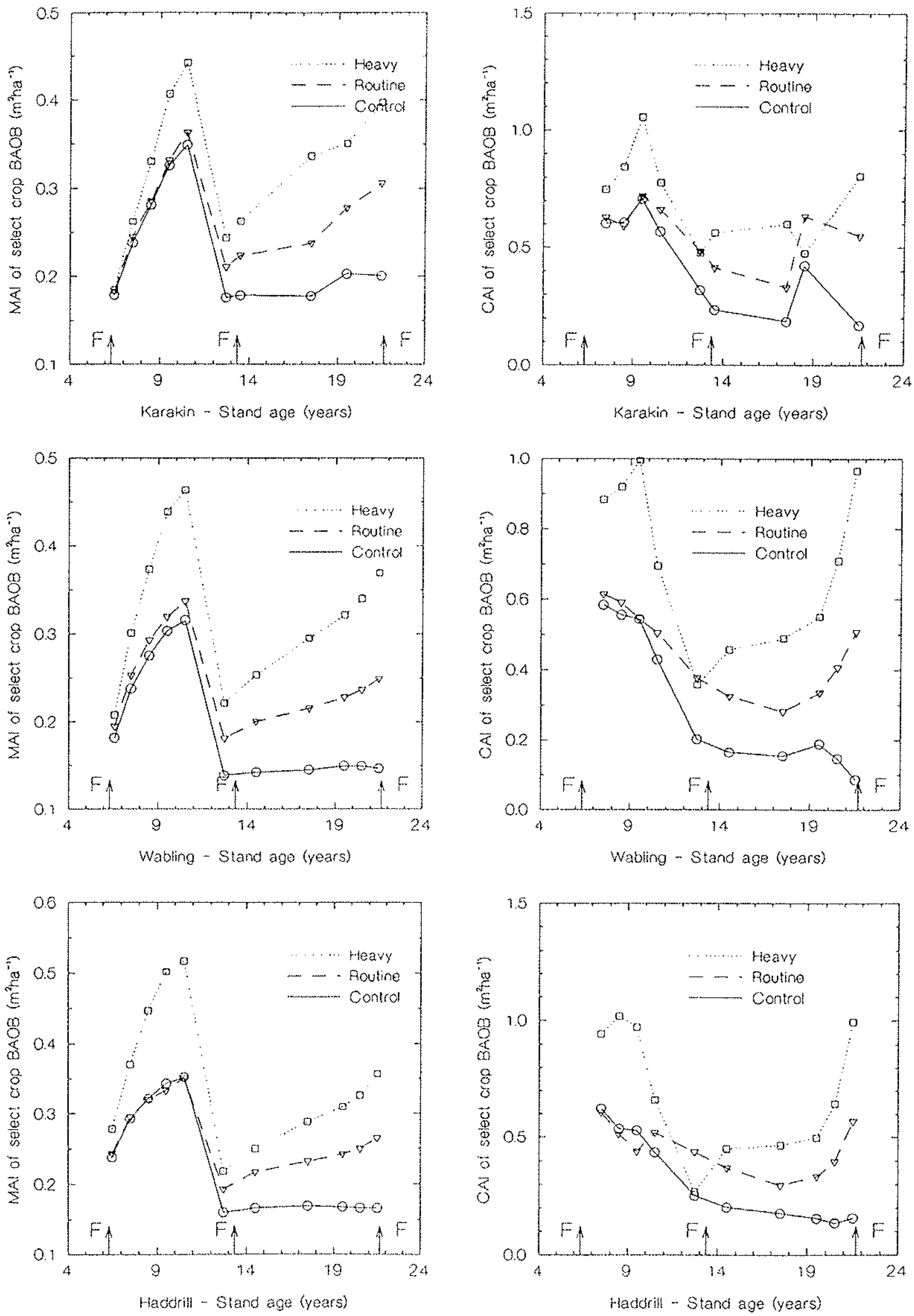

Figure 4. Plot of MAI and CAI for basal area of the select crop (m^2 ha^{-1}) for thinning treatment classes at each location. The F and arrow on the x axis mark fertiliser applications.

Table 7. Results of analysis of variance for current annual increment in basal area (m^2 ha^{-1}) of the total stand and the select stand, for treatment combinations. The data are probabilities that the F value obtained would be exceeded by chance. The error mean square is included.

		Increment period (years)							
Source	DF	7-8	8-9	9-10	10-11	11-13	13-18	18-20	20-22
		Total stand							
Location	2	0.00	0.00	0.00	0.03	0.00	0.05	0.10	0.35
Block(Loc)	6	0.00	0.00	0.50	0.11	0.89	0.05	0.59	0.89
Thinning	2	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.51
Fert.	2	0.00	0.02	0.01	0.06	0.24	0.02	0.43	0.33
Loc*Thin	4	0.79	0.07	0.76	0.00	0.00	0.03	0.10	0.62
Loc*Fert.	4	0.18	0.15	0.00	0.13	0.03	0.02	0.01	0.10
Thin*Fert.	4	0.62	0.48	0.18	0.01	0.22	0.12	0.17	0.23
L*T*F	8	0.74	0.76	0.58	0.18	0.03	0.35	0.01	0.76
Error	48	.147	.080	.077	.170	.561	.017	.017	.086
Total	80								
		Select crop							
Location	2	0.00	0.91	0.00	0.00	0.00	0.00	0.22	0.50
Block(Loc)	6	0.07	0.42	0.46	0.28	0.28	0.27	0.70	0.15
Thinning	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fert.	2	0.00	0.01	0.02	0.21	0.02	0.00	0.77	0.34
Loc*Thin	4	0.00	0.00	0.19	0.95	0.09	0.31	0.22	0.95
Loc*Fert.	4	0.01	0.16	0.72	0.07	0.05	0.13	0.78	0.85
Thin*Fert.	4	0.04	0.60	0.09	0.09	0.49	0.45	0.21	0.15
L*T*F	8	0.24	0.80	0.35	0.93	0.04	0.15	0.70	0.65
Error	48	.003	.006	.016	.020	.011	.006	.006	.030
Total	80								

interactions significant at the .05 level were obtained for select crop increment within the 7-8 and 11-13 year interval (Table 7). In the initial 7-8 year period response was better for the P treatment immediately after application at Karakin while in the 11-13 year interval response of the dominants to fertilisers was significant at Haddrill but not at the other two locations (Fig. 5 right). Significance of the interactions was removed using a square root or log transform for the select crop increment data. Transforms were not generally used as homoscedasticity appeared to be satisfactory for the data.

Table 8. Mean basal area (m^2 ha^{-1}) and volume (m^3 ha^{-1}) for the whole stand and the select stand, within fertiliser and thinning treatments. Stand age 17.5 years in 1985.

Location	Treatment	BA85	Tvol85	SCBA85	SCvol
		Fertiliser			
Karakin	N+P	23.12	127.4	4.88	27.3
	P	23.27	126.7	4.92	27.4
	Control	20.77	102.4	4.00	20.5
Wabling	N+P	22.10	109.6	3.92	21.0
	P	21.70	106.9	3.89	20.6
	Control	20.47	105.2	3.71	20.2
Haddrill	N+P	21.45	120.2	4.34	26.2
	P	21.90	120.7	4.10	24.5
	Control	22.92	126.1	3.65	21.7
		Thinning			
Karakin	Control	32.88	159.7	3.29	15.8
	Routine	20.73	116.2	4.63	23.9
	Heavy	13.55	80.6	5.88	35.5
Wabling	Control	32.11	149.0	2.54	12.7
	Routine	18.92	99.4	3.79	20.0
	Heavy	13.24	73.3	5.18	29.1
Haddrill	Control	32.12	165.0	2.96	16.3
	Routine	19.83	112.6	4.07	24.1
	Heavy	14.32	89.5	5.06	31.9

Volume production - All heights and bark thickness were measured in 1985 to allow accurate estimation of stand volume production. Means for the whole crop and select crop are compared for treatments in Table 8. Combined analysis for total stand volume found significant differences between Locations and Thinning treatments. At Karakin both Fertiliser and Thinning treatments were highly significant (.001) while at Wabling and Haddrill only

Thinning differences were significant for the total stand. Total volumes for Locations were 118.9, 107.3 and 122.4 m^3 ha^{-1} for Karakin, Wabling and Haddrill, respectively.

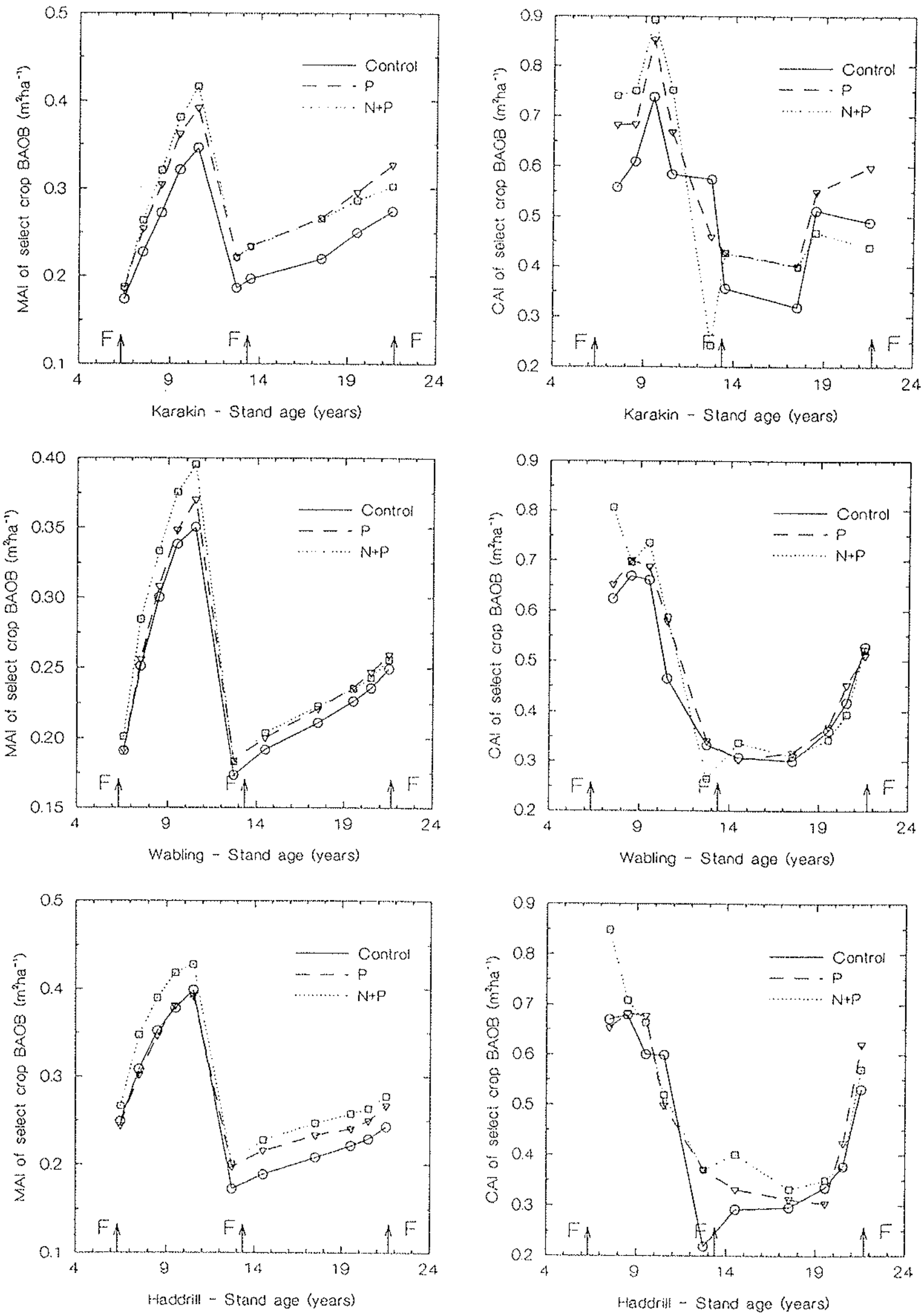

Figure 5. Plot of MAI and CAI for basal area of the select crop (m^2 ha^{-1}) for fertiliser treatment classes at each location. The F and arrow on the x axis mark fertiliser applications.

Table 9. Mean values for foliar nutrients sampled in March 1975 for each pilot plot. The P value is the probability that the differences in the main effect occurred by chance. The thinning by fertiliser interaction was not significant in the analysis of variance for data at each location.

Main effect	Factor level	P (%)	K (%)	Zn (ppm)	Mn (ppm)	Significance. P	K	Zn	Mn
				Karakin					
Site	Lower	0.068	0.806	25.2..	12.2				
	Middle	0.067	0.835	24.1..	11.1	.008	.031	.000	.001
	Upper	0.059	0.877	19.2...	7.8				
Thinning	Nil	0.065	0.822	22.6..	10.7				
	Routine	0.065	0.846	22.4..	10.7	.950	.457	.566	.497
	Heavy	0.064	0.851	23.5..	9.7				
Fertiliser	N+P	0.072	0.826	22.3..	9.9				
	P	0.074	0.862	22.9..	12.5	.000	.306	.726	.006
	Nil	0.048	0.831	23.2..	8.8				
				Wabling					
Site	Lower	0.077	0.714	21.8	13.1				
	Middle	0.067	0.767	19.9	10.8	.008	.024	.012	.026
	Upper	0.064	0.774	16.9	11.0				
Thinning	Nil	0.069	0.746	19.9	12.5				
	Routine	0.073	0.748	18.8	12.0	.252	.771	.693	.771
	Heavy	0.066	0.761	19.9	10.4				
Fertiliser	N+P	0.069	0.725	20.0	11.2				
	P	0.080	0.752	20.0	12.4	.000	.072	.544	.072
	Nil	0.059	0.778	18.6	11.3				
				Haddrill					
Site	Lower	0.059	0.826	12.9	19.2				
	Middle	0.063	0.884	13.7	16.0	.335	.158	.184	.206
	Upper	0.066	0.937	11.0	16.4				
Thinning	Nil	0.061	0.927	12.2	16.8				
	Routine	0.064	0.868	13.5	18.7	.818	.369	.502	.375
	Heavy	0.062	0.852	11.9	16.1				
Fertiliser	N+P	0.067	0.818	11.7	17.5				
	P	0.065	0.926	12.3	18.2	.030	.147	.486	.482
	Nil	0.055	0.903	13.5	16.0				

Combined analysis for select crop volume were significant for Locations, Thinning and Fertiliser treatments. Both thinning and fertiliser effects were highly significant for the select crop volume at Karakin, Thinning only was significant (.000) at

Wabling and Thinning was highly significant and Fertiliser significant (.040) at Haddrill.

Foliar nutrients - Mean values for foliar nutrients sampled in March 1975 are presented for Locations, Sites, Thinning and Fertiliser categories in Table 9. Foliar P decreased significantly from the lower (1) to the upper (3) slopes for sites at both Karakin and Wabling but not for Haddrill where site differences for P were not significant. Zn and Mn were significantly lower on the upper sites for Karakin (0.000) and Wabling (0.01), respectively. K was significantly higher on the upper site (3) at Wabling and Karakin. Means for nutrient levels within thinning treatments did not differ significantly at any site. Increases in foliar P with fertiliser addition were highly significant at Karakin and Wabling and significant (.030) at Haddrill. At Karakin foliar Mn increased significantly (.006) with P addition but not with the N+P addition. The thinning by fertiliser interactions were not significant in any trial.

Foliar N measured in 1977 for Karakin was not significant for any interaction and main effect. The values ranged from 0.922 per cent on the lower site to 0.890 per cent on the upper site.

Soil moisture depletion - Soil moisture variation was monitored by neutron probes in a number of plots covering the range of treatments. The pattern of seasonal variation on both thinned and unthinned plots on the lower site at Haddrill and Karakin is shown in Figures 6 and 7.

At Karakin soil at 5 and 6 metres depth in the profile failed to recharge in 1972 leaving a water deficit within the rooting zone of the stand at that stage. There were however, no pine mortalities in the young stand. In 1973 and 1974 the balance between incoming precipitation and stand evapotranspiration was positive leaving the profile fully charged with water at the end of each winter. The drought of 1976-78 commenced with a serious water deficit at soil depths greater than 2 m in 1975, continued with serious deficits throughout the whole profile for 1976 and 1977. It was completely relieved by rewetting from precipitation in 1978. Water deficits within the rooting zone were also present in 1979 and 1980 and continued almost every year over the period of monitoring up to 1986. The thinned stand registered lesser water deficits at depth than in the unthinned plot.

Results at the more southern Haddrill location show reduced water depletion at depth but the condition of drought in 1975-1978 is still obvious. The soil moisture available for the thinned stand appears satisfactory up to 1983 but reveals signs of drought stress at depth 5.7 m in 1985 and 1986. Measurement of the unthinned plot 60 below 4 m (Fig. 6) was not continued after 1982 on the assumption that available water was completely exhausted and the profile at depth was dry.

Discussion

Mortality - The period 1976-1978 included the worst drought in the history of the region and tree deaths were present in pine stands (and native bushland) at both Gnangara and Yanchep

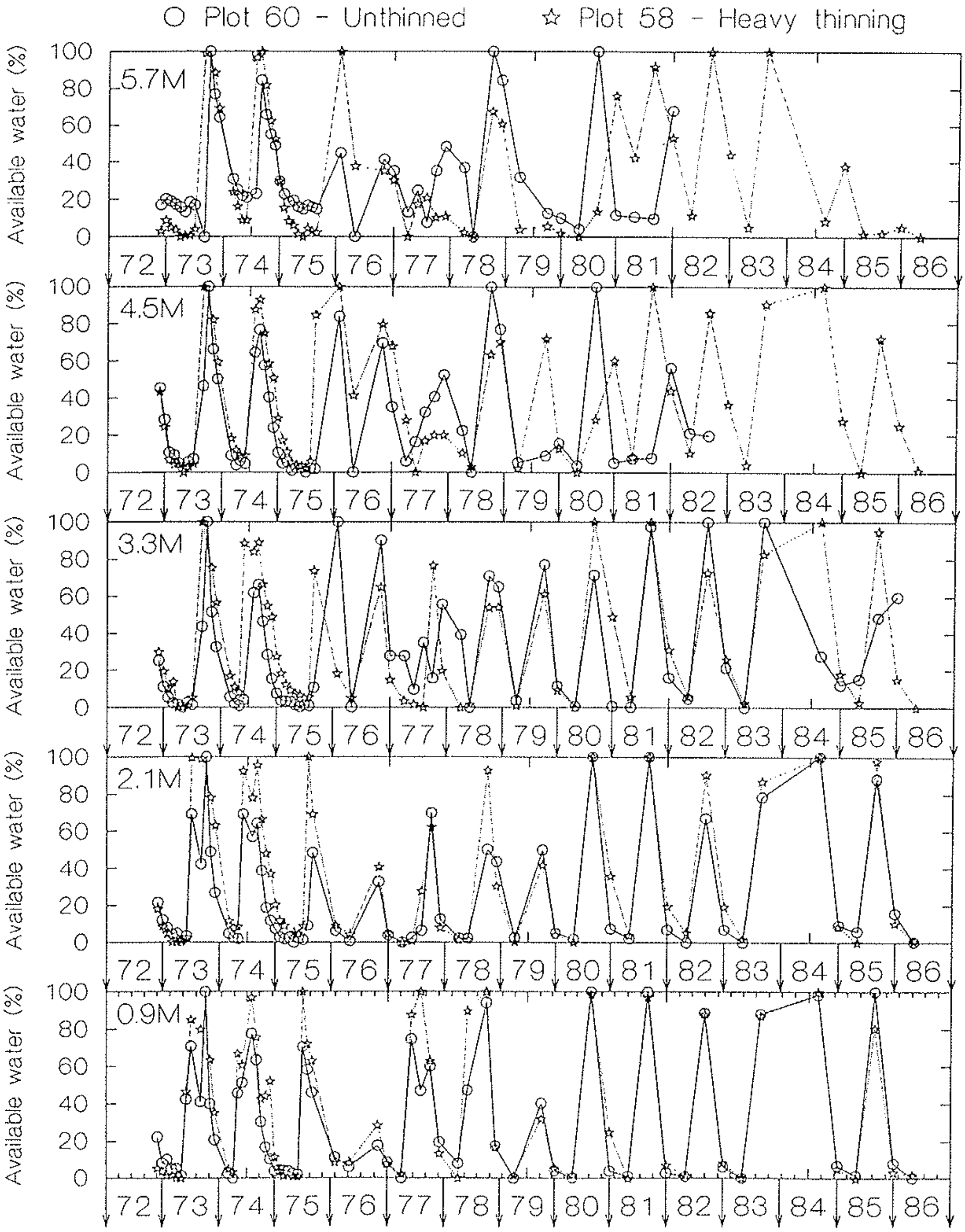

Figure 6. Comparative plots of the extent of soil water availability in thinned and unthinned stands at Haddrill location during the trial. The data is summarised by presenting the 0.9 m, 2.1 m, 3.3 m, 4.5 m and 5.7 m neutron probe traces.

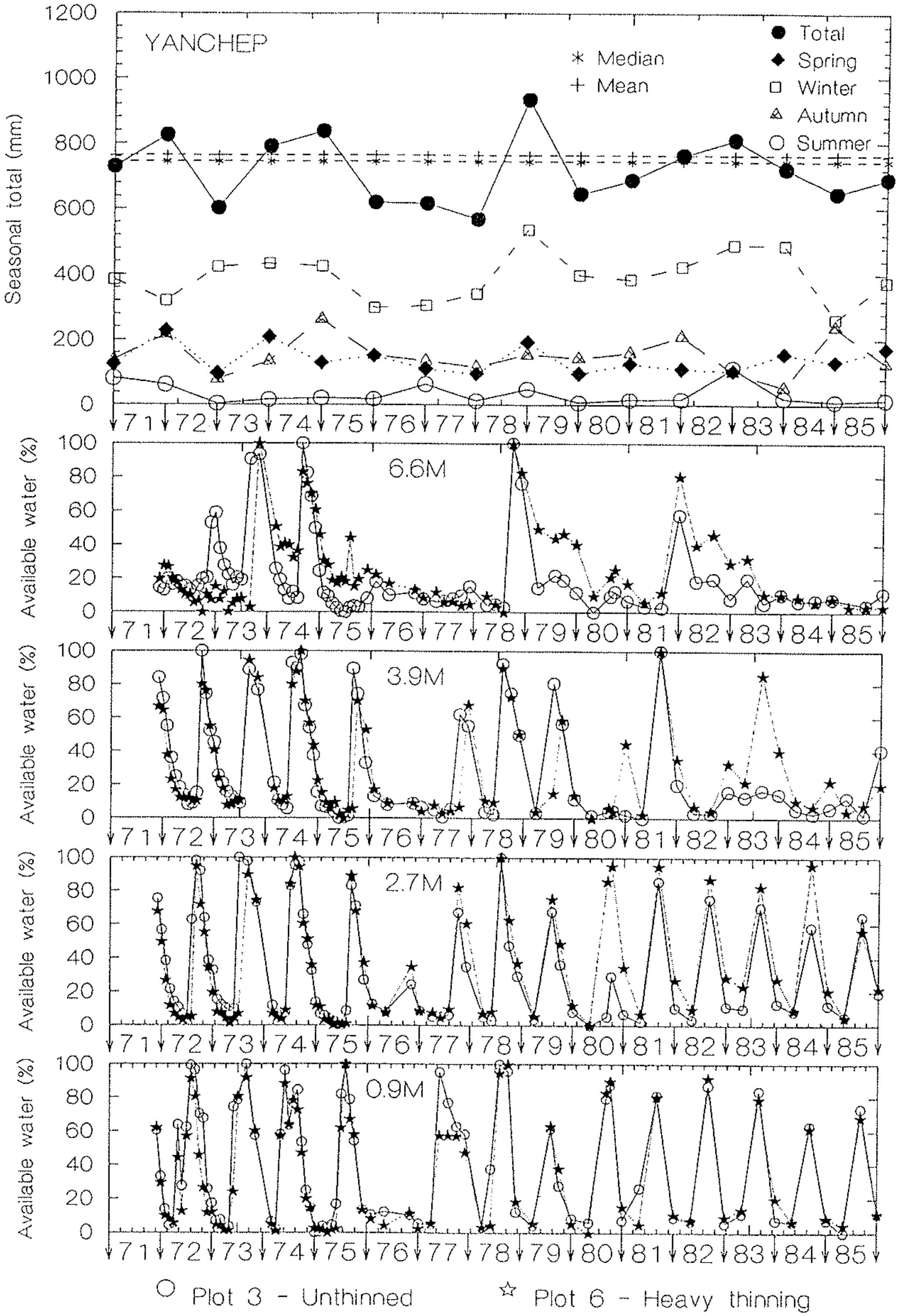

Figure 7. Comparative plots of the extent of soil water availability in thinned and unthinned stands at Karakin location during the trial. The top graph relates mean annual and seasonal rainfall at Yanchep to the trend in soil moisture.

plantations. Butcher (1979) noted two documented accounts of extensive pine deaths to drought in the region at Gnangara, the first in 1949-50 and the second in 1976-77. Both were in dense pine stands, rainfall in the preceding year was 25 per cent below average and was followed by five months without any rainfall. Rainfall at Yanchep for 1875, 1976, 1977 and 1978 was -10, -20, -26 and +22 per cent of the average. The drought hence reached it full intensity in the summer of 1977-78 and was associated with a continuing rainfall deficit during the period. Mortality was greatest in older unthinned stands with a high stand density.

Table 10. Tree mortalities recorded during the trial period for Karakin (K), Wabling (W) and Haddrill (H). Results are the mean deaths per hectare for Thinning, Fertiliser and Site classes in the years tree deaths were observed.

Loc	Year	Thinning			Fertiliser			Site			
		C	R	H	N+P	P	Nil	L	M	U	All
K	1977	105	172	13	138	77	75	38	122	130	97
	1978	61	13	13	50	25	13	33	38	16	29
	1980	44	2	5	41	2	8	13	36	2	17
	1982	13	0	0	2	5	5	2	2	8	4
	1986	125	8	2	11	8	116	25	38	72	45
	1989	41	2	0	2	19	22	30	2	11	14
K	All	391	200	36	247	138	241	144	241	241	209
W	1977	83	27	8	30	22	66	86	19	13	39
	1978	244	2	38	130	50	105	22	113	150	95
	1980	0	0	0	0	0	0	0	0	0	0
	1982	0	0	0	0	0	0	0	0	0	0
	1986	0	0	0	0	0	0	0	0	0	0
	1989	5	0	0	0	5	0	5	0	0	1
W	All	333	30	47	161	77	172	113	133	163	137
H	1977	19	19	0	11	13	13	13	5	19	12
	1978	405	5	27	200	163	75	163	141	133	146
	1980	2	0	0	0	2	0	0	0	2	0
	1982	19	0	0	13	0	5	0	5	13	6
	1986	11	5	0	0	13	2	0	8	8	5
	1989	0	2	13	2	11	2	0	16	0	5
H	All	458	33	41	212	140	171	145	184	194	174
All	1977	69	73	7	60	37	51	60	37	51	50
	1978	237	7	26	126	79	64	46	49	54	90
	1980	15	0	1	13	1	2	73	98	100	6
	1982	11	0	0	5	1	3	4	12	1	3
	1986	45	4	0	3	7	39	0	2	7	16
	1989	15	1	4	1	12	8	8	15	26	7
	All	394	87	41	212	140	171	145	184	194	174

Within the pilot plots deaths were initially recorded in 1977 where they were most severe in the northern location at Karakin (Table 10). Most deaths were present in the unthinned stands so steps were taken to thin the Routine treatment (2) to 500 s ha^{-1} in October 1977. Further massive mortalities recorded, mainly in the unthinned southern plots, in 1978, prompted the further reduction of the Heavy thinning treatments from 750 to 250 s ha^{-1} in October 1980. The relatively fewer deaths in Thinning treatment 2, than in the unthinned T1, in 1978 (Table 10), result from the release of T2 in October 1977 which removed sickly and poorer stems and reduced the drought stress on the remaining trees in the Routine treatment. Some further deaths were recorded in 1980 by which time it was obvious that the conditions of drought had passed.

Reduction of stand density by thinning generally prevented further mortality in the developing stands in both the Routine and Heavy thinned treatments. Mortalities continued in the unthinned treatment. This was particularly so in 1986. At Karakin in 1993 mortality was noticed as severe by a partial measurement when approximately a further 100 s ha^{-1} were dead in the unthinned stands on the upper and lower sites.

The mortalities in the 1976-80 drought are of importance in that they record a severe drought sequence of relevance to plantation planning and management. They also show the impact of increasing stand density on stand health with stand development (Butcher 1979).

Examination of deaths and stand factors by subset regression showed significant effects for Location and stem numbers in 1977. The Location effect was due to concentration of deaths earlier in the drought at the driest more northern sites, Karakin and Wabling (Table 10). For the mortalities in 1978 significant associations with Location, stem numbers, thinning and Basal area in 1978 were obtained, the Location term here referring to a concentration of deaths in the southern plots. No associations with mortality were significant for the 1980 data. For the whole drought 1977-1980, the Location term was no longer significant and deaths were significantly related to stem numbers in 1978, thinning and basal area in 1978 (Table 11).

The only two parameters which were significant in combination in regression association were basal area and thinning treatment.

The regression equation is

Mortality 77-78 = 199 + 11.7 BA78 - 103 Thin class

Predictor	Coef	Stdev	t-ratio	p
Constant	198.61	72.43	2.74	0.008
BA78	11.695	3.255	3.59	0.001
Thin	-103.04	21.18	-4.87	0.000

s = 140.1 R^2 = 45.0% R^2(adj) = 43.6%

Table 11. Best subsets regression for tree deaths in 1977 and 1978 against stocking, density and environmental factors.

Response is Mort1977-78

Vars	R^2	Adj. R^2	C-p	s	Stems 77	Height 77	BA 77	Stems 78	Height 78	BA 78	Location	SITE	Thin	Fert
1	38.7	37.9	10.3	147.08				X						
1	35.9	35.1	14.2	150.33									X	
2	45.0	43.6	3.2	140.14						X			X	
2	43.0	41.5	6.1	142.68				X					X	
3	46.8	44.8	2.7	138.70						X			X	X
3	46.3	44.2	3.4	139.39						X		X	X	
4	48.1	45.3	2.9	137.95						X		X	X	X
4	47.6	44.8	3.6	138.61		X				X			X	X
5	48.4	44.9	4.5	138.50					X	X		X	X	X
5	48.3	44.9	4.5	138.51		X				X		X	X	X
6	49.4	45.3	5.0	138.04	X		X	X		X			X	X
6	49.0	44.9	5.5	138.50		X		X		X		X	X	X
7	50.3	45.5	5.7	137.75	X		X	X		X		X	X	X
7	49.9	45.0	6.3	138.33	X		X	X		X	X		X	X
8	50.5	45.0	7.5	138.43	X		X	X	X	X		X	X	X
8	50.5	45.0	7.5	138.43	X		X	X		X	X	X	X	X
9	50.8	44.6	9.0	138.95	X		X	X	X	X	X	X	X	X
9	50.8	44.6	9.0	138.95	X	X	X	X		X	X	X	X	X
10	50.8	43.8	11.0	139.93	X	X	X	X	X	X	X	X	X	X

Basal area is representative of both age and stem numbers. Thinning class is not represented satisfactory by either stem numbers or basal area in the above association as thinning in the previously unthinned treatment 2 (Routine), after initial mortalities were observed in 1977, reduced its basal area to below that of the heavily thinned treatment resulting in few further deaths. Hence the Routine treatment suffered heavy mortality in 1977 but relatively few in 1978.

Table 12. Number of years out of 100 in which drought duration exceeds specified periods.

Locality	Duration of drought in months						
	3	4	5	6	7	8	9
Perth	100	99	90	65	16	1	0
Yanchep	100	97	90	83	41	14	0
Cowalia	100	100	91	90	48	18	2

Water Balance - Butcher (1979) provides details of precipitation, evaporation and evapotranspiration up to 1977. A more recent and detailed treatment of rainfall variation the region is contained in Butcher 1986. Rainfall was measured at the Karakin and Wabling sites from January 1967 to December 1979. It was not measured over the whole period at Haddrill as continuous weather data was available at the nearby Yanchep National Park. For the period of comparison Karakin precipitation was 91 per cent of Yanchep and Wabling was 96.1 per cent of Yanchep. The differences in the drought exposure for the area in question calculated by the Commonwealth Bureau of Meteorology (1966) presented by Butcher (1979) is depicted in Table 12. The northern site Cowalia is 10 km north east of the Karakin plots.

Figure 7 relates the rainfall pattern at Yanchep with soil water depletion in unthinned and thinned plots at Karakin. Soil water deficit at depth occurred whenever the annual precipitation equalled or fell below the long term mean value. Drought was a progressive build up of 2 or more such annual rainfall events and led to almost continual soil moisture deficit at profiles deeper than 4 m, even in the heavy thinned treatment. At the more southern, wetter Haddrill plot the heavy thinned treatment was generally free of cumulative soil moisture deficits except in the 1976-1977 and 1985-1986 periods (Fig. 6).

Stand density - Stand density was reduced from the unthinned control in the Routine (ages 10 and 18 years) and Heavily thinned (ages 6, 10 and 18 years) treatments. In most years water is limiting to stand growth and it was thought that fertiliser effects may have been more pronounced in the heavily thinned stands. Significant thinning by fertiliser interaction was not detected for either growth or mean annual increment of the select stand. For the whole stand (Fig. 3) the interaction between Location and Thinning showed no indication of improved growth under heavy thinning but, as explained above, was the result of high mortality in the N+P treatment. Increased space from thinning in the trial thus gave no advantage to fertiliser response in either the select stand or the whole stand (Figs. 3 and 5).

The degree of stand release from lowered stand density associated with the thinning treatments and its impact of reducing moisture stress in the residual stand is reflected in the record of final crop height. Improved height development was detected at age 7 years in the heavy thinning treatment (Tables 4, 5 and Fig. 1) soon after the first release of the treatment to 750 s ha^{-1} at age 6 years (1973). With the release of the Routine treatment at age 10 years (1977) and the further release of the Heavy thinned treatment at age 13 years (1980) the height growth advantage continued in accord with the degree of release. Height increment data (Fig. 1) separate an early height advantage for the Heavy treatment at all Locations, response of height growth in the Routine treatment following thinning at age 10 years and the continuing advantage of the Heavy treatment with successive reductions in stand density.

Height growth is generally considered to be independent of stand density (Carmean 1975, Spurr 1953) but in exceptional cases of high density and drought stress (Lanner 1985, Vanclay and Henry 1988) may be depressed with high stand density. The depressed height growth during periods of soil moisture deficits is directly the result of water stress associated with stand density. At Gnangara with stands favoured by water tables, stand density had no association with height increment even in the 1976-1980 drought period. In the Basal Area Control trial (Hopkins 1971, Butcher 1977, Butcher and Havel 1976) for stands planted in 1954 in the proximity of the Haddrill plot, height growth decreased with increasing stand density only during the 1976-1980 drought.

Drought mortality was common after age 12 years in all but heavily thinned stands. Deaths in the young pilot trials were within unthinned stands with a stocking of the order of 2000 s ha^{-1} and were associated with stand densities of 14.5 m^2 ha^{-1} at Karakin in 1977 and 18-19 m^2 ha^{-1} at Wabling and Haddrill in 1978. Mortalities in the pilot plots after the 1976-1978 drought were largely associated with stand densities of 30 m^2 ha^{-1} or more. The inability of the Locations of the pilot plots to provide adequate moisture for optimum pine growth, even outside the record drought period, is obvious.

Fertiliser effects. - Butcher (1979) reported the early development of the trial to age 11 years. Response to fertiliser applied at stand age 6 years, in particular phosphorus and nitrogen, was significant in the first two years but this was not prolonged. To age 11 years he concluded that addition of phosphorus fertiliser had no positive effect on stand development and growth increase due to the addition of nitrogen and phosphorus was slight. He suggested that fertiliser addition may be more relevant to the stands at medium and mature ages.

For the Haddrill and Wabling sites a significant (.05 level) response to the second fertiliser addition at stand age 13 years was measured in the 13-15 year increment period (Table 7). Thereafter there was no significant fertiliser influence on growth observed. For the northern Karakin trial both phosphorus and nitrogen and phosphorus treatments significantly improved growth for measurement intervals from age 7 to 18 years. No advantage was shown for the nitrogen addition. Percentage improvements in stand basal area and volume of the treatments over the unfertilised control are summarised in Tables 8 and 13. For all locations to age 22 years it can be expected that response to fertiliser additions of superphosphate at the rate of 750 kg ha^{-1} at age 6 years and 500 kg ha^{-1} at ages 13 and 21 years range from 0 to 10 per cent at the southern locations and 10 to 20 per cent at the northern location. Nitrogen was not effective and it is expected from associated work that applications of urea would have to exceed 350 kg ha^{-1} if an effect was to be obtained.

Foliar nutrients

Foliar sampling related to the residual effects from thinning and fertiliser additions up to stand age 8 years and natural site variation. Nitrogen levels measured at age 10 years at Karakin did not vary with plot and treatment and remained high at about

0.9 per cent. It is assumed that this element is not limiting on these sites although it was not possible to examine foliage levels closer to the time of N+P application.

Table 13. Basal area and volumes for fertiliser treatments at ages 13 and 22 years showing the ratio of the N+P and P treatments to the Control. Basal areas (m^2 ha^{-1}) and volumes (m^3 ha^{-1}) are provided for both the whole stand and the select crop at each location.

Location	Fert	BA1980		BA1989		Vol1980		Vol1989	
		m^2	%	m^2	%	m^3	%	m^3	%
		Stand basal area				Stand volume			
Karakin	N+P	16.6	108	21.2	117	62.6	108	124.0	120
	P	17.0	110	22.2	123	64.9	112	130.5	127
	Control	15.4	100	18.1	100	57.9	100	103.1	100
Wabling	N+P	16.6	109	20.6	106	48.2	108	115.7	103
	P	16.9	110	20.7	106	48.0	107	115.1	102
	Control	15.2	100	19.4	100	44.8	100	112.3	100
Haddrill	N+P	16.7	92	18.9	88	53.3	88	118.4	88
	P	16.8	93	20.4	94	56.9	94	126.1	93
	Control	18.0	100	21.5	100	60.0	100	134.3	100
		Select crop basal area				Select crop volume			
Karakin	N+P	2.76	118	6.50	110	10.9	123	39.6	109
	P	2.76	118	7.02	119	11.1	126	43.8	121
	Control	2.33	100	5.89	100	8.8	100	36.2	100
Wabling	N+P	2.32	105	5.52	102	8.1	108	34.6	102
	P	2.33	106	5.59	103	7.6	101	35.4	105
	Control	2.19	100	5.38	100	7.5	100	33.6	100
Haddrill	N+P	2.54	116	5.98	114	10.4	107	39.8	112
	P	2.50	114	5.75	109	10.3	106	37.8	106
	Control	2.18	100	5.24	100	9.7	100	35.4	100

Thinning had no effect on foliar levels of the four nutrients measured at age 8 years. This was also found with fertiliser additions within the Free Growth plots at Gnangara (Hatch and Mitchell, 1971). Different levels due to site were significant for all nutrients at both Karakin and Wabling, P, Zn and Mn decreasing with position upslope while K increased in foliage percentage with position upslope. Nutrient levels did not vary significantly with slope position at the Haddrill, southern location (Table 9). Fertiliser addition produced significantly higher levels in foliar P at all sites and also resulted in an increase in Mn with superphosphate, in the absence of added nitrogen, at Karakin.

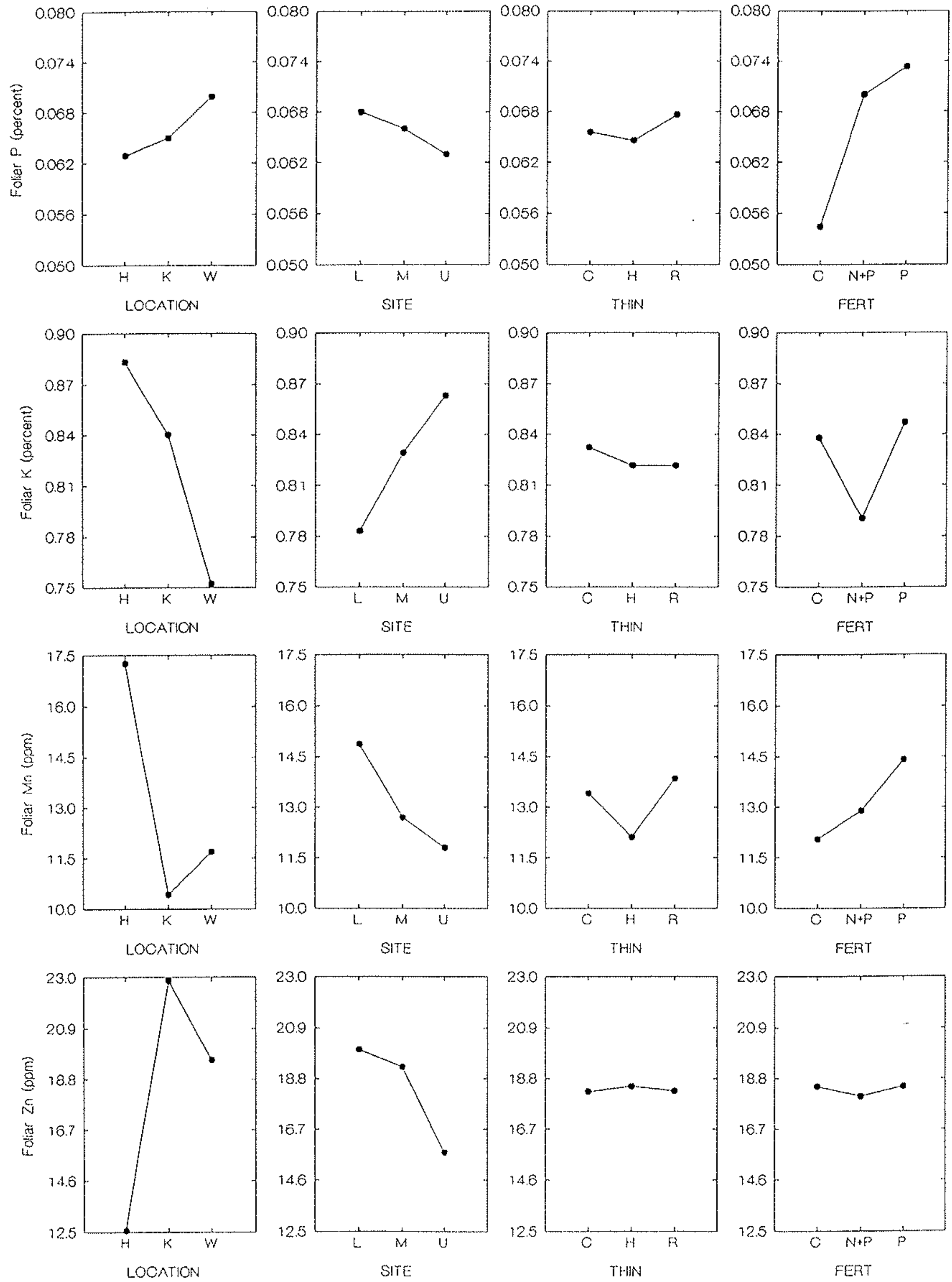

Figure 8. Trend lines of the main effects of foliar nutrient contents for locations, site positions and thinning and fertiliser classes. Foliar sampling was in March 1975 at stand age 7.6 years.

The data were combined in a repeated measures analysis with sites nested within locations to summarise the major effects displayed within foliar samples for the plots (Fig. 8, Table 14).

Table 14. Results of analysis of variance for foliar nutrients sampled on the three pilot plots in 1975. Table values are the probability that F values obtained were due to chance.

		P(%)	K(%)	Zn(ppm)	Mn(ppm)
Source	DF	p	p	p	p
Location	2	0.005	0.000	0.000	0.000
Site(Locat)	6	0.002	0.024	0.000	0.004
Thin	2	0.333	0.842	0.953	0.068
Fert	2	0.000	0.022	0.822	0.010
Locat*Thin	4	0.805	0.277	0.523	0.723
Locat*Fert	4	0.003	0.348	0.518	0.632
Thin*Fert	4	0.643	0.546	0.368	0.607
Loc*Thin*Fert	8	0.107	0.655	0.773	0.320
Error	48				
Total	80				

Analysis of variance of the total data set (Table 14) revealed a significant (.003) interaction for location by fertiliser means for foliar P levels. This was associated with an abnormally high P level for the P treatment (.080 per cent) above the N+P treatment (.069 per cent) at Wabling (Table 9, Fig 8). The two fertiliser additions had similar P levels at the other locations. The most productive location at Haddrill had highest foliar levels of K and Mn but the lowest in P and Zn (Fig. 8). The poorest growth at Wabling appeared to differ mainly from the southern and northern locations through significantly lower K levels (Fig. 8). A general decrease in productivity with progressive site changes upslope was associated in the 1975 foliar samples with increasing levels of K but decreasing levels of P, Zn and Mn. The effect of K contradicts that indicated for Locations i.e. for low foliar K levels to be associated with relatively low productivity.

The lowest K levels recorded are relatively high with respect to values required for satisfactory growth of the species at Gnangara and in other trials at Yanchep.

Butcher (1979) suggested that zinc concentrations were more than adequate in the north and central plots and adequate in the southern plot. Manganese levels although low, were not limiting to growth of *P. pinaster* but additions of this element were necessary for satisfactory growth of *P. radiata* on the limestone soils of the Coastal Plain

Fertiliser levels for foliar P (Fig. 8) are in accord with a productive effect for super as great or greater than that of super + nitrogen. The control (unfertilised) level of .055 per cent is just below the threshold often associated with satisfactory growth for *P. pinaster* in the region (Butcher 1979). N+P addition significantly depressed K levels. Mn levels increased significantly with superphosphate addition, particularly without added nitrogen.

Site effects - Locations were selected to range from the south to central to the north of any expected range for *P. pinaster* planting on the Spearwood Dunes soils of the Swan Coastal Plain north of Perth. Water stress is a known problem in the area and drought stress increased considerably from the southern to the northern location (Table 12). Nutrient deficiency was not found to be major problem to stand growth on these soils. Drought mortality was a serious problem on the three sites from stand age 9 years onwards. Most deaths occurred during the record 1976-78 drought but drought mortality, in the absence of thinning, has been consistent almost every year since. The heavy thinning regime generally prevented further drought mortality within the residual stands (Table 10).

Drought mortality was initially greatest in the southern Haddrill block and in the N+P treatment in which growth potential was greatest of all sites. The high mortality on this site impaired comparison of the N+P treatment at Haddrill with those of the other Locations. Thinning was included in the trial, however, and the fertiliser comparisons, even in the present of drought mortality, must be considered as satisfactory. Stand management in these areas must realise that drought mortality can be a major factor which is aggravated by high basal areas.

Top height means of 16.1. 15.8 and 16.5 m at age 20 years for Karakin, Wabling and Haddrill, respectively, place the sites as equivalent to the average to low pine growth potential assessed for stand development from Yanchep south.

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WP 17/67 - Early application of phosphatic fertilisers on highly leached sands of the Bassendean dune system.

Summary and Conclusions

Superphosphate and rock phosphate fertilisers, singly and in mixture were applied to *Pinus pinaster* established on poor quality, grey sands of the Bassendean Dunes System. The objective was to overcome phosphate deficiencies resulting from leaching from the soil. Initial additions were spot applications at time of planting using the 60 g dose that is standard practice. Both single and double doses of each fertiliser and a mixture were compared, either applied in year 1 or split to apply half at year 1 and half at year 3. The trial was designed as a 3x2x2 factorial within 6 randomised blocks. Unfertilised controls were maintained for three of the blocks.

Best early response was obtained with the superphosphate and rock phosphate mixture which was significantly better than the rock phosphate but not significantly superior to super alone. The double dose was no more effective and in fact the half dose split over 3 years was adequate for the stimulus obtained. Better overall responses may have been obtained if the applications at age 3 years had been broadcast instead of spot applications. The best treatments maintained height growth and volume growth (MAI 1.4 m^3 ha^{-1}) to an index considered unsatisfactory for plantation practice.

Foliar analysis for per cent P at ages 2 and 4 revealed a rapid decrease of the initial phosphate application with time, demonstrating the transitory nature of superphosphate on such sites.

At age 15 years the stands were thinned and further superphosphate was added at a basic dressing of 250 kg ha^{-1} comparing single and double doses and dressings split between year 1 and year 3. Half the treatments were commenced immediately after thinning and half one year after thinning to gauge the effect of stand recovery after thinning on fertiliser response.

Subsequent superphosphate stimulated height growth within a year of application and had a significant effect on CAI for up to 4 years after application. Dosage differences and splitting the Application were not significant but fertiliser additions immediately after thinning were superior to delaying the additions for one year.

The trial provides no effective amelioration for the unsatisfactory pine growth. The poor sites which occur as dune crests or lower slopes within the Bassendean Dunes System have always been considered as unplantable. Considerable areas of similar sites occur however, as flatter areas in the transition region between the Bassendean and Spearwood Dunes systems.

Introduction

A large area of the poorest quality, highly leached sites at Gnangara was cleared for planting. Previous experience suggested that pine growth on similar sites suffered from intense phosphate deficiency which was only partly corrected by applying superphosphate at time of planting. The main problem appeared to be related to the lack of organic matter or any deposition layer in the near surface soil profile to retain added nutrients, which were rapidly leached from the effective profile. It was desirable to see if growth on such sites could be improved by increasing the dose of fertiliser added, by using slower release fertilisers and or splitting the fertiliser application over several years to increase exposure to the tree roots.

Location

The trial was established at Gnangara Plantation (Section G, Compartment 7), in Staley Block in a narrow strip extending from Silver road to the southern boundary of Location 1584. The stand was planted with *Pinus pinaster* at a spacing of 2.4 m x 1.8 m in 1967.

Procedure

Seventy two plots of 30 m x 20 m (0.06 ha) were selected to represent 6 replications of 12 plot treatment units. Uniformity and allocation to blocks were assessed on the 24 trees within a central plot of 11 m x 9.75 m (0.01 ha). Control plots were also selected in Blocks 2, 4 and 6 to provide a total of 75 plots in the trial. The initial fertilisers were applied in August 1970. In 1982 the trial was thinned and redesigned to incorporate later (subsequent) applications of superphosphate. The second phase of measurement was associated with 9 trees remaining per plot (840 stems ha^{-1}).

Design

A - Initial Treatments - The initial trial was designed as a 3x2x2 factorial within 6 randomised blocks. Controls were maintained for three blocks. Treatments were

1. Fertiliser - (i) 60 g per tree of superphosphate.
   (ii) 60 g super + 60 g calcined rock phosphate per tree.
   (iii) 60 g rock phosphate per tree.

2. Quantity - (i) Single dose.
   (ii) Double dose.

3. Application - (i) All applied in 1967.
   (ii) Half dose in 1967 + half dose in 1970.

Foliar analysis - Treatments were sampled and analysed for percentage foliar phosphorus (P) on January 5, 1969 and February 5, 1971.

B. Subsequent Treatments - Following measurement and thinning in

1982 the second set of treatments were installed. Superphosphate was added within a 2x2x2 factorial with three blocks in which the initial three fertiliser treatments were allocated to each cell of the replicates to counter the initial fertiliser differences. Treatments were -

1. Time - (i) First additions in 1982.
   (ii) First additions in 1983.

The different starting times were included to assess whether fertiliser addition was most effective if added immediately after thinning or a year later after crown and root recovery had commenced.

2. Dose - (i) Single dose of 250 kg ha^{-1}.
   (ii) Double dose of 500 kg ha^{-1}.

3. Application - (i) All in year 1 (1982 or 1983).
   (ii) Half in year 1 + half in year 1+3.

The controls were retained for the three blocks but remained unthinned.

Measurement

Initial Trial - Heights were measured in spring 1967, 1968, 1969, 1970, 1971, 1972, 1973 and 1974.

Subsequent trial - Heights and diameter over bark at stem height 1.3 m (DBHob) were measured in August 1982 and in January or February in 1983, 1984, 1985, 1986, 1987, 1988 and 1989.

Analysis

The initial data were examined firstly as a randomised experiment of 12 treatments with 6 replications and the controls with three replications. The control data were then discarded to allow analysis of the 3x2x2 factorial with replication within 6 randomised blocks.

Foliar P data were analysed with the blocks clustered within the two times of analysis.

Data from the subsequent fertiliser treatments were compared as a fully randomised trial with nine treatments to include the controls. The control data were then discarded to allow factorial analysis of a 2 (Time) x 2 (Dose) x 2 (Application) factorial with three randomised blocks and three replications randomised within each block. Replications were clustered within each year of the Time of starting for analysis.

Results

A. The Initial Trial. - Means for current annual increment (CAI) for the 13 treatments are compared in Figure 1 for yearly periods and 3, 5 and 7 year intervals. The later intervals are necessary to compare the impact of the two application levels.

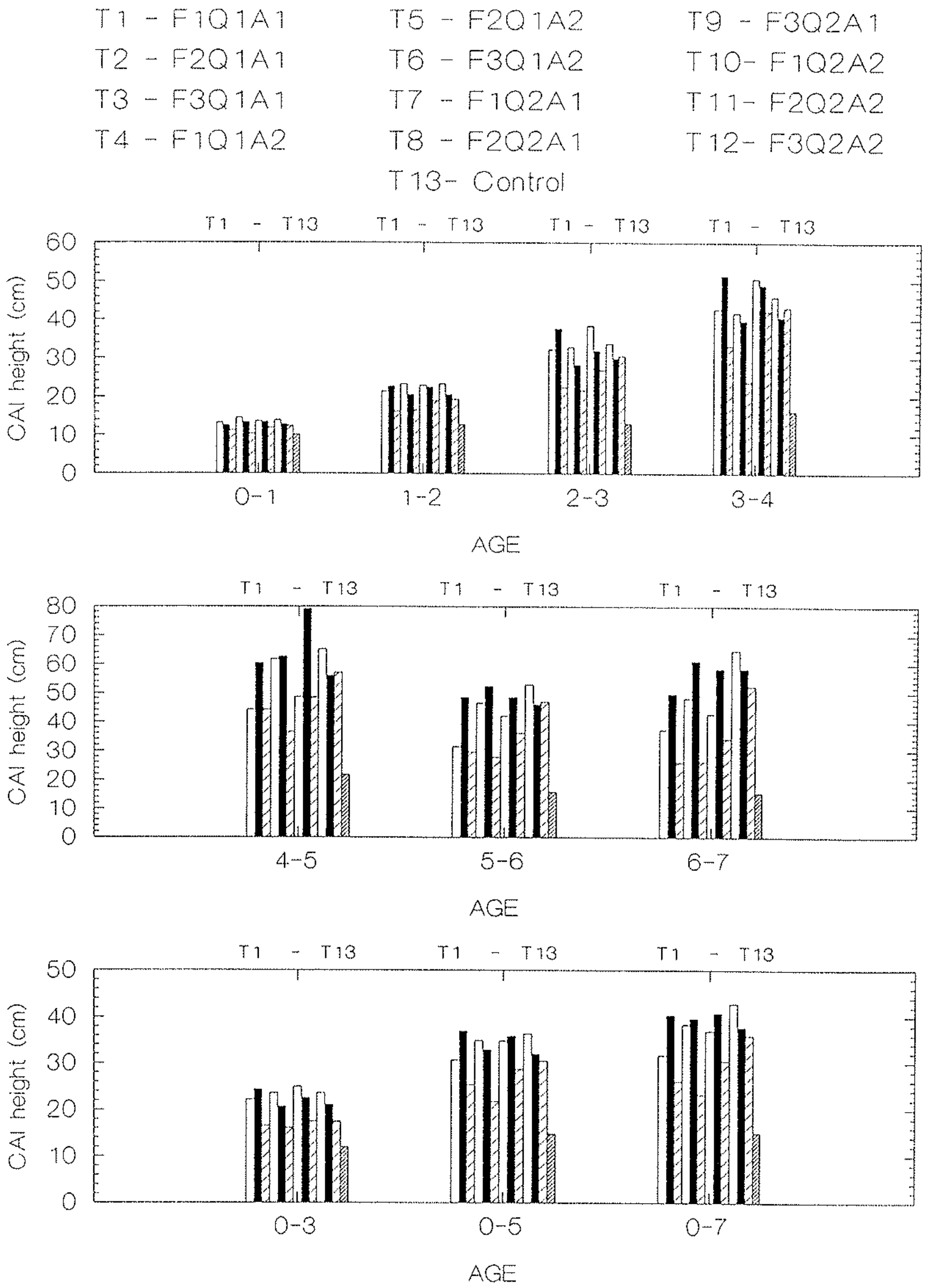

Figure 1. Current annual increment of height for treatments and controls for the initial seven years of the trial. Treatments are arranged in order from the left to the right for each measurement interval.

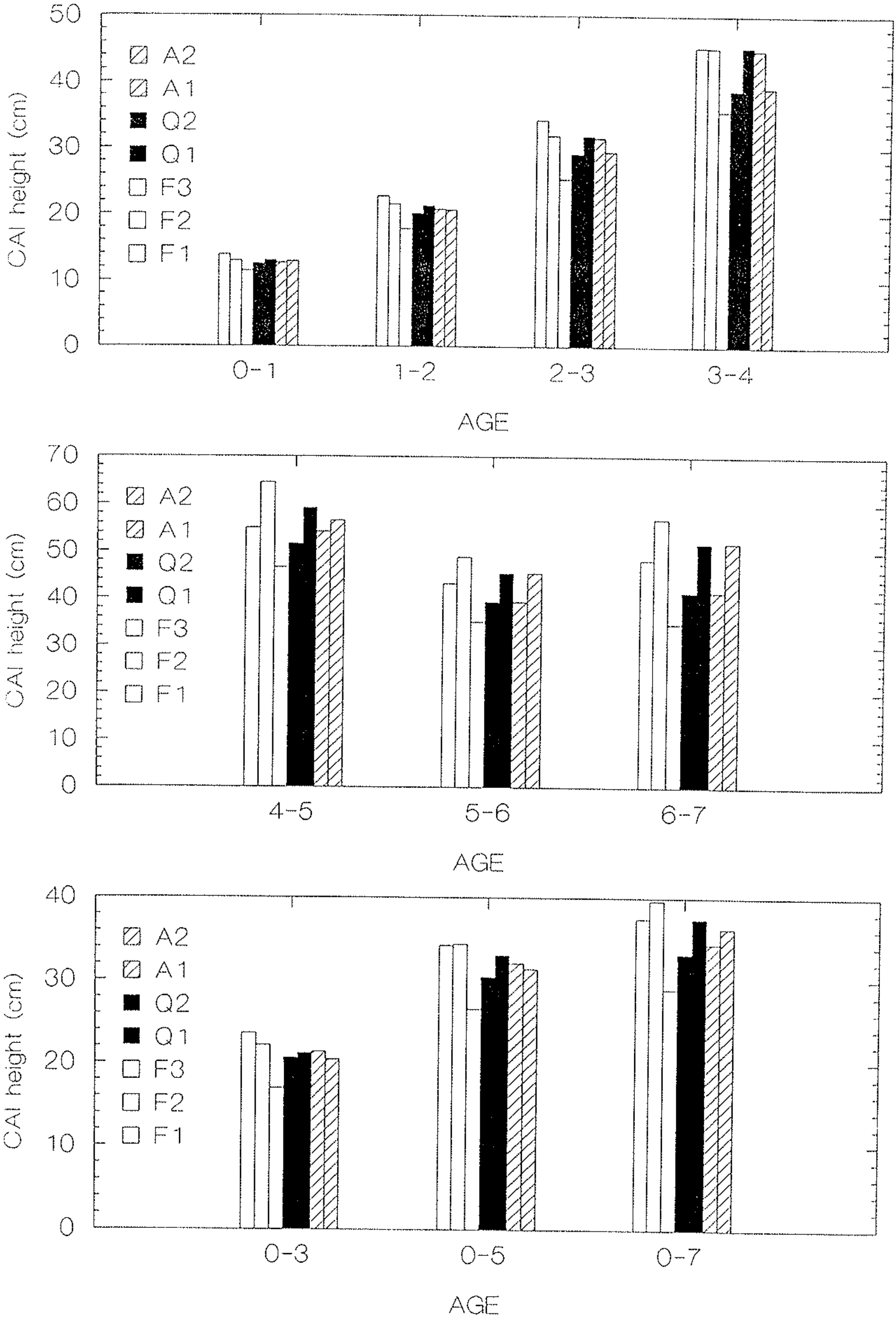

Figure 2. Current annual increments in height of the main effects for different measurement intervals.

Table 1. Probabilities that differences in treatment and replication means for current annual increment for height of treatments (including the controls) occurred by chance.

Increment Period		67-68	68-69	69-70	70-71	71-72	72-73
Source	DF	Probability					
Treatment	12	0.003	0.000	0.000	0.000	0.000	0.000
Replication	5	0.012	0.000	0.008	0.012	0.478	0.066
Error	57						
Total	74						
Increment Period		73-74	67-70	67-71	67-72	67-73	67-74
Source	DF	Probability					
Treatment	12	0.000	0.000	0.000	0.000	0.000	0.000
Replication	5	0.049	0.027	0.002	0.007	0.017	0.043
Error	57						
Total	74						

Treatment effects were highly significant for all measurement intervals (Table 1). For year 0-1 treatment 4 (superphosphate) was significantly better (.03 level) than treatments 6 (rock phosphate) and the control. For year 1-2 treatments 1, 4, 7 and 10 (super) and 2, 5, 8 and 9 (super + rock phosphate) were highly significantly better than the control. Calcined rock alone (treatment T3) was significantly less than T2 and T7 and T6 was less than T10. With trial development, significantly superior height growth was maintained over the controls by the super (T1, T4, T7, T10) and super + calcined rock phosphate (T2, T5, T8, T11) treatments. The double dose of rock phosphate alone (T9, T12) was also better than the control from age 2 onwards while increment from the single dose of rock phosphate (T3, T6) was significantly less than the double dose of super + rock phosphate (T8, T10, Fig. 1.). Most P additions were superior to the control with the super + rock phosphate treatments performing best of all. Over the 7 year period of growth the double dose showed no advantage over the single dose and splitting the application over two years appeared to have the same effect as a single application.

Means for the main effects of the factorial arrangements of treatments without the control are compared in Figure 2. Significance of mean differences are summarised in Table 2. The fertiliser effect was highly significant throughout the trial with the super and the super + rock phosphate being better than the calcined rock phosphate. For the first five years these later two treatments had similar effects. From age 5 years the super effect decreased to the 0.05 level of significance better than the calcined rock while the super + rock mix maintained the highly significant difference with the calcined rock. The super alone effect hence decreased after about 4 years while P from the rock phosphate became available to the trees after about 5 years.

Table 2. Probabilities obtained from analysis of variance of current annual increment in height that differences between means of main effects and interaction occurred by chance.

Increment Period		67-68	68-69	69-70	70-71	71-72	72-73
Source	DF	Probability					
Fertiliser	2	0.000	0.000	0.000	0.002	0.002	0.001
Quantity	1	0.279	0.113	0.116	0.010	0.068	0.032
Application	1	0.654	0.845	0.222	0.024	0.558	0.032
Replication	5	0.031	0.000	0.006	0.011	0.476	0.036
F*Q	2	0.367	0.216	0.110	0.053	0.669	0.053
F*A	2	0.655	0.164	0.223	0.437	0.024	0.179
Q*A	1	0.654	0.784	0.523	0.499	0.664	0.895
Error	57						
Total	71						
Increment Period		**73-74**	**67-70**	**67-71**	**67-72**	**67-73**	**67-74**
Source	DF	Probability					
Fertiliser	2	0.000	0.000	0.000	0.000	0.000	0.000
Quantity	1	0.008	0.481	0.049	0.044	0.032	0.014
Application	1	0.007	0.265	0.043	0.593	0.765	0.266
Replication	5	0.035	0.016	0.002	0.003	0.008	0.022
F*Q	2	0.316	0.556	0.135	0.085	0.060	0.080
F*A	2	0.495	0.399	0.282	0.093	0.095	0.138
Q*A	1	0.432	0.957	0.713	0.687	0.736	0.614
Error	57						
Total	71						

The double dose effect in the Quantity factor was significantly better than the single dose from about age 4 onwards (Fig. 2, Table 2). The Application factor had variable effect, generally non-significant, depending on proximity of measurement to the last application. By age 7 years response to the half dose at age 0 years was significantly less than the all applied at age 0 years. The situation was reversed with the application of the second level in 1970 to become highly significantly superior to the single application by age 6-7 years(Fig. 2, Table 2). Collectively, however, the Application factor was only significant for increment over the 1 to 4 year time period (Table 2).

The measurement at age 15 years in 1982 for the stand marked for thinning to 840 stems ha^{-1} stocking (Fig. 3) provided further opportunity to assess the residual effects of the added fertiliser. The double dose, double application of phosphate rock (T12) produced one of the better effects. Analysis of the treatments and control by the General Linear Model however, did not show a significant treatment effect. Analysis of the balanced factorial, gave a highly significant response for the fertiliser main effect (Fig. 4, Table 3), due to significant improvement of the super + rock phosphate mixture (level 2) over

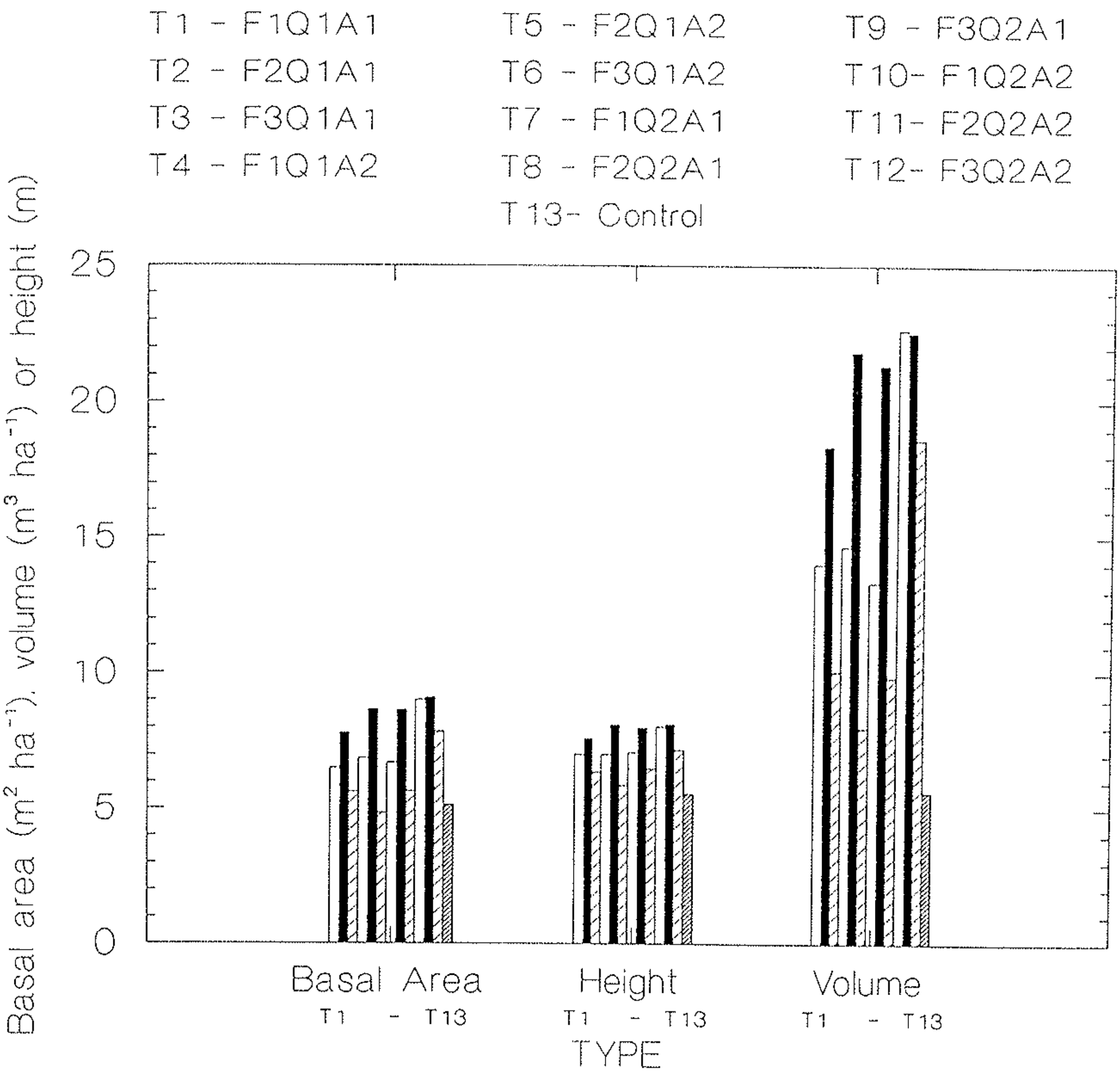

Figure 3. Treatment means for basal area, height and volume of the stands marked for thinning in 1982. Treatments with the same fertiliser type have the same fill for recognition.

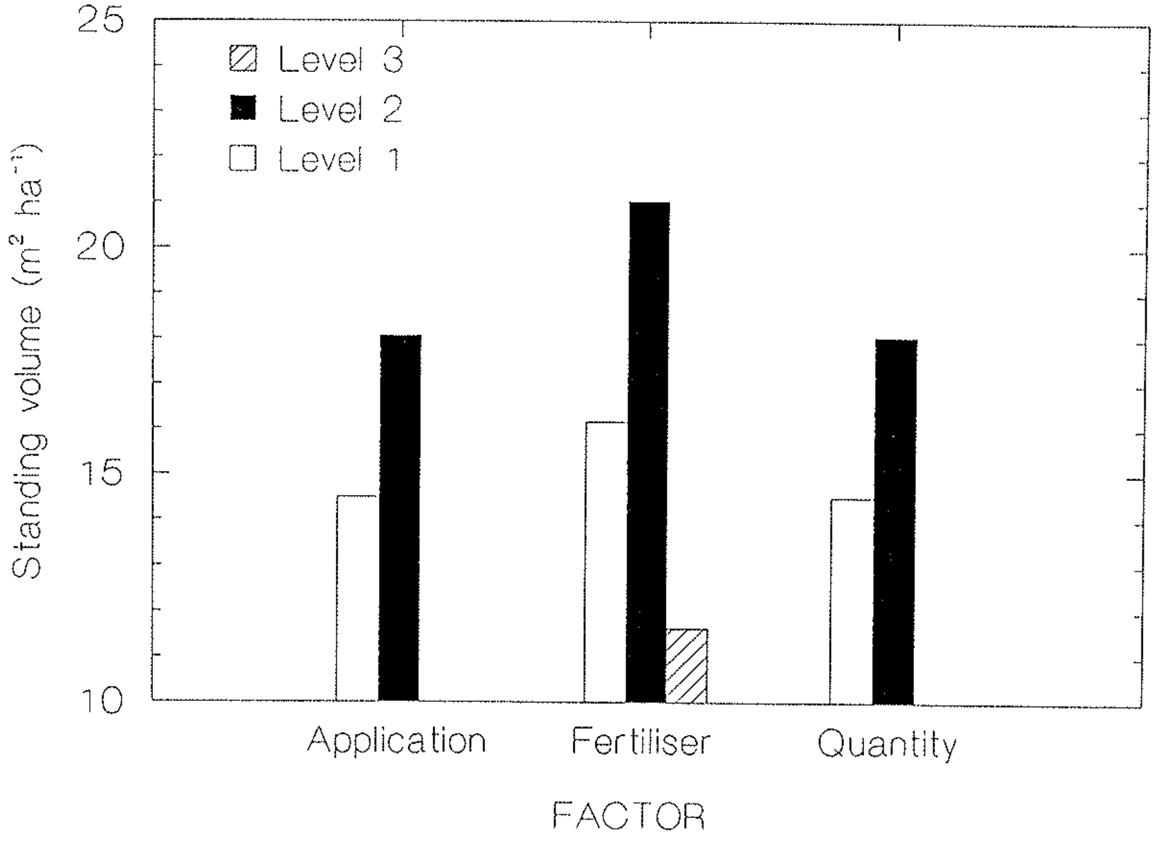

Figure 4. Main effects for Application, Fertiliser and Quantity factors for mean volume of the thinned stand at age 15 years (1982).

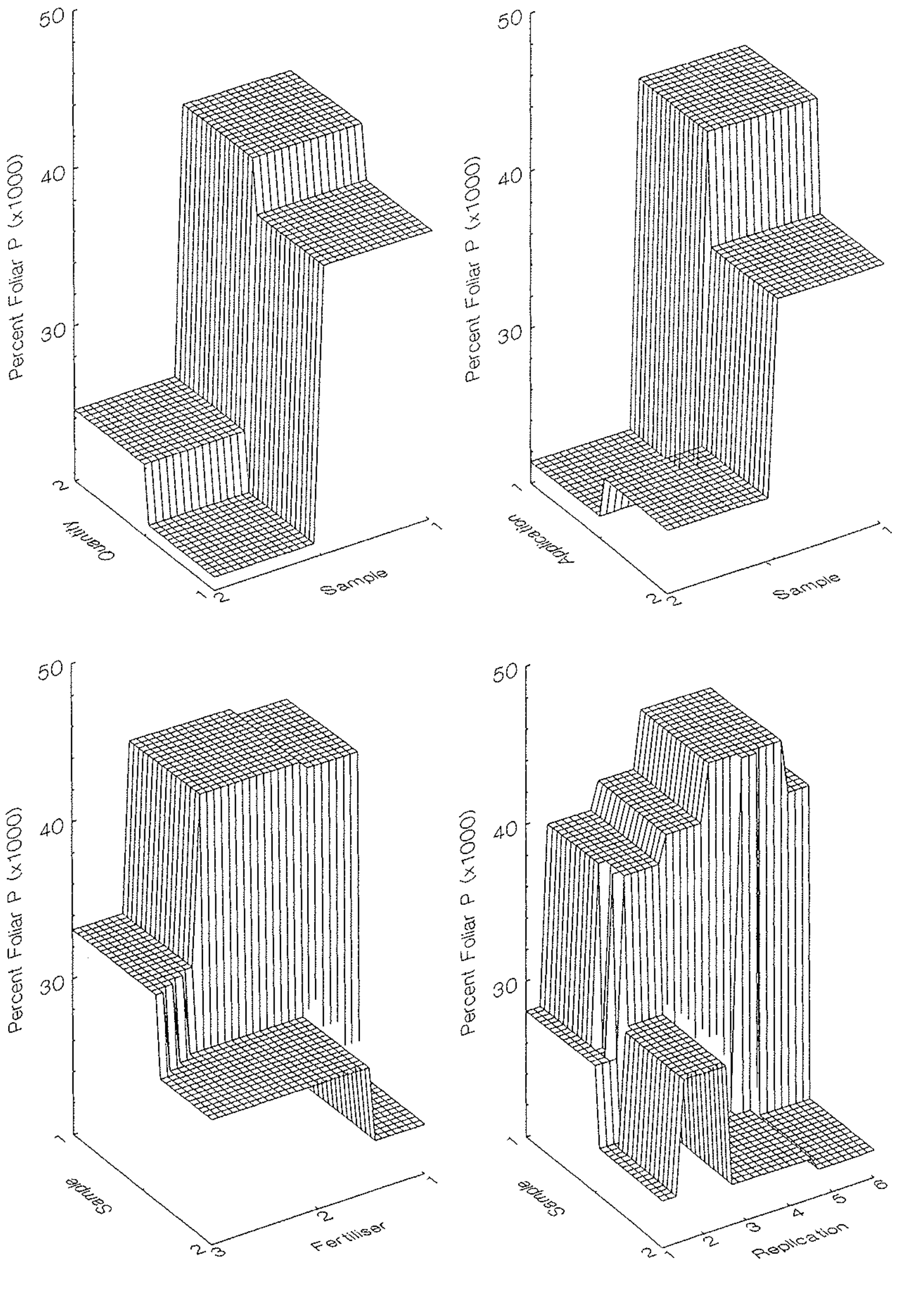

Figure 5. Diagrams of interactions of main effects with sampling to show the decreasing foliar P values between the sample 1 at 2 years and sample 2 at 4 years.

the rock phosphate treatment (level 3). The super alone treatment was not significantly different to the rock phosphate and level 2 was not significantly different to level 1. Hence, the fertiliser effect remained highly significant in the thinned standing crop in 1982 at age 15 years while neither the Quantity nor Application factors left a significant mark on the stand (Table 3).

Table 3. Results of analysis of variance of original treatments prior to redesigning the trial and applying the subsequent fertiliser treatments. The probabilities are for the differences between means to occur by chance.

		BA1982	VOL1982	SCHT1982
Source	DF	p	p	p
Fertiliser	2	0.006	0.007	0.001
Quantity	1	0.082	0.135	0.119
Time	1	0.153	0.134	0.334
Replication	5	0.013	0.009	0.001
Fert*Quant	2	0.847	0.843	0.800
Fert*Time	2	0.888	0.897	0.890
Quant*Time	1	0.229	0.227	0.350
Error	57			
Total	71			

Foliar analysis. Means for foliar analysis showed a dramatic reduction in foliar P between the first sample at age 2 years and the second sample at age 4 (Table 4). Data were transformed to natural logarithms for analysis. For the two measurements Fertiliser and Quantity main effects were highly significant while Application was not significant (Table 5). Highly significant interactions for Sample x Application and Sample x Replication are plotted in Figure 5. The per cent P of the first application level was highest in the 1969 sample 1. By the time the 1971 sample was taken most of the P applied in 1967 had leached from the system. For the second application level the split application in August 1970 had stimulated the foliage by the February sampling date.

B. The Subsequent Treatments. The controls were not thinned along with the treatment plots and height was the only valid parameter which could be compared with the control situation following the 1982 treatments. Results for CAI in select crop height of the 8 treatments plus control are summarised in Figure 6. No significant treatment effect was observed in the first year following fertiliser addition (Table 6), the effects of treatment were highly significant in the 1983-85

Table 4. Means for the main effects and first order interactions of percentage P assessed by foliar analysis of treatments in 1969 (S1) and 1971 (S2).

Fertiliser			Quantity			Application			Sample			Block		
F	N	%P	Q	N	%P	A	N	%P	S	N	%P	B	N	%P
1	48	0.033	1	72	0.029	1	72	0.032	1	72	0.040	1	24	0.025
2	48	0.035	2	72	0.033	2	72	0.030	2	72	0.022	2	24	0.034
3	48	0.025										3	24	0.031
												4	24	0.032
												5	24	0.032
												6	24	0.031

F x Q				F x A				F x Sample			
F	Q	N	%P	F	A	N	%P	F	S	N	%P
1	1	24	0.030	1	1	24	0.034	1	1	24	0.043
1	2	24	0.036	1	2	24	0.031	1	2	24	0.023
2	1	24	0.033	2	1	24	0.036	2	1	24	0.043
2	2	24	0.038	2	2	24	0.035	2	2	24	0.027
3	1	24	0.025	3	1	24	0.026	3	1	24	0.033
3	2	24	0.025	3	2	24	0.023	3	2	24	0.017

Q x A				Q x Sample				A x Sample			
Q	A	N	%P	Q	sample	N	%P	A	S	N	%P
1	1	36	0.030	1	1	36	0.038	1	1	36	0.043
1	2	36	0.028	1	2	36	0.020	1	2	36	0.021
2	1	36	0.034	2	1	36	0.041	2	1	36	0.036
2	2	36	0.031	2	2	36	0.024	2	2	36	0.024

Table 5. Repeated measures analysis of foliar data for percentage P (x1000) of treatments in January 1969 and February 1971. The log transform was used for analysis.

Source	DF	SS	MS	F	p
sample	1	12.38080	12.38080	301.28	0.000
Repl (sample)	10	3.00491	0.30049	7.31	0.000
Fertiliser (F)	2	3.47949	1.73974	42.34	0.000
Quantity (Q)	1	0.48747	0.48747	11.86	0.001
Application (A)	1	0.02816	0.02816	0.69	0.410
sample*F	2	0.22870	0.11435	2.78	0.066
sample*Q	1	0.06412	0.06412	1.56	0.214
sample*A	1	0.51630	0.51630	12.56	0.001
F*Q	2	0.23579	0.11790	2.87	0.061
F*A	2	0.09576	0.04788	1.17	0.316
Q*A	1	0.00480	0.00480	0.12	0.733
sample*F*A	2	0.81174	0.40587	9.88	0.000
sample*F*Q	2	0.01796	0.00898	0.22	0.804
sample*Q*A	1	0.04475	0.04475	1.09	0.299
Error	114	4.68470	0.04109		
Total	143	26.08545			

Table 6. Results from analysis of variance of current annual increment in select crop height for treatments including the controls during the subsequent fertiliser application. The probabilities are that the differences between means were by chance.

Increment Period		82-83	83-85	85-87	87-89	82-87	82-89
Source	DF	Probability					
Treat	8	0.542	0.007	0.005	0.663	0.035	0.025
Block	2	0.085	0.005	0.038	0.852	0.001	0.002
Treat*Block	16	0.338	0.250	0.044	0.454	0.067	0.014
Error	48						
Total	74						

and 1987-89 periods but were again insignificant in the 1987-89 period, five years after application (Fig. 6). Bonferroni tests indicated that for the 1983-85 interval, treatment 1 was the only effective treatment being significantly greater than T5 (.032 level), T8 (.023 level) and the control (.017 level). By the 1985-87 growth interval the treatments which commenced a year later (T2, T4, T6, T8) were fully effective and all except T6 were significantly better than the control. Between treatment differences were not significant. For growth over the 1982-87 and 1982-89 periods treatment 1 was the only significantly different treatment being better than the control (.010 level).

Table 7. Results of analysis of variance for current annual increment in volume for the factorial arrangements of treatments in subsequent fertiliser additions. The probabilities are that the differences in treatments were due to chance. The original three fertiliser level treatments were randomised within blocks.

Measurement interval		82-83	83-85	85-87	87-89	82-89
Source	DF		Probability			
Timing	1	0.262	0.114	0.314	0.274	0.141
Quantity	1	0.258	0.069	0.368	0.288	0.323
Application	1	0.342	0.051	0.684	0.571	0.584
Block	2	0.000	0.000	0.000	0.000	0.000
Timing*Quantity	1	0.590	0.022	0.993	0.895	0.829
Timing*Applic	1	0.912	0.757	0.757	0.948	0.936
Quantity*Applic	1	0.175	0.441	0.110	0.165	0.129
Timing*Block	2	0.667	0.368	0.648	0.932	0.846
Quantity*Block	2	0.162	0.607	0.105	0.200	0.127
Applicat*Block	2	0.123	0.228	0.093	0.109	0.102
Error	57					
Total	71					

CAI for volumes over the measurement period are shown for treatments in Figure 7 and for main effects in Figure 8. No main effect was significant and the Time x Quantity interaction for the 1983-85 growth period was the only significant interaction (Table 7). The interaction resulted from both the single dose (Q1) and double dose (Q1) being equally effective when applied immediately after thinning (T1) while only Q2 was slightly effective when Q1 and Q2 were applied in the second year (T2) after the thinning. Fertilising immediately after thinning (T1) was more effective than fertilising after a year's delay.

Foliar sampling confirmed that the transitory responses to added superphosphate were associated with a rapid increase and decline in foliar phosphate after fertiliser application.

Discussion.

The trial is located mainly on Type G soils (Havel 1976) characteristic of deep, dry, pale grey sands which are strongly leached throughout and occur on lower slopes in the transition zone and slopes and dune crests within the Bassendean Dune

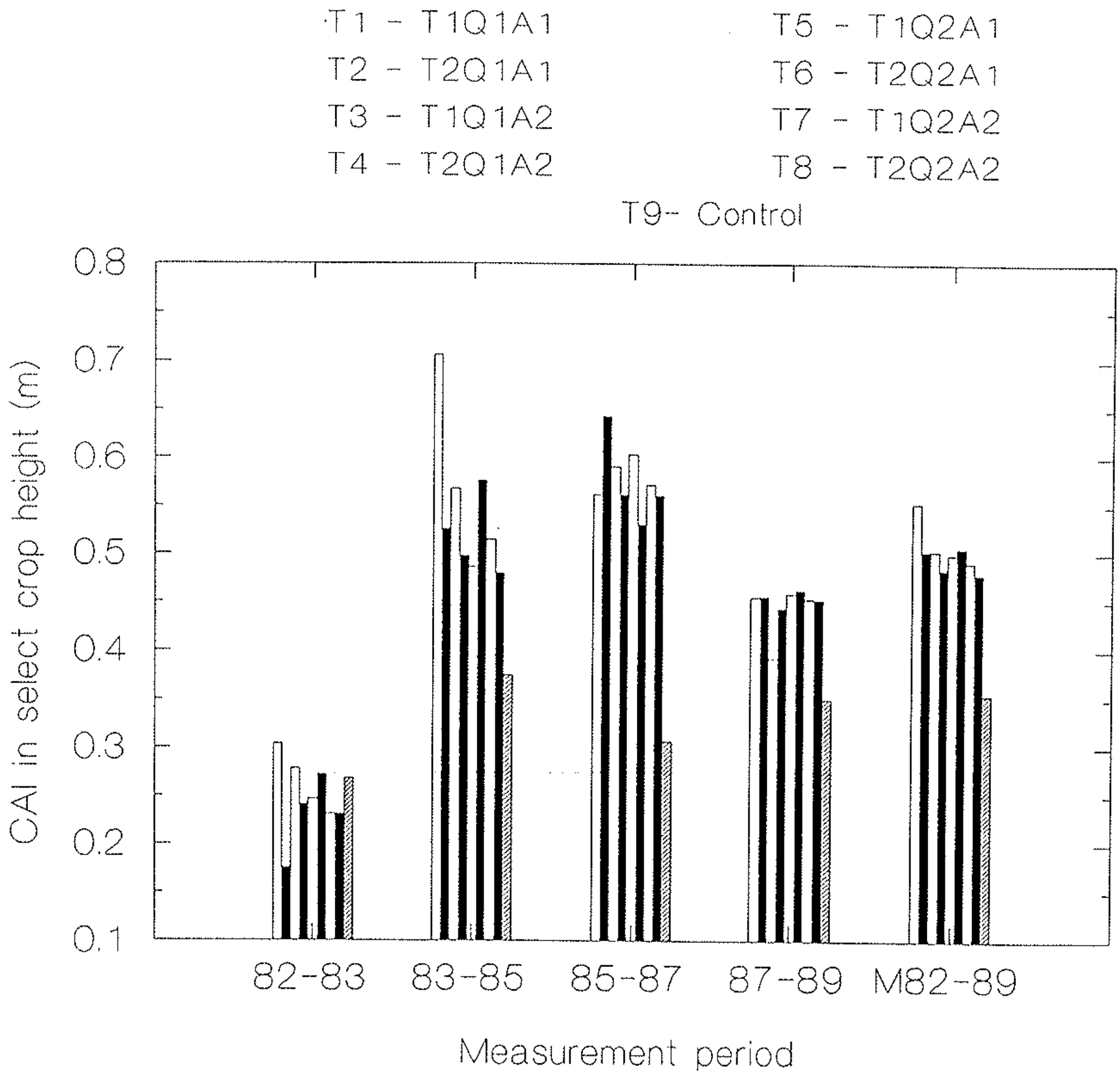

Figure 6. Means for current annual increment in select crop heights (top-height) for treatments and controls within measurement intervals for subsequent fertilisation.

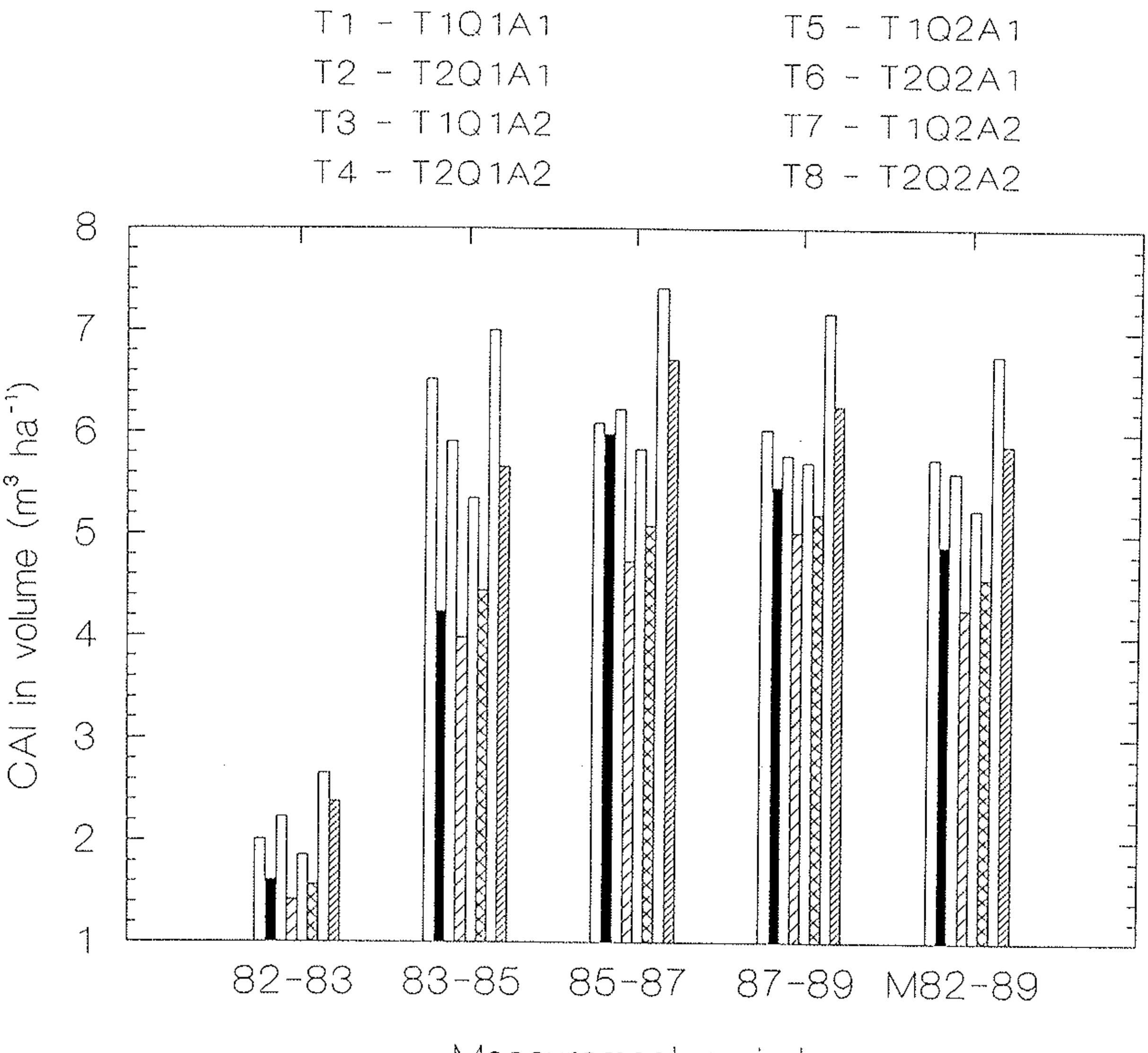

Figure 7. Current annual increment in volume for treatments used in the subsequent fertiliser trial. Treatments with similar fertiliser types are filled similarly to assist comparison.

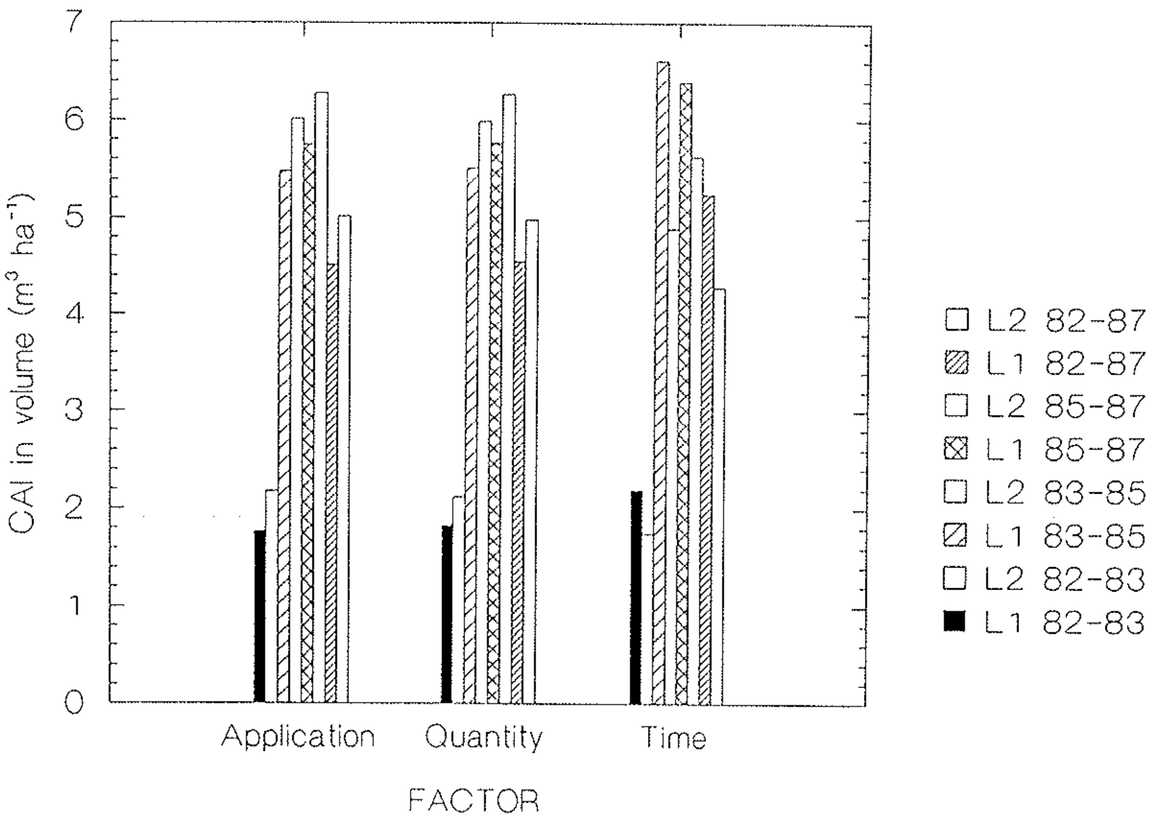

Figure 8. Comparisons of the main effects for current annual increment in volume in the subsequent trial over different measurement intervals

System. The type was planted by default in early plantation establishment and would not be planted today. The experiment aimed at improving the phosphate status of the site and investigating means of overcoming the soils inability to hold applied fertiliser against leaching. To achieve this the usual application of 60 g superphosphate per seedling was added as a single or double dose and this was either applied singly at planting or again at the age of 3 years. A slow release phosphatic fertiliser, calcined rock phosphate was also tested in the same way, either on its own or in combination with superphosphate. Response to further (subsequent) fertiliser with stand development, from age 15 years, was also tested on the same plots after completion of the first measurement series.

Early height growth to age 8 years revealed conclusively that heavy repeated fertiliser during this period had only transitory response of limited magnitude. There was never any evidence or expectation that the sites could be manipulated to produce satisfactory pine growth. The normal 60 g spot addition of superphosphate at time of planting had an immediate and superior response (to the control) which lasted for 5 years (Table 1, Fig. 1) and was neither increased nor extended by doubling the spot dose to 120 g per seedling at planting. Splitting the initial application to 30 g and adding the other half at age three produced no significant difference in growth response to age three but was significantly better than the single application from age 5 to 7 years. Hence it is more effective to apply 30 g at planting and 30 g at age 3 than the normal 60 g at planting, on such sites. Apparently a 30 g dose is adequate to satisfy the site for a single dressing of superphosphate. The split application of the double dose also benefited the stand for a longer period than for a single application.

Single doses of rock phosphate had no significant effect on height growth during the period (Fig. 1) but the double dose at 1 and 3 years (Treatment 12) had a significant effect from age 2 to age 6 years. The mixture of superphosphate and rock phosphate proved to be best of all having a significant effect for the double dose lasting to age 7 years. From age 4 the mixture was more effective than the super alone but was not significantly better over the 7 years of measurement (Fig. 2).

Volumes of the thinned stands at age 15 years in 1982 showed the superphosphate and super + rock phosphate treatments to be 39 and 81 per cent better respectively, than the rock phosphate treatment over the 15 years of growth (Figs. 3 and 4). It should be noted that the control with 840 stems ha^{-1} averaged 7.1 m^3 ha^{-1} with a mean annual increment (MAI) of 0.4 m^3 ha^{-1}. The best fertilised treatment at age 15 years, super + rock phosphate mixture, averaged 21.9 m^3 ha^{-1}, 300 per cent of the control but still only representing a MAI of 1.4 m^3 ha^{-1}. The improvement over the control could be obtained by the single dose of super at time of planting, a fact previously established in the 1930's as required practice for any planting on the grey sands of the Bassendean dunes system (Hopkins 1960). The initial trial showed that the standard fertiliser practice for initial addition of P is as good as any tried for these poor soils.

It is surprising that the split applications of fertiliser in Application were in fact spot applications. Experience (Hopkins 1960) should have indicated that broadcast applications can be expected to be more effective after the first year of establishment. Broadcast repeats of the single dose of super at ages 3, 7 and 11 may have materially improved growth but, as demonstrated with the above MAI's, would still only provide for low production stands.

The subsequent fertiliser additions of varying doses and application times significantly improved height growth over the control, commencing within 18 months of application and continuing for a maximum of 4 years (Fig. 6, Table 6). There were no significant increments in volume growth measured for the

WP 29/71 - Fertiliser and cultural effects on a mature stand in preparation for a second rotation.

Summary and Conclusions

The effects of thinning, an application of superphosphate and urea and repeated light dressings of superphosphate with lupin culture were compared in a 31 year old stand. Comparisons were on the basis of the cumulative girth increment of 5 select trees in each plot.

The heavy fertiliser addition provided up to 38 per cent better growth than the unfertilised control and the effect was up to 20 per cent better for a period of at least 4 years after application. The lighter, repeated, superphosphate dressings were 7 to 12 per cent better than the control and the effect was observed for 4 years. It was not possible to evaluate the separate effect of Nitrogen or the impact of lupin culture beneath the thinned stand.

The most dramatic growth difference between the select trees resulted from thinning. Drought killed four of the five dendrometer trees in the unthinned stand (30+ m^2 ha^{-1}) while only 1 of the 30 dendrometer trees in the thinned stand (<20 m^2 ha^{-1}) succumbed.

Aim - The trial was part of a second rotation study and aimed to compare the effects of fertiliser and several soil preparation methods on final stand development and the potential for developing an effective second rotation crop. Heavy fertiliser additions, removal of slash by burning or rolling and crushing and growing lupins under the heavily thinned stand were considered.

Location - The trial is located in Gnangara Plantation, Sections A75 and A76. The stand was planted in 1942 at 1.8 m x 1.8 m spacing with spot fertiliser additions of 57 g of superphosphate at time of planting and 2 years of age. Superphosphate was broadcast at the rate of 500 kg ha^{-1} at stand age 20 years. At age 26 a further 500 kg ha^{-1} of superphosphate and 120 kg ha^{-1} urea were applied. A first thinning to 750 stems ha^{-1} was carried out at age 17 years and a second thinning to 500 stems ha^{-1} at stand age 26 years. The site is a flat of the Bassendean Dunes System covering good to excellent site quality of Havel types G and H.

Procedure

In 1974 the stands were measured with basal area sweeps and spot heights to select 10 plots of general size 120 m x 60 m (1.92 ha).

Treatments - Treatments compared were the following -

3. An unthinned stand in A76 was included as a control.

4. Thinned to 125 stems ha^{-1} in March 1973 and slash

burned in June 1974.

5. Thinned to 125 stems ha^{-1} in March 1973 and slash crushed in December 1975.

6. Thinned to 125 stems ha^{-1} in March 1973, slash burned in June 1974, fertilised at the rate of 1 ton ha^{-1} superphosphate plus 500 kg ha^{-1} ammonium sulphate in September 1973.

7. Thinned to 125 stems ha^{-1} in March 1973, fertilised at the rate of 1 ton ha^{-1} superphosphate plus 500 kg ha^{-1} ammonium sulphate in September 1973. Slash rolled and crushed in December 1975.

8. Thinned to 125 stems ha^{-1} in March 1973 and fertilised with 230 kg ha^{-1} superphosphate in September 1973. Slash burned in June 1974,and sown with lupin seed plus 230 kg ha^{-1} super, copper, zinc fertiliser in July 1974. Lupins were resown in May 1975 and 1976 with a further addition of 120 kg ha^{-1} super, copper, zinc fertiliser.

9. Thinned to 125 stems ha^{-1} in March 1973 and fertilised with 230 kg ha^{-1} superphosphate in September 1973. Sown with lupin seed plus 230 kg ha^{-1} super, copper, zinc in July 1974. Lupins were resown in May 1975 and 1976 with a further addition of 120 kg ha^{-1} super, copper, zinc fertiliser. Slash was crushed and rolled in December 1975.

Measurement - In September 1974 five final crop trees in each plot were fitted with dendrometer bands at stem height 1.3 m. Dendrometer bands were read at monthly intervals from September 1974 to November 1979.

Results

Plot measurement in September 1974 placed the stand densities of the plots as in Table 1.

Table 1. Stand density in September 1974 of plots used for dendrometer studies.

Plot	Basal Area (m^2 ha^{-1})
3	32.0
4	12.0
5	10.0
6	11.5
7	12.9
8	11.5
9	12.4

The cumulative increment in girth of the five measured trees per plot was calculated for growth years, commencing in October and terminating in September for each year of measurement. Data from plots 4 and 5, 6 and 7 and 8 and 9 were combined and averaged to provide increment traces for an unfertilised control, a heavy N+P fertiliser application and a phosphate fertiliser application with continued lupin cover. The unthinned control was a single plot of almost treble the stand density of the other thinned stands. For each 12 month data set the initial increment was subtracted from the data set to commence each year's trace at zero allowing visual comparisons between treatments within years (Fig. 1) and for each treatment between years (Fig. 2).

For the 1974-75 measurement period the N+P treatment was better than the supered lupin treatment with both superior to the unfertilised treatment (Fig. 1). Girth increment on the best five trees of the unthinned trial was much lower than that of any of the thinned plots. Results in 1975-76 were similar with the exception that there was a depression in girth in February (Fig. 2) for all plots. By October 1977 the effect of the light fertiliser application in 1973 and the subsequent superphosphate dressings in 1974, 1976 and 1976 had ceased. For 1976-77 there was no difference between this treatment and the thinned, unfertilised control (Fig. 1). Growth superiority of the N+P treatment was maintained but at a reduced level. For 1977-78 and 1978-1979 the fertiliser stimulus was absent and there was no difference in radial growth between the three thinned treatments.

Following the apparent reduction in girth in February 1976, all plots registered continuous girth shrinkage from January to May in 1976-77 and 1977-78 . Cumulative growth for the twelve months was lowered in 1977, lowest in 1978 and showed some recovery in 1979 for the thinned plots (Fig. 2). This pattern for girth increment was common to the fertilised plots.

The crowns of the unthinned trees in plot 3 displayed severe drought symptoms from February 1977 but the first mortality in the dendrometer trees was not recorded until June 1977. Four of the five measurement trees had died by September 1977. Drought symptoms were evident in some crowns in the thinned stand but only one dendrometer tree in the six plots involved died. This was in plot 6 and the death was recorded in October 1978. The pattern of mortality in the unthinned control is recorded in the dendrometer traces in Figures 1 and 2.

Discussion.

The relatively large areas required for cultural operation such as burning, rolling and crushing slash and lupin management and the limited area of uniform mature stand available made it impossible to provide this trial with adequate replication for statistical analysis. Considerable effort was made to select comparable plots for treatment and to allow replication within the thinned stand. It also would have been desirable to have commenced the dendrometer measurements after thinning in 1973 so that the initial impact of the fertilisers could be compared. With these obvious deficiencies in mind, the dendrometer traces provide a useful record and comparison of main treatment effects. The similarity of the growth traces of the thinned stands in 1978 and 1979 after treatment effects had ceased (Fig. 1) indicated that the stand comparisons were not biased by initial stand differences.

Fertiliser application - The very heavy N+P fertiliser application in September 1973 produced a superior girth increment in 1975, 1976 and 1977 measurements. The light P fertiliser treatment in 1973 with repeated dressings in 1774, 1975 and 1976 maintained better growth than the thinned, non-fertilised control up to September 1976. The 12 monthly totals measured for treatments are compared in Table 2.

Table 2. Twelve monthly cumulative girth increment for the unthinned control, thinned control, heavy application of N+P fertiliser and superphosphate and lupin treatments. Per cent values are relative to the performance of the thinned control.

	Unthinned		Control		N+P		P+Lupin	
	(cm)	(%)	(cm)	(%)	(cm)	(%)	(cm)	(%)
1974-75	1.540	38	4.090	100	5.626	138	4.560	112
1975-76	1.378	35	3.934	100	5.391	137	4.213	107
1976-77	0.785	28	2.779	100	3.326	120	2.823	102
1977-78	2.100	87	2.407	100	2.451	102	2.423	100
1978-79	-		2.696	100	3.058	113	2.888	107

Fertiliser application had a considerable effect on growth in these mature stands for at least 4 years after application. This period could be longer. The lack of difference between the control and fertilised treatments in 1977-78 in Table 2 may be a result of the drought as the 1978-79 totals suggest a continuing fertiliser effect. This cannot be determined from the trial. It is not possible within the study to assess whether the superior response in the heavy N+P treatment was due to the higher level of superphosphate added, to the urea added or to a P x N interaction. Possible effects of lupin culture on current growth also cannot be separated from added fertiliser.

Drought effects - The period of study from 1977 to 1980 was the worst drought period experienced in the region. Deaths were widespread, particularly in 1977 and 1978, throughout much of the plantation area. A further water stress factor was also operating in the area. The Water Authority had established a bore to the south of the stands studied and was pumping from this source for the city supply. Drought stress was evident in the native vegetation adjacent to the bore as a result of lowering of the water table through pumping. Some pine deaths in stands closest to the bores had been noted and water table studies were implemented within the pine stands to assess the extent of water table lowering and its impact on plantation growth. Both the drought and the water table depression by pumping can be expected to operate in the study area.

Thinning to approximately 13 m^2 ha^{-1} stand density avoided deaths which were extensive in the 30+ m^2 ha^{-1} density of the unthinned stand represented by plot 3. An investigation of the impact of

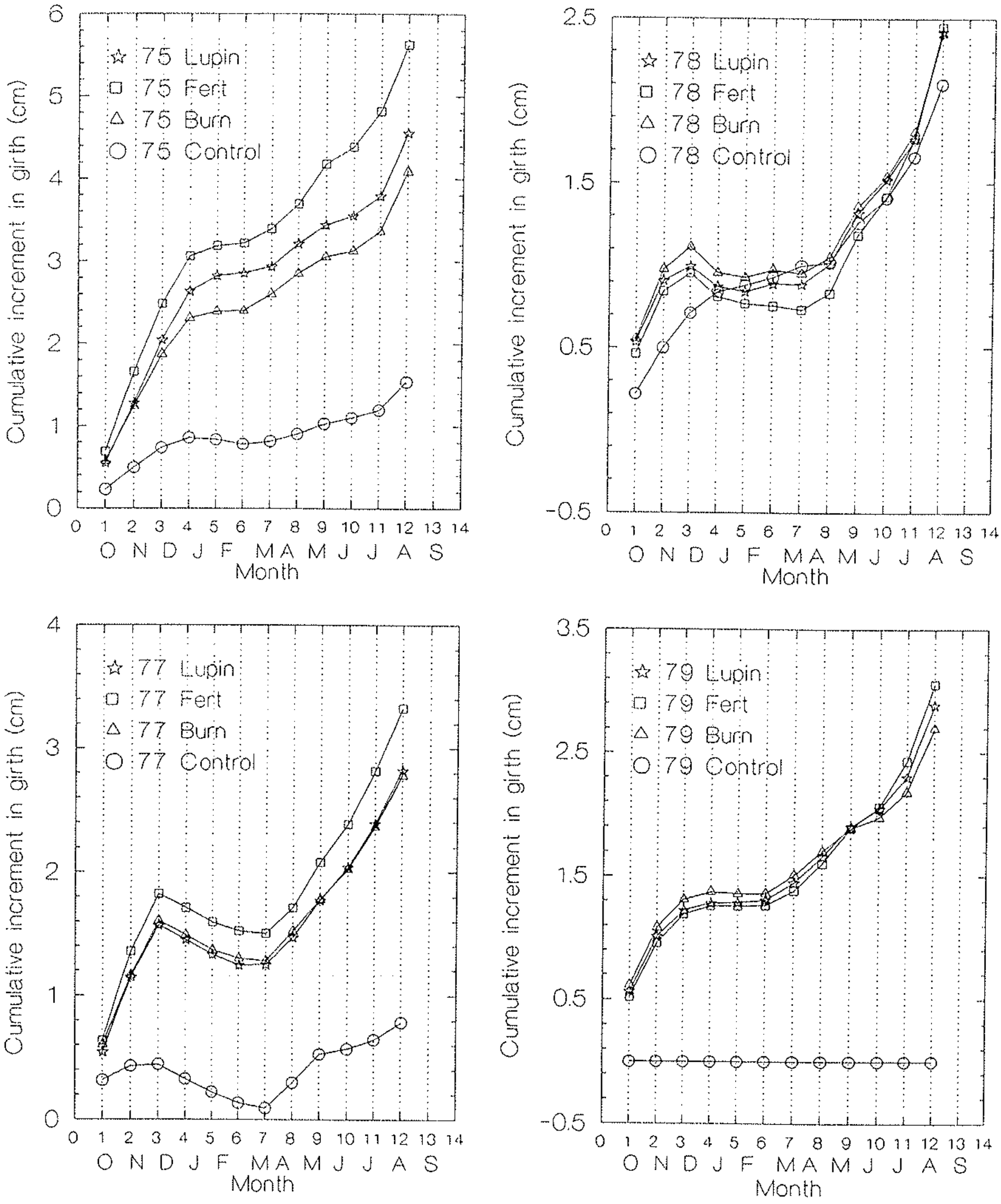

Figure 1. Dendrometer traces of stand treatments for the years 1974-75, 1976-77, 1977-78 and 1978-79. The cumulative girth increment of five trees in each plot was recorded at monthly intervals. The Burn treatment is the thinned control.

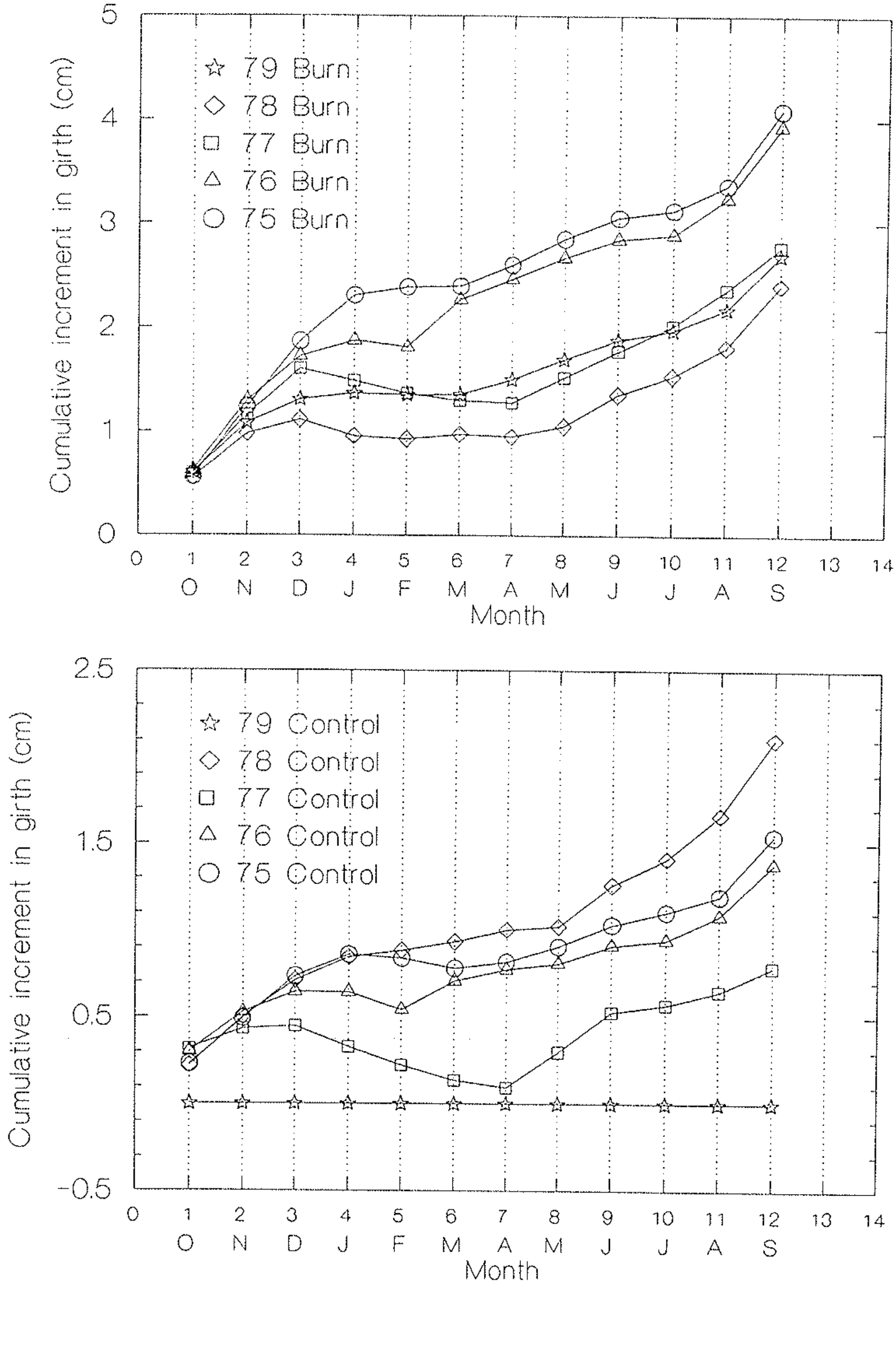

Figure 2. Comparison of cumulative girth increment for the thinned and unthinned controls by 12 monthly periods to show the effect of drought. Four of the five dendrometer trees in the unthinned control were dead by September 1977.

stand density on drought mortality over a range of stand densities in an adjacent trial in stands one year older (WP 15/57) showed that drought mortality was generally absent from all stands with stand densities of 20 m^2 ha^{-1} or less.

The increment trace for the unthinned control in 1977-78 is the growth of the single remaining tree surviving drought. This tree, under the low stand density resulting from stand mortality, grew at a rate equivalent to that of the trees in the thinned stand (Fig. 1) and superior to the stand mean previously recorded (Fig. 2). The continued vigour and rapid response of survivors to the reduction in stand density from drought deaths has been observed as a characteristic of the species on these sites. Survivors seem to have few adverse effects from drought and respond immediately to the thinning provided by surrounding mortalities.

TRIAL YS35 - The Interaction between Varied Fertiliser Application and Genotype.

Summary and Conclusions

The responses of fifteen full sib families of *Pinus pinaster* to superphosphate (P) and ammonium sulphate (N) fertiliser additions were compared on a good site at Gnangara plantation. The families resulted from 3 female parents crossed with 5 male parents.

On the sites sampled a fertiliser regime applying 57 g of superphosphate to the plant at time of planting and 500 kg ha^{-1} broadcast at ages 6 and 8 years was favourable. There was no evidence that broadcast dressings at an earlier age and / or at age 12 could improve on this performance.

The effects of N addition as ammonium sulphate at rates of 250 kg ha^{-1} were small and transitory with no significant effect on the stand at age 21 years.

Responses of full-sib families to applied fertilisers were highly significant. There were no significant interactions between fertiliser and families or between N and P and male and female genotypes. Selection of the top 8 of the 15 families could improve standing volume at age 21 years by 9 per cent.

Table 1. Fertiliser treatments for trial YS35. The amounts are in kg ha^{-1} and refer to superphosphate for P and ammonium sulphate for N. Applications in 1971 and 1973 were spot applications (g $tree^{-1}$), the remainder were broadcast.

Fertiliser		1971 Year0		1973 Year2		1975 Year4		1977 Year6		1979 Year8		1983 Year12	
Code	P N	P	N	P	N	P	N	P	N	P	N	P	N
1	P1N0	57	-	-	-	-	-	500	-	500	-	-	-
2	P1N1	57	-	-	-	-	250	500	250	500	250	-	250
3	P2N0	57	-	-	-	500	-	-	-	-		500	-
4	P2N1	57	-	-	-	500	250	-	250	-	250	500	250
5	P3N0	57	-	57	-	500	-	500	-	500	-	500	-
6	P3N1	57	-	57	-	500	250	500	250	500	250	500	250

Introduction

Trial YS35 was established 1971 with three major objectives:

1. to assess the effect of repeated dressings of fertiliser on stand growth;
2. to assess whether both nitrogenous and phosphate fertiliser elements were favourable to stand development;
3. to assess whether particular parents within the tree improvement program were especially adapted to added nutrients.

The trial was one of a series designed to determine optimum fertiliser regimes for stand growth but had the further development to identify special results which may apply using improved seed from the seed orchards

Treatments

The trial is located in Walton Block at Gnangara Plantation on a good quality site. It was planted in 1971 with tubed stock at 3.3 m x 3.3 m spacing. It has four randomised blocks.

Fertilisers - Three levels of superphosphate (P) and 2 levels of ammonium sulphate (N) were applied at different intervals over the 21 year trial period. The fertiliser treatments are described in Table 1.

Genotypes - Fifteen full-sib families from crossing 5 selected pollen parents with 3 selected female parents (Table 2) were used in the trial.

Table 2. Families and parents used in the trial.

Family	Female Parent	Male Parent
S57	E19	E29
S56	E19	E33
S55	E19	E41
S99	E19	E154
S100	E19	E182
S64	E40	E29
S63	E40	E33
S17	E40	E41
S202	E40	E154
S125	E40	E182
S161	E46	E29
S168	E46	E33
S191	E46	E41
S205	E46	E154
S215	E46	E182

Design - The 15 family groups were planted as single tree plots randomised six times within each treatment sub-plot. Treatment sub-plots were randomly allocated to 6 treatment plots within each of 4 uniformity blocks.

The number of treatment plants involved was 15x6x6x4 = 2160 to provide a (3x5) x (3x2) x 4 factorial within a split plot design.

Each treatment unit was a line plot of 15 progeny at 3.3 m x 3.3 m spacing. Two rows at similar spacing were planted between each fertiliser plot to buffer the effect of added nutrients.

Measurement - Heights were measured in 1975, 1977 and 1980 at ages 3.5, 5.5 and 8.5 years, respectively. The height measurement in 1980 was for two of the four blocks. Diameters were measured in 1980, 1983, 1987 and 1992 at ages 9, 12, 16 and 21 years, respectively.

In March 1977 the current foliage of 3 of the 6 trees for each family per treatment for Block 4 was sampled and bulked. This was analysed for N, P and K.

Soil samples were taken from treatments 6 and 3 in Blocks 3 and 4 for analysis in October 1980. Three profiles were sampled at each location for depth intervals 0-25, 25-50, 50-75, 75-100, 100-125, 125-150 and 150-175 cm.

Analysis - The trial was analysed as a split plot design with the 6 fertiliser plots and 4 blocks having an error term with 15 degrees of freedom. The fertiliser treatments formed a 3x2 factorial. The family treatments formed a 5x3 factorial.

Results

Height - Mean heights of treatments for measurements and measurement intervals are graphed in Figure 1. main effects for fertilisers and the genotypes at ages 4, 6 and 9 years are set out in Tables 3 and 4, respectively.

Table 3. Means for N and P effects for height growth (m) for different measurement and increment periods.

Source		Stand Age (years)					
		4	6	9	4-6	6-9	4-9
	1	3.32	5.96	8.63	2.64	2.78	5.37
P	2	3.43	6.34	8.92	2.90	2.64	5.51
	3	3.56	6.54	8.83	2.98	2.37	5.38
N	1	3.43	6.23	8.86	2.80	2.67	5.46
	2	3.44	6.33	8.72	2.88	2.52	5.38

Height data analysed for standing height at each measurement and for height increment between measurements are summarised in Table 5. The P1 main effect for the standing crop was significantly less than P2 and P3 at ages 4 and 6 years reflecting lack of fertiliser addition to this level at age 2 years (Table 1). Fertiliser addition to P1 at ages 6 and 8 resulted in a catch up with no significant differences in standing diameters at age 9 (Fig. 1, Tables 3 and 5). The effect of fertiliser addition on stand growth resulted in significantly lower growth by P1 during the 4-6 year interval and greater growth (but not significantly so) for this treatment during the 6-9 year period. An N response recorded at age 6 years was significant in the 4-6 year increment period. No significant P x N interactions were recorded by height measurement.

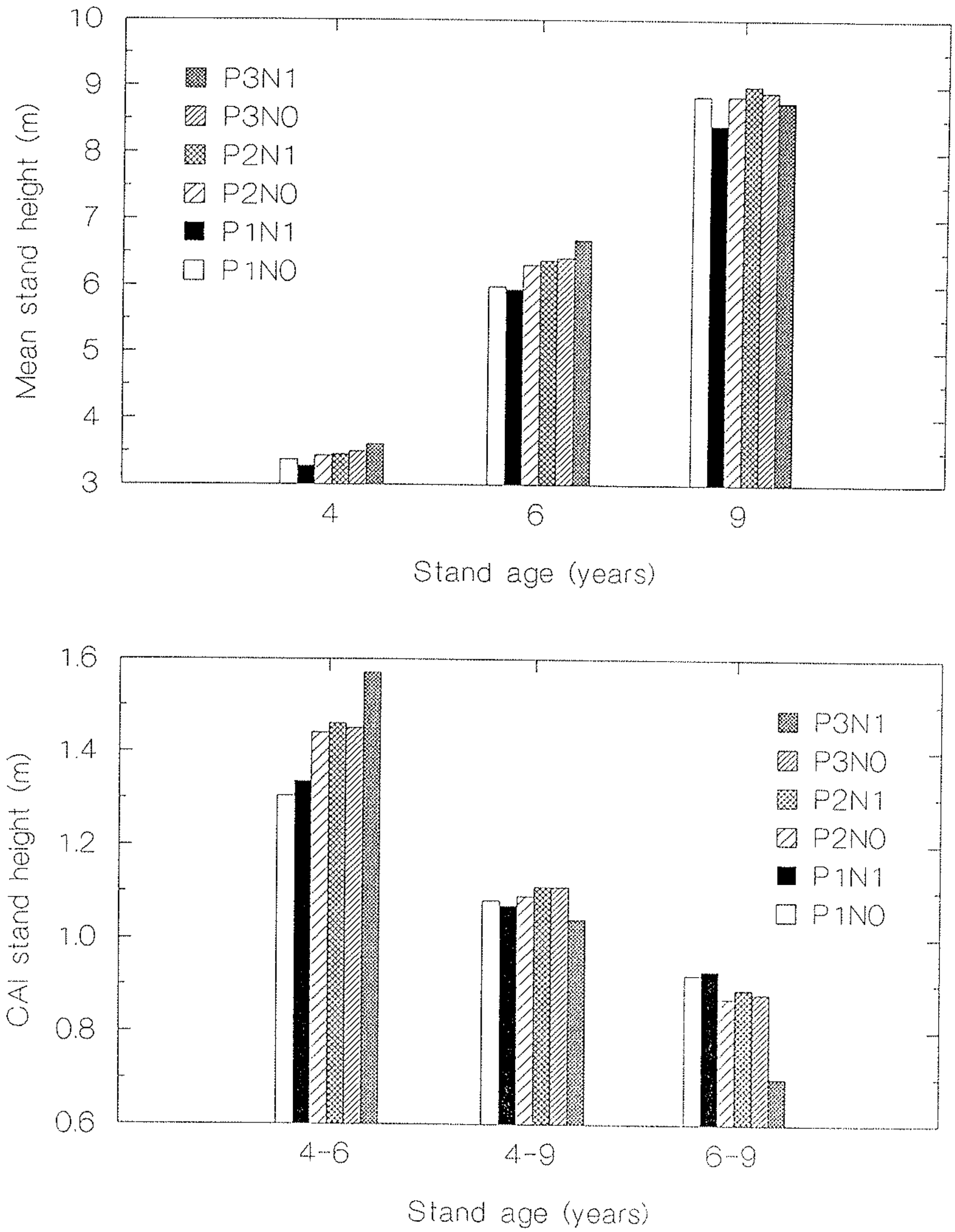

Figure 1. Means for height growth within fertiliser treatments at ages 4, 6 and 9 years.

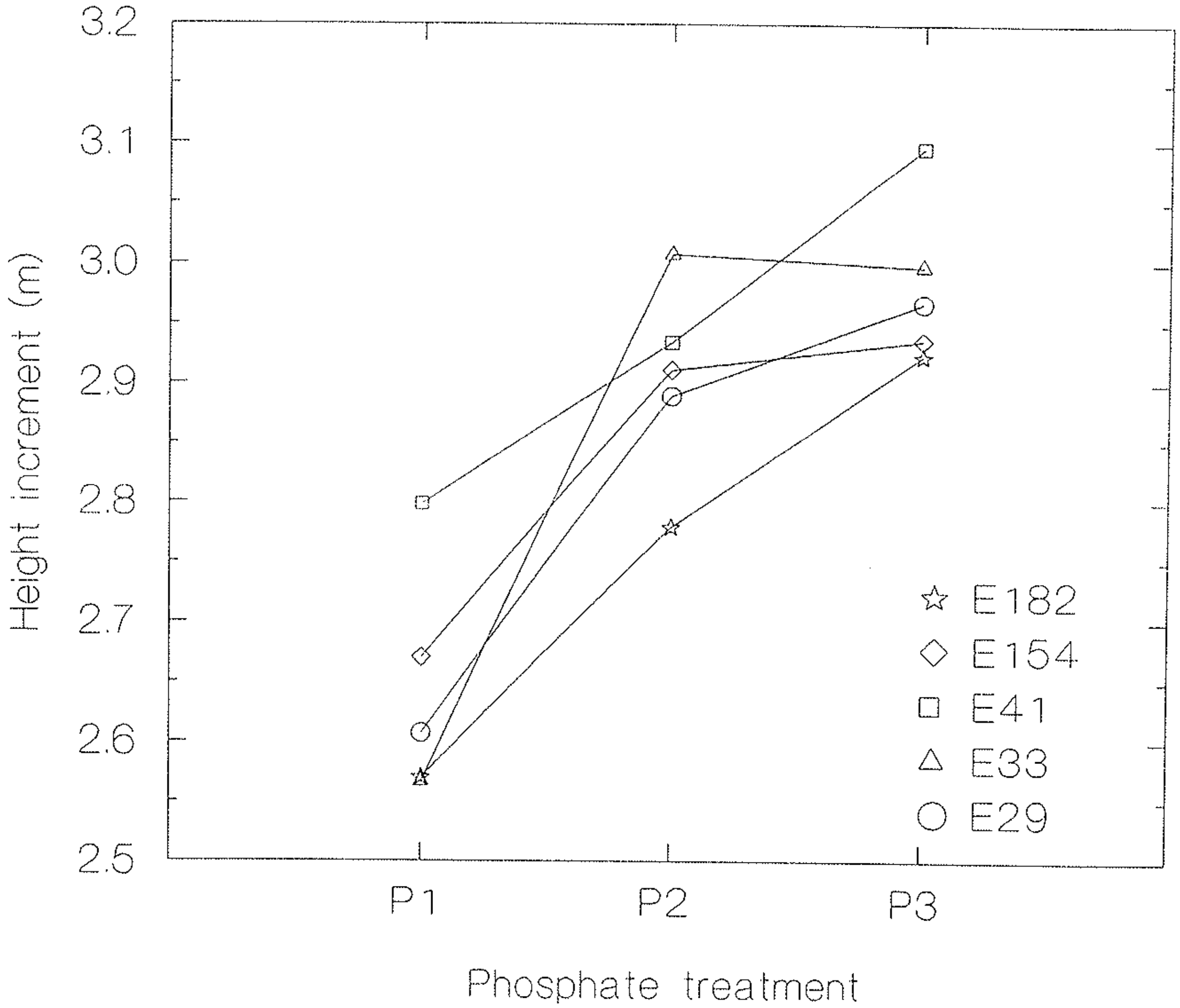

Figure 2. Trend lines for the Male x P interaction recorded for height growth in the 4-6 year increment period.

Significant differences in the female and male main effects and the Female x Male interaction were recorded for the 4 and 6 year height measurements and the 4-6 year increment period (Tables 4 and 5). Trend lines for the P x Male interaction, highly significant in the 4-6 year growth period, are plotted in Figure 2.

Table 4. Means for Male and Female genotypes for height growth (m) for different measurement and increment periods. Means with similar letters or no letters in the column are not significantly different.

Source		Stand age (years)					
		4	6	9	4-6	6-9	4-9
Female	E19	3.37 a	6.21 a	8.77	2.83 a	2.64	5.47
	E40	3.50 b	6.25 a	8.83	2.74 b	2.69	5.40
	E46	3.44 a	6.39 b	8.77	2.94 b	2.45	5.40
Male	E29	3.52 a	6.34 a	8.91	2.82 a	2.65	5.46
	E33	3.38 b	6.23 a	8.83	2.85 a	2.71	5.52
	E41	3.33 b	6.28 a	8.75	2.94 b	2.57	5.51
	E154	3.58 a	6.41 a	8.70	2.83 a	2.37	5.20
	E182	3.37 b	6.13 b	8.77	2.75 a	2.67	5.43
Female	Male						
E19	E29	3.51	6.30	8.93	2.79	2.66	5.48
E19	E33	3.36	6.20	8.78	2.84	2.76	5.53
E19	E41	3.17	6.13	8.58	2.95	2.55	5.51
E19	E154	3.52	6.36	8.95	2.84	2.64	5.49
E19	E182	3.31	6.04	8.57	2.72	2.60	5.33
E40	E29	3.61	6.35	8.94	2.73	2.71	5.40
E40	E33	3.47	6.27	8.83	2.80	2.64	5.40
E40	E41	3.35	6.18	8.72	2.83	2.68	5.44
E40	E154	3.72	6.44	9.02	2.71	2.71	5.38
E40	E182	3.34	6.00	8.66	2.66	2.70	5.36
E46	E29	3.43	6.36	8.84	2.93	2.59	5.50
E46	E33	3.31	6.23	8.87	2.92	2.72	5.61
E46	E41	3.49	6.53	8.95	3.03	2.49	5.56
E46	E154	3.49	6.45	8.13	2.95	1.76	4.72
E46	E182	3.47	6.36	9.09	2.88	2.71	5.58

Diameter and Basal Area - Mean diameters for each fertiliser treatment at ages 9, 12, 16 and 21 years and basal area increments for the 9-12, 12-16, 16-21 and 9-21 year periods are set out in Table 6 and Figure 3. Mean diameters and basal areas for genotypes are presented in Table 7. Analyses of variance of the diameter data are in Table 8.

The P1 treatment response was significantly less than P2 and P3 at age 9. Growth for P1 following fertiliser additions at

Table 5. Analysis of the results of N and P fertiliser treatments and Male and Female genotypes for standing height and height increment. The values in the table are the probabilities of F ratios obtained in the analysis of variance being obtained randomly. Only 2 replications were measured at age 9 years.

		Stand age and Degrees of Freedom						
Source	DF	4	6	4-6	DF	9	4-9	6-9
Block	3	0.680	0.105	0.741	1	0.681	0.200	0.251
P	2	0.026	0.000	0.000	2	0.390	0.747	0.273
N	1	0.865	0.277	0.022	1	0.412	0.613	0.447
P*N	2	0.376	0.337	0.412	2	0.391	0.419	0.394
Error	15				5			
Fem	2	0.001	0.000	0.000	2	0.875	0.205	0.838
Male	4	0.000	0.000	0.000	4	0.832	0.355	0.390
P*Fem	4	0.810	0.906	0.101	4	0.506	0.607	0.437
N*Fem	2	0.454	0.398	0.339	2	0.168	0.354	0.215
P*Male	8	0.737	0.572	0.005	8	0.525	0.448	0.410
N*Male	4	0.631	0.639	0.455	4	0.216	0.376	0.295
Fem*Male	8	0.000	0.005	0.711	8	0.098	0.343	0.413
Error	319				141			
Total	359				179			

Table 6. Means for N and P and N x P effects on standing diameter and basal area increment in stands aged 9 to 21 years.

			Stand age (years)							
Source			9	12	16	21	9-12	12-16	16-21	9-21
			Diameter (cm)				Basal area (m^2 ha^{-1})			
	1		12.7	16.8	19.4	21.7	3.21	2.06	1.63	2.19
P	2		13.5	16.9	19.5	21.8	2.75	2.06	1.58	2.05
	3		13.7	16.9	19.2	21.2	2.63	1.86	1.37	1.86
N	1		13.0	16.6	19.2	21.5	2.81	2.00	1.61	2.05
	2		13.5	17.1	19.6	21.7	2.91	1.98	1.45	2.01
	P	N								
	1	1	12.5	16.5	19.2	21.7	3.12	2.07	1.75	2.21
	1	2	13.0	17.1	19.7	21.8	3.29	2.06	1.51	2.16
N*P	2	1	13.3	16.7	19.2	21.4	2.65	2.01	1.54	1.98
	2	2	13.7	17.2	19.8	22.1	2.85	2.10	1.63	2.11
	3	1	13.3	16.7	19.1	21.3	2.67	1.93	1.53	1.96
	3	2	14.0	17.1	19.4	21.1	2.60	1.79	1.21	1.76

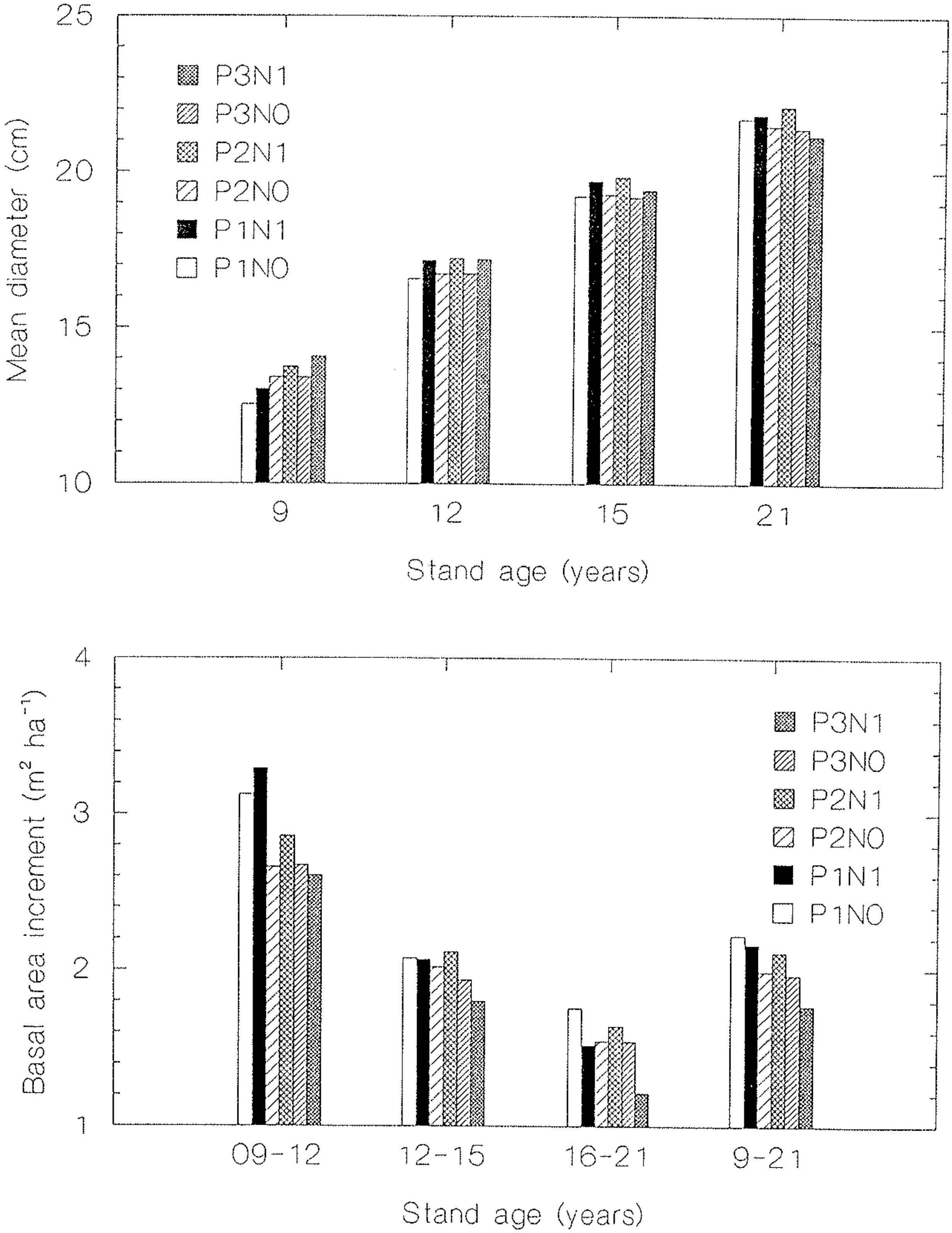

Figure 3. Progress of mean diameter of the standing crop and basal area increment for treatments over the trial period.

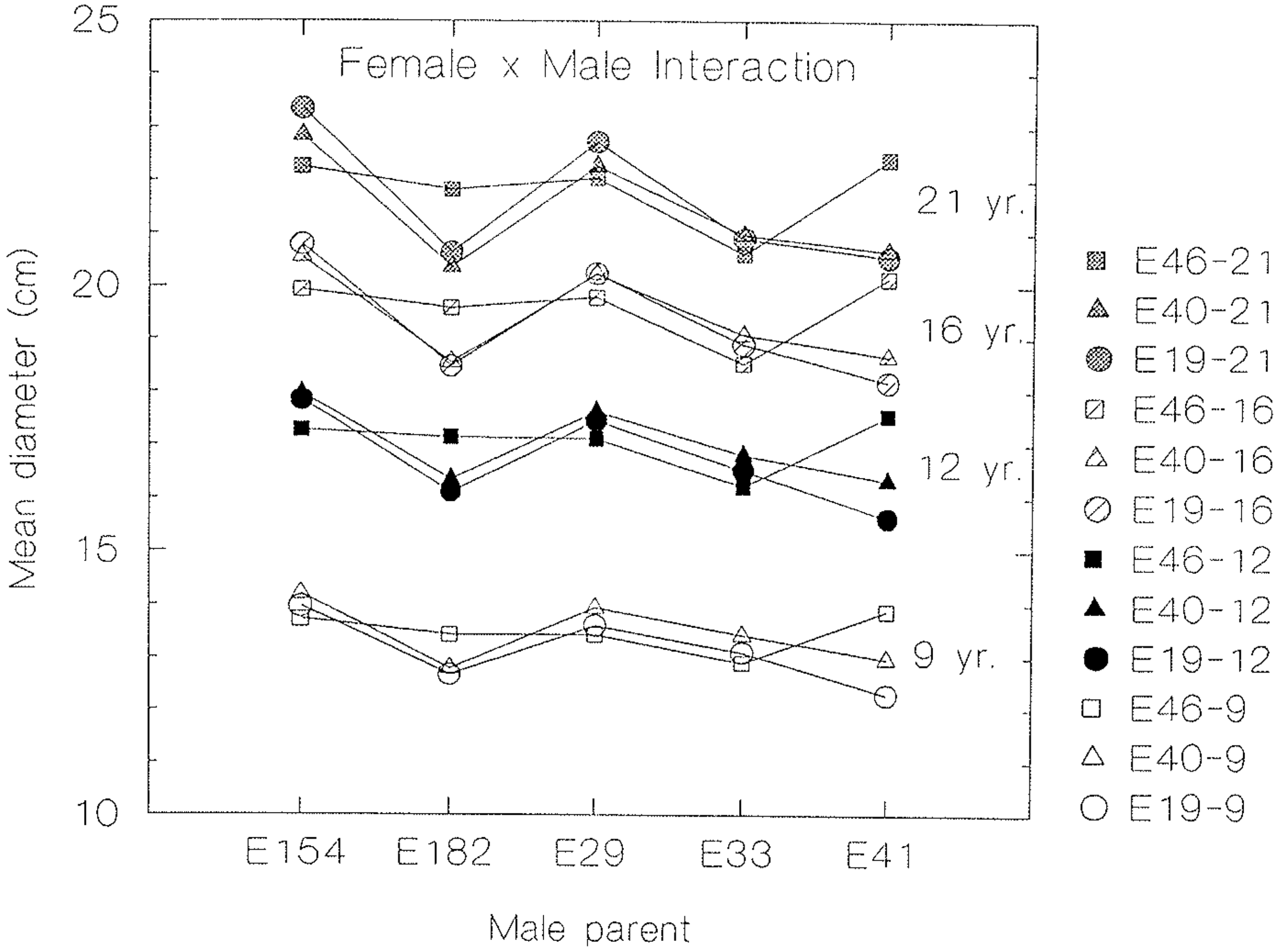

Figure 4. Interaction of Female x Male for diameter data at age 21 years and for the 9-21 year increment period.

Table 7. Means for male and female genotypes and the interaction of standing diameter and basal area increment. Stands are aged 9-21 years.

Source		9	12	16	21	9-12	12-16	16-21	9-21
		Diameter (cm)				Basal area (m^2 ha^{-1})			
	E19	13.1	16.7	19.3	21.6	2.83	2.05	1.61	2.08
Female	E40	13.4	17.0	19.4	21.4	2.86	1.90	1.40	1.95
	E46	13.4	17.0	19.5	21.8	2.89	2.03	1.57	2.07
	E29	13.6	17.3	20.0	22.3	3.06	2.19	1.62	2.19
	E33	13.1	16.5	18.8	20.8	2.65	1.78	1.35	1.83
Male	E41	13.0	16.4	18.9	21.2	2.70	1.93	1.50	1.96
	E154	13.9	17.6	20.4	22.8	3.11	2.27	1.76	2.28
	E182	12.9	16.5	18.8	20.9	2.79	1.79	1.40	1.89
Female	Male								
E19	E29	13.6	17.4	20.2	22.7	3.14	2.29	1.81	2.32
E19	E33	13.0	16.5	18.8	20.9	2.69	1.82	1.36	1.86
E19	E41	12.2	15.6	18.1	20.5	2.48	1.88	1.57	1.91
E19	E154	13.9	17.8	20.7	23.3	3.24	2.48	1.91	2.45
E19	E182	12.6	16.1	18.4	20.6	2.62	1.77	1.43	1.85
E40	E29	13.9	17.6	20.2	22.2	3.07	2.14	1.47	2.11
E40	E33	13.4	16.8	19.0	20.9	2.72	1.77	1.29	1.83
E40	E41	12.9	16.3	18.6	20.6	2.60	1.77	1.33	1.81
E40	E154	14.1	17.9	20.5	22.8	3.19	2.18	1.70	2.25
E40	E182	12.7	16.3	18.5	20.3	2.74	1.66	1.20	1.75
E46	E29	13.4	17.1	19.7	22.0	2.96	2.14	1.59	2.13
E46	E33	12.8	16.2	18.5	20.6	2.55	1.74	1.39	1.81
E46	E41	13.8	17.5	20.1	22.3	3.03	2.14	1.61	2.16
E46	E154	13.7	17.2	19.9	22.2	2.90	2.15	1.67	2.15
E46	E182	13.4	17.1	19.5	21.8	3.00	1.95	1.58	2.07

ages 6 and 8 years was significantly greatest in the 9-12 year growth interval. This superiority in growth was maintained over the whole 9-21 year measurement period even though fertiliser levels had no significant effect on growth during the later 12 to 16 year period (Fig. 3, Table 8). The stimulus from N1 was significantly better than no nitrogen for diameters at ages 9 and 12 years. No significant P x N effect was evident in the diameter and basal area data.

The trend for genotypic response shown for earlier height measurements continued for diameters and basal area increments from ages 9 to 21 years. The nature of the interactions are shown for diameter at age 21 years and basal area increment for the 9-21 year period in Figure 4. The E41 and E182 parents were the poorest crosses for E19 and E40 females but were amongst the best for crossing with E46 females. At age 21 years standing diameters of the Females were similar while the E29 and E154 males were significantly more vigorous than the other three.

Table 8. Results of N and P fertiliser treatments and Male and Female genotypes for standing diameter and basal area increment. The values are the probabilities of F ratios obtained in the analysis of variance being obtained randomly.

		Stand age (years)							
Source		9	12	16	21	9-12	12-16	16-21	9-21
	DF	Standing diameter				Basal area increment			
Block	3	0.407	0.293	0.503	0.460	0.011	0.946	0.369	0.229
P	2	0.006	0.905	0.745	0.317	0.000	0.116	0.073	0.003
N	1	0.035	0.032	0.128	0.586	0.160	0.844	0.105	0.490
P*N	2	0.829	0.980	0.782	0.536	0.236	0.556	0.174	0.146
Error 1	15								
Female(F)	2	0.002	0.021	0.233	0.118	0.552	0.007	0.000	0.005
Male(M)	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P*F	8	0.809	0.732	0.748	0.903	0.332	0.766	0.918	0.885
N*F	4	0.425	0.357	0.610	0.575	0.450	0.438	0.811	0.743
P*M	2	0.621	0.687	0.522	0.530	0.567	0.086	0.593	0.323
N*M	8	0.522	0.448	0.669	0.740	0.467	0.991	0.667	0.748
F*M	4	0.000	0.000	0.000	0.000	0.000	0.005	0.131	0.000
Error2	304								
Total	359								

Table 9. Means for N and P main effects and the N x P interaction for percentage of nitrogen, phosphorus and potassium in foliar samples of March 1977 for trial YS35.

		% Nitrogen	% Phosphorus	% Potassium
P				
1		0.981 a	0.022 a	0.904 a
2		0.815 b	0.054 bc	0.763 b
3		0.767 b	0.062 bd	0.745 b
N				
1		0.847	0.046	0.812
2		0.861	0.047	0.796
P	N			
1	1	1.000 a	0.026 a	0.926 a
1	2	0.962 a	0.019 a	0.883 ac
2	1	0.792 b	0.047 b	0.716 bd
2	2	0.838 b	0.062 b	0.810 bce
3	1	0.750 b	0.064 b	0.794 bde
3	2	0.784 b	0.059 b	0.696 bdf

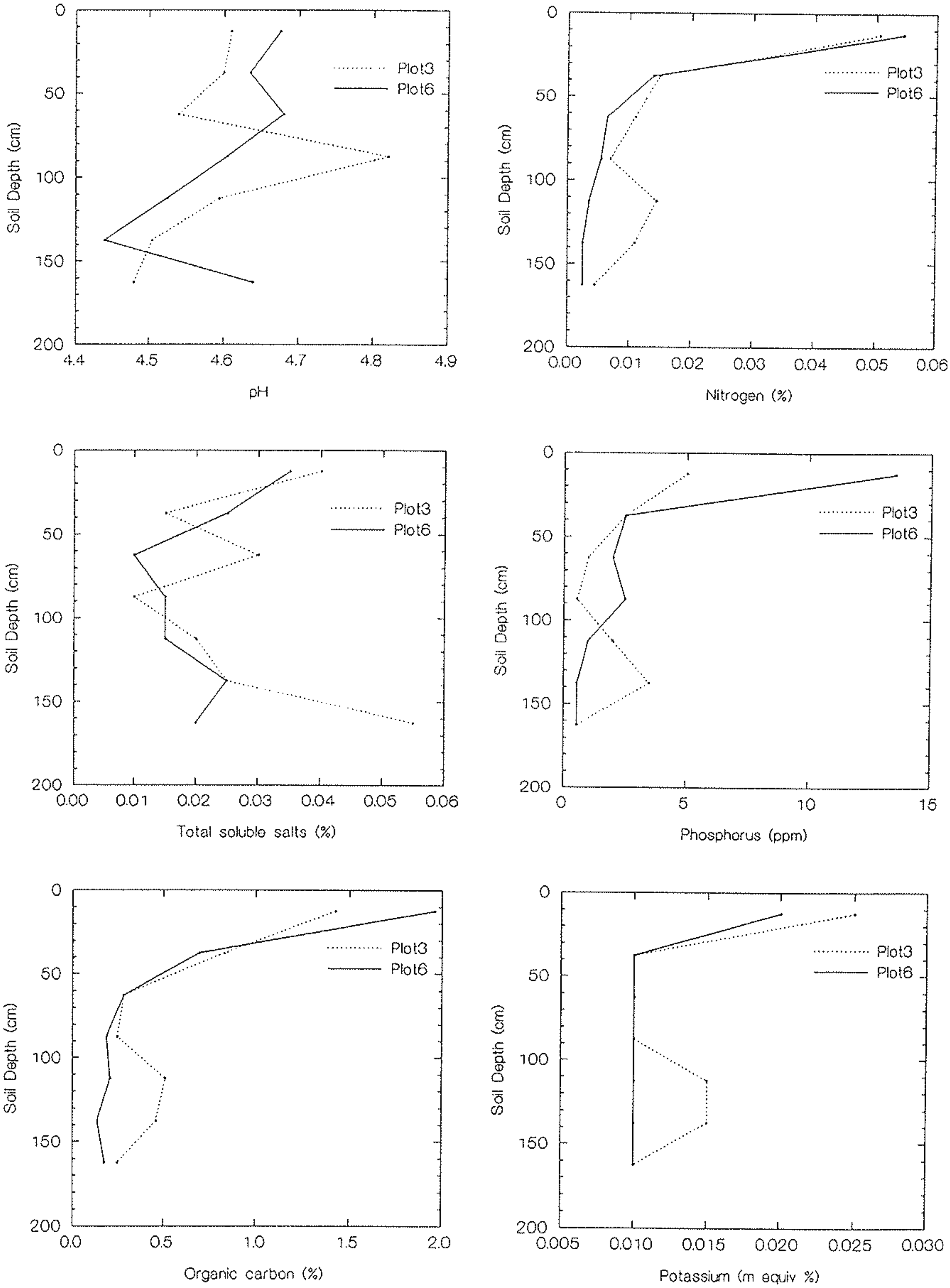

Figure 5. Profiles for pH, total soluble salts, organic carbon %, phosphorus % and potassium in milli-equilivants % for soils sampled in two study plots.

Soil Sampling - Comparisons of the means of data for the two blocks for pH, total soluble salts, organic carbon Nitrogen, phosphorus and potassium are depicted in Figure 5. The only result from the heavy fertiliser applications to Treatment 6 and the lighter applications to Treatment 3 (Table 1) is a higher surface P value for treatment 6 which was fertilised with 500 kg ha^{-1} super and 250 kg ha^{-1} ammonium sulphate in spring of the year preceding sampling. Figure 5 clearly indicates the sparse, acidic nature of the soil profile in the more fertile sites for pine growth in the region. The high value for total soluble salts at depth for treatment 3 indicates the present of a coffee rock, depositional horizon.

Foliar analysis - Means for the main effects and interaction for per cent N, P and K for the foliar samples are set out in Table 9. The fertiliser P and NxP treatments were highly significant for foliar N, P and K percentages. There was no influence of N levels on foliar concentration (Table 9) even though ammonium sulphate was applied in spring 1976, some 18 months previously. For per cent P in the foliage P3 > P2 > P1, corresponding to the level of phosphate additions. A highly significant N x P interaction for foliar P was associated with a higher value for P2N1 whereas the N1 levels for P1 and P2 were lower than the N0 values (Table 9). An interaction for Foliar K concentrations also resulted from high N1 values for P2 but lower values for P1 and P3.

Table 10. Significance of difference of means for fertiliser treatments determined by Bonferroni comparisons. Means with similar letters are not significantly different at the 0.05 level of probability.

		Stand age (years)											
Treatment		4	6	9	4-6	9	12	16	21	9-12	12-16	16-21	9-21
		Height				Diameter				Basal area			
1	P1N0	a	a	a	a	a	a	a	a	a	a	a	a
2	P1N1	ab	a	a	a	b	b	a	a	a	a	b	a
3	P2N0	b	b	a	b	bc	ab	a	a	b	a	ab	b
4	P2N1	b	b	a	b	cd	b	a	a	b	a	ab	ab
5	P3N0	bc	b	a	b	bc	ab	a	a	b	ab	ab	b
6	P3N1	c	c	a	c	d	b	a	a	b	b	c	c

Discussion

Fertiliser and Height Growth

Height measurements recorded the early stand development (Fig. 1). Measurement at age 9 (1980), however, included only 2 of the 4 randomised blocks of the trial and showed no significant difference between treatments. As full diameter data for the 1980 measurement gave highly significant treatment differences it is considered that the restricted 1980 height measurement was inadequate and was ignored for analysis.

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		Stand age (years)											
Treatment		4	6	9	4-6	9	12	16	21	9-12	12-16	16-21	9-21
		Height				Diameter				Basal area			
1	P1N0	a	a	a	a	a	a	a	a	a	a	a	a
2	P1N1	ab	a	a	a	b	b	a	a	a	a	b	a
3	P2N0	b	b	a	b	bc	ab	a	a	b	a	ab	b
4	P2N1	b	b	a	b	cd	b	a	a	b	a	ab	ab
5	P3N0	bc	b	a	b	bc	ab	a	a	b	ab	ab	b
6	P3N1	c	c	a	c	d	b	a	a	b	b	c	c

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The significant (0.026) P effect at age 4 (Tables 3, 5 and 10) was associated with spot applications of superphosphate in both 1971 and 1973 in P3 as opposed to the single application in 1971 for the P1 and P2 treatments (Table 1). No N was added up to the measurement date and no difference in the N0 and N1 means was recorded. At age 6 further broadcast dressings in 1975 for the P2 and P3 treatments significantly increased height growth over that of the single spot application treatment P1 treatment (Fig. 1).

For early stand development a broadcast superphosphate application at age 4 to supplement the initial spot application maximised height growth.

The N main effect in the 4-6 years increment period was significant (Tables 3 and 5, Fig. 1)) indicating a beneficial effect of the ammonium sulphate addition in the N1 treatments in 1975 at age 4 years (Table 1). The N x P interactions for height growth were not significant.

No interactions between N and P and genotype were observed for the 4 and 6 year measurements but a significant P*Male interaction was recorded for the increment period. This resulted (Fig. 2) from the increment rate of parents E41 and E182 continuing to increase with increasing phosphate from P2 to P3. The other three male parents had a decreased rate of increment under these conditions.

Fertiliser and Diameter Growth

The effect of P on diameter was highly significant at age 9 years (Table 8) with P2 and P3 diameters being greater than P1 (Tables 6 and 10)). Basal area growth for the 9-12 year growth interval was also significant but in this case the recently fertilised P1 treatment outgrew the P2 and P3 levels. The P treatments had no measurable effect on the stand at 12, 16 and 21 years of age but had a residual influence for increment over the whole 9-21 year increment period.

N application had a significant, favourable influence on standing diameter at ages 9 and 12 years, but not thereafter or on basal area growth. Interactions were insignificant. By age 16 years, 4 years after the last fertiliser application, there were no significant differences between standing basal area or stand volume (Table 8). Fertiliser addition favoured increased growth on these sites as shown by treatment differences with early fertiliser additions in Figures 1 and 2. Evidence in the trial however, indicate that apart from spot additions of superphosphate at time of planting, broadcast dressings of 500 kg ha^{-1} at ages 4 and 12 will maximise growth to age 16 years. No additional benefit was recorded for up to 4 applications of 250 kg ha^{-1} ammonium sulphate spread over the first 12 years of stand development. The effects of added ammonium sulphate were minor and of short duration. The data indicate that there is no advantage to growth by using other than the P1N0 and P2N0 regimes.

Foliar concentrations - Foliar analysis was carried out to trace the influence of added fertiliser on plant uptake and retention. It was only possible to sample one block instead of the four originally intended but this was sufficient for the intended purpose. There was no measurable influence of N additions on foliar N, P and K. Foliar P levels were significantly higher in the order P3 < P2 < P1 (Table 9) reflecting the amount of phosphatic fertiliser added to the time of sampling. The extra 57 g of super added to P3 in 1973 (Table 1) still showed a significantly higher foliar P concentration over P2 in 1977, 3.5 years after application. Significantly lower concentrations in per cent N and per cent K for P1 and P2 levels in Table 9 result from dilution of the fixed amounts of N and K due to greater needle growth as a result of added phosphate. Height growth of treatments (Table 3) reflected the foliar level of P. A significant (.043 level) effect in per cent K for families resulted from family E57 with the highest K concentration being significantly (0.02 level) higher than families S202 and S205 with the two lowest foliar K levels. There was no apparent effect of the K level on growth as the three families were not significantly different in diameter at age 21 years (Table 11).

Table 11 Grouping of families to show those in which the mean diameter at stand age 21 years is not significantly different progressing from the best family S99 to the worse family S125.

Family	99	202	57	191	64	205	161	215	63	56	17	100	168	55	125
	----	----	----	----	----	----	----	----							
				----	----	----	----	----	----	----					
							----	----	----	----	----	----	----	----	
								----	----	----	----	----	----	----	----

Stand Volume

Heights were not measured fully after age 6 but a sample of trees were measured at age 21 to allow heights to be estimated. From this individual tree volumes were estimated. The means for treatments are set out in Table 12.

The average mean annual increment for total volume is 13 m^3 ha^{-1} which is excellent for the species. The site is of good quality, all plants were from full-sib selections and fertiliser treatments covered any reasonable range contemplated for the species. No unfertilised control was included in the trial to demonstrate the absolute need for at least initial applications of phosphate for pine growth on such sites. Data would suggest that satisfactory stands can be grown on such sites using fertiliser treatment 1 which is the simplest to apply and cheapest of the treatments compared.

Genotype and Stand Growth

Family effects were highly significant for height, diameter and stand increment. The Male genotype was significant for all data except height data associated with the reduced 1980 measurement

(Tables 4 and 5). Results for the Female were significant for these data sets except for standing diameter at ages 16 and 21 and the 9-12 year increment period.

Table 12. Total standing volume (m^3 ha^{-1}) under bark estimated for families and fertiliser treatments at age 21 years

Family	Fertiliser treatment						
	P1N0	P1N1	P2N0	P2N1	P3N0	P3N1	Mean
S17	253	235	230	247	227	269	244
S55	284	260	219	257	213	217	242
S56	242	265	191	271	267	270	251
S57	311	283	306	328	311	315	309
S63	257	299	264	262	254	191	254
S64	298	317	282	269	312	287	294
S99	338	317	323	369	346	298	332
S100	222	243	257	275	216	243	243
S125	216	233	221	264	221	247	234
S161	285	297	284	327	251	271	286
S168	252	256	237	266	229	213	242
S191	287	286	300	302	334	283	299
S202	331	328	354	346	279	252	315
S205	321	305	274	324	285	257	294
S215	278	292	318	249	264	282	281
MEAN	278	281	271	290	267	260	275

The Male x Female interaction was significant for all standing measurements but not for current annual increments in height and basal area for the 16-21 year period. The interaction was constant in trend for all diameter measurements (Fig. 6) and associated with above average performance of E46 with the pollen parents E182 and E41.

On the basis of the vigour measured by stem diameter the genotype E154 was the best male parent and E33 the worst. The best females were E19 and E46.

The 15 full-sib families are ranked on the basis of volume production in Table 11. The best was S99 and the worst S125. Selection to use seed from the top 8 families which were not significantly different from S99 (0.05 level) could provide a 9 per cent improvement in total volume at age 21 years.

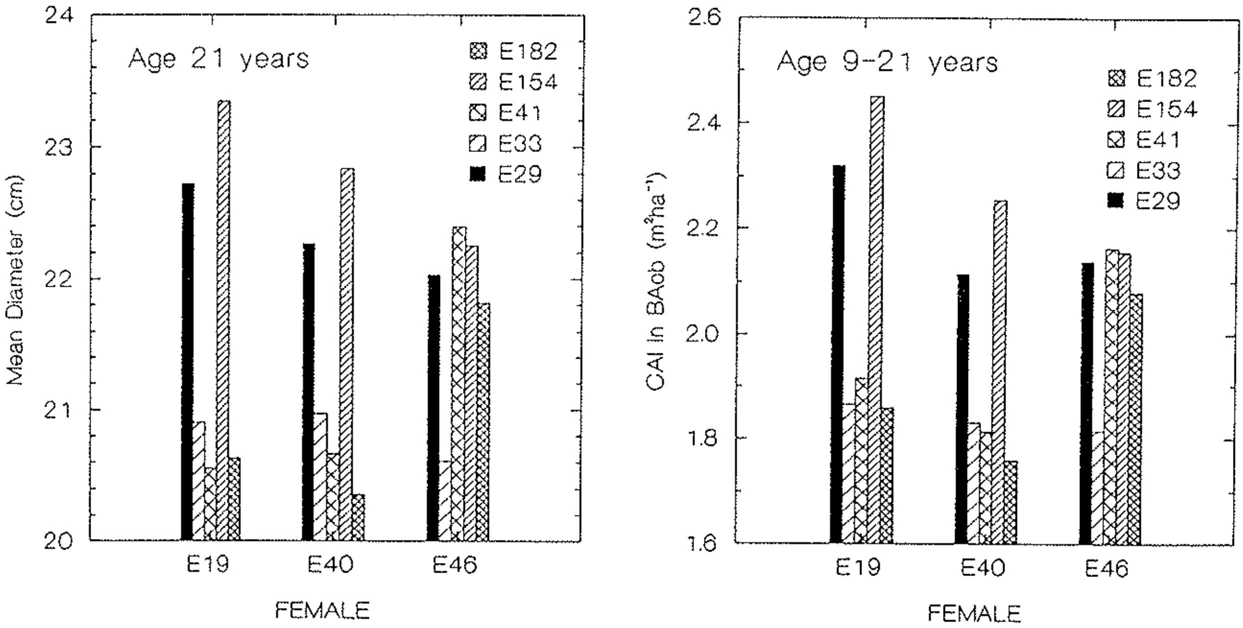

Figure 6. Trend lines for the significant Male x Female interaction within the trial. The interaction mainly results from outstanding performance of pollens E41 and E182 with the female parent E46.

Conclusion

On the sites sampled a fertiliser regime applying 57 g of superphosphate to the plant at time of planting and 500 kg ha^{-1} broadcast at ages 6 and 8 years was favourable. There was no evidence that broadcast dressings at an earlier age and / or at age 12 could improve on this performance.

The effects of N addition as ammonium sulphate, at rates of 250 kg ha^{-1} were small and transitory with no significant effect on the stand at age 21 years.

Responses of full-sib families to fertilisation were highly significant. There were no significant interactions between Fertiliser and Families or between N and P and Male and Female genotypes. Selection of the top 8 of the 15 families could improve standing volume at age 21 years by 9 per cent..

TRIAL YS36 - The Interaction between Varied Fertiliser Application and Genotype.

Summary and Conclusions

The responses of fifteen full sib families of *Pinus pinaster* to superphosphate (P) and ammonium sulphate (N) fertiliser additions were compared on an average site at Gnangara plantation. The families included crosses of 3 female parents with 4 male parents and a commercial routine seed batch. The trial was designed as a (5x3) x (3x2) factorial with four replications in a split-plot randomised block design.

On the sites sampled the most favourable fertiliser regime applied 57 g of superphosphate to the plant at time of planting and 500 kg ha^{-1} broadcast at ages 4 and 8 years. There was no evidence that broadcast dressings at an earlier age and, or at age 12 could improve this performance. The heaviest fertiliser treatment applied increased stand basal area at age 16 years 18 per cent more than the lightest treatment.

The effects of N addition as ammonium sulphate at rates of 250 kg ha^{-1} were small and transitory with no significant effect on the stand up to age 16 years.

Responses of full-sib families to fertilisation were highly significant. Significant interactions obtained between fertiliser and families and between P and the female genotypes are considered to be minor in nature and relatively unimportant in practice.. Selection of the top quartile of the 14 full-sib families could improve basal area growth by 60 per cent and height growth by 11 per cent above that of the commercial seed used for planting at that time.

Introduction

Trial YS36 was established 1971 with three major objectives:

1. to assess the effect of repeated dressings of fertiliser on stand growth;
2. to assess whether both nitrogenous and phosphate fertiliser elements were favourable to stand development;
3. to assess whether particular parents within the tree improvement program were especially adapted to added nutrients.

The trial was one of a series designed to determine optimum fertiliser regimes for stand growth but had further development to identify special results which may apply using improved seed from the seed orchards. It is almost identical to Trial YS35 applied to superior site types and a different group of genotypes.

Treatments

The trial is located in the Neaves area in Section J, Gnangara Plantation on an average quality site. It was planted in 1971 with tubed stock at 3.3 m x 3.3 m spacing, in three randomised blocks.

Fertilisers - Three levels of superphosphate (P) and 2 levels of ammonium sulphate (N) were applied at different intervals over the 16 year trial period. The fertiliser treatments are described in Table 1.

Table 1. Fertiliser treatments for trial YS36. The amounts are in kg ha^{-1} and refer to superphosphate for P and ammonium sulphate for N. Applications in 1971 and 1973 were spot applications (g $tree^{-1}$), the remainder were broadcast.

Fertiliser		1971 Year0		1973 Year2		1975 Year4		1977 Year6		1979 Year8		1983 Year12	
Code	P N	P	N	P	N	P	N	P	N	P	N	P	N
1	P1N0	57	-	-	-	-	-	500	-	500	-	-	-
2	P1N1	57	-	-	-	-	250	500	250	500	250	-	250
3	P2N0	57	-	-	-	500	-	-	-	-		500	-
4	P2N1	57	-	-	-	500	250	-	250	-	250	500	250
5	P3N0	57	-	57	-	500	-	500	-	500	-	500	-
6	P3N1	57	-	57	-	500	250	500	250	500	250	500	250

Genotypes Twelve full-sib families from crossing 4 selected pollen parents with 3 selected female parents, two other select families and a routine control batch of seed were used in the trial. Details of the 15 families are contained in Table 2.

Table 2. Families and parents used in trial YS36.

Family	Female Parent	Male Parent
S57	E19	E29
S56	E19	E33
S99	E19	E154
S100	E19	E182
S64	E40	E29
S63	E40	E33
S202	E40	E154
S125	E40	E182
S161	E46	E29
S168	E46	E33
S205	E46	E154
S215	E46	E182
S55	E19	E41
S17	E40	E41
Routine		

Design. The 15 family groups were planted as single tree plots randomised six times within each of six randomly selected fertiliser treatment plots. The treatment plots were replicated within each of three randomised uniformity blocks.

The number of treatment plants involved was 15x6x6x3=1620 to include a (3x4) x (3x2) x 3 factorial design.

Each treatment unit was a line plot of 15 progeny at 3.3 m x 3.3 m spacing. Two rows at 3.3 m x 3.3 m spacing were planted between each fertiliser plot to buffer the effect of added nutrients.

Measurement. Heights were measured in 1975, 1977 and 1980 at ages 3.5, 5.5 and 8.5 years, respectively. Diameters were measured in 1980, 1983 and 1987 at ages 9, 12, and 16 years, respectively.

Table 3. Means of main effects for fertiliser treatments for measurements and measurement intervals for height. Means associated with a similar letter are not significantly different.

Source		Stand attribute and age (years).					
		Ht 4	Ht 6	Ht 9	BA 9	BA 12	BA 16
	1	1.87 a	3.59 a	6.76 a	9.96 a	17.43 a	23.96 a
P	2	1.87 a	4.17 bc	7.86 ac	12.90 bc	20.19 bc	26.06 bc
	3	2.20 b	4.87 bd	8.51 bd	15.20 bd	22.73 bd	28.39 bd
N	5	1.99 a	4.21 a	7.79 a	12.54 a	19.71 a	25.80 a
	6	1.97 a	4.21 a	7.63 a	12.84 a	20.52 a	26.48 a
Source		Ht 4-6	Ht 6-9	Ht 4-9	BA 9-12	BA 12-16	BA 9-16
	1	0.86 a	1.06 a	0.98 a	2.49 a	1.63 a	2.00 a
P	2	1.15 a	1.23 b	1.20 b	2.43 a	1.47 a	1.88 a
	3	1.34 b	1.21 b	1.26 b	2.51 a	1.42 a	1.89 a
N	5	1.11 a	1.19 a	1.16 a	2.39 a	1.52 a	1.89 a
	6	1.12 a	1.14 a	1.13 a	2.56 a	1.49 a	1.95 a

In March 1977 the current foliage of 3 of the 6 trees for each family per treatment for each Block was sampled and bulked. This was analysed for per cent N, P and K.

Soil samples were taken from treatments 2, 3, 4 and 5 in each block in October 1980. Three profiles sampled at each location for the depth intervals 0-25 cm were analysed for N and P content.

Analysis. The trial was initially analysed as a split-plot design with the 6 fertiliser plots and 3 blocks having an error term with 10 degrees of freedom. The fertiliser treatments formed a 3x2 factorial with 15 family treatments in the complete data set.

The routine control and the two miscellaneous families were removed from the data set. A second analysis was carried out to investigate the genotypic effect of the 3 female and 4 male parents as a 2x3 factorial.

Results

Mortality - Severe drought in 1980 caused mortalities resulting in the survival of 534, 534, and 482 stems in blocks 1, 2 and 3, respectively. Mortality tended to be concentrated in fertiliser treatments 1, 2 and 3 and in families S55, S64 and S205. This unequal thinning effect within the trial prevented comparison of mean diameters for treatments (as used in the analysis of the companion Trial YS35). Comparisons after 1980 are on the basis of standing basal areas of surviving trees.

Table 4. Analysis of variance of trial data for each measurement and measurement interval. Fertiliser treatments are analysed in factorial form within a split plot design. The whole 15 families are included. The probabilities recorded are that the F values would be exceeded by chance.

Source		Height at age (years)			Basal area (years)		
	DF	4	6	9	9	12	16
Block	2	0.001	0.000	0.000	0.000	0.036	0.780
P	2	0.005	0.000	0.000	0.000	0.000	0.003
N	1	0.720	0.997	0.399	0.583	0.242	0.400
N*P	2	0.181	0.827	0.814	0.659	0.743	0.568
Error 1	10						
Family (F)	14	0.000	0.000	0.000	0.000	0.000	0.000
P*F	28	0.030	0.049	0.095	0.015	0.407	0.582
N*F	14	0.153	0.360	0.177	0.373	0.823	0.745
P*N*F	28	0.752	0.797	0.332	0.860	0.883	0.842
Error 2	168						
Total	269						
Source	DF	4-6	6-9	4-9	9-12	12-16	9-16
Block	2	0.000	0.404	0.000	0.000	0.000	0.000
P	2	0.000	0.001	0.000	0.756	0.028	0.289
N	1	0.691	0.115	0.380	0.092	0.613	0.425
N*P	2	0.290	0.175	0.322	0.805	0.273	0.742
Error 1	10						
Family (F)	14	0.000	0.000	0.000	0.002	0.000	0.000
P*F	28	0.231	0.377	0.609	0.878	0.760	0.895
N*F	14	0.708	0.798	0.368	0.893	0.561	0.801
P*N*F	28	0.626	0.056	0.082	0.468	0.574	0.554
Error 2	168						
Total	269						

Fertiliser Responses

Height - Height means for the 6 fertiliser treatments are plotted for different measurements and growth intervals in Figure 1. Means for the main effects and results from analysis of variance of data are included in Tables 3 and 4.

Analysis of variance for stand height in 1975 (age 4 years), 1977 (age 6) and 1980 (age 9) gave highly significant effects for the P main effect but no significant effects for N and P x N. A significant P x Family interaction was present in the 4 and 6 year height data. For increment data the P effect remained significant but the interactions were not significant. By the January 1975 measurement (age 4) all treatments had received the standard dose of fertiliser at time planting and treatments 5 (P3N0) and 6 (P3N1) also received a second spot application at age 2 years (Table 1). The double dose (P3) resulted in significantly greater growth in the 1975 measurement (Table 3, Fig. 1). In 1977 phosphate applications at age 4 years to treatments 3 to 6 (Table 1) resulted in significant height differences between treatments representing P1, P2 and P3 levels of application (Table 3, Fig. 1). No response to the nitrogen added was detected (Table 3). In 1980 (age 9), following further treatment at age 6 years (Table 1), measurement recorded a similar situation with the response to P1 less than P2 which was less than P3 (Table 3 and Fig. 1). Slightly depressed growth with nitrogen additions recorded in Figure 1 and Table 3 at 9 years of age were not significant.

Height increments were in accord with results from standing heights. From stand age 4 to 6 Years P1 response was less than P2 which was less than P3 (Table 3, Fig. 1). No significant effect of nitrogen was recorded although a depression in height growth in P1N1 and P3N1 and an increase in P2N1 was associated with the N fertiliser addition in at age 4 years (Fig. 1, Table 1). In the 6 to 9 year increment period there was no difference between P2 and P3 despite further phosphate additions to P3 and P1 in 1977 and 1979 (Fig. 1, Tables 1 and 3). Depressed growth associated with N addition to P1N1 and P2N1 was not significant for this growth period and for the overall 4 to 9 year height growth interval (Tables 3 and 4).

Basal Area - Stand basal area at age 9, 12 and 16 years showed significant to highly significant responses to P levels. There was no response to N or P x N (Tables 3, 4, Fig. 2). A trend for a beneficial response to N addition (Fig. 2, Table 3) was not significant within the split plot design. The P x Family interaction recorded for height growth at ages 4 and 6 years was also significant for basal area at age 9 years. No significant differences were detected in growth between treatments (Fig. 2) in measurement intervals from age 9 to 16 years, despite additional fertiliser additions at ages 8 and 12 years (Table 1).

Increment for the whole period 9 to 16 years was not significantly different between treatments or P levels. The standing basal area in 1987 (age 16 years) showed the regular frequent fertilising with phosphate in P3 to be significantly

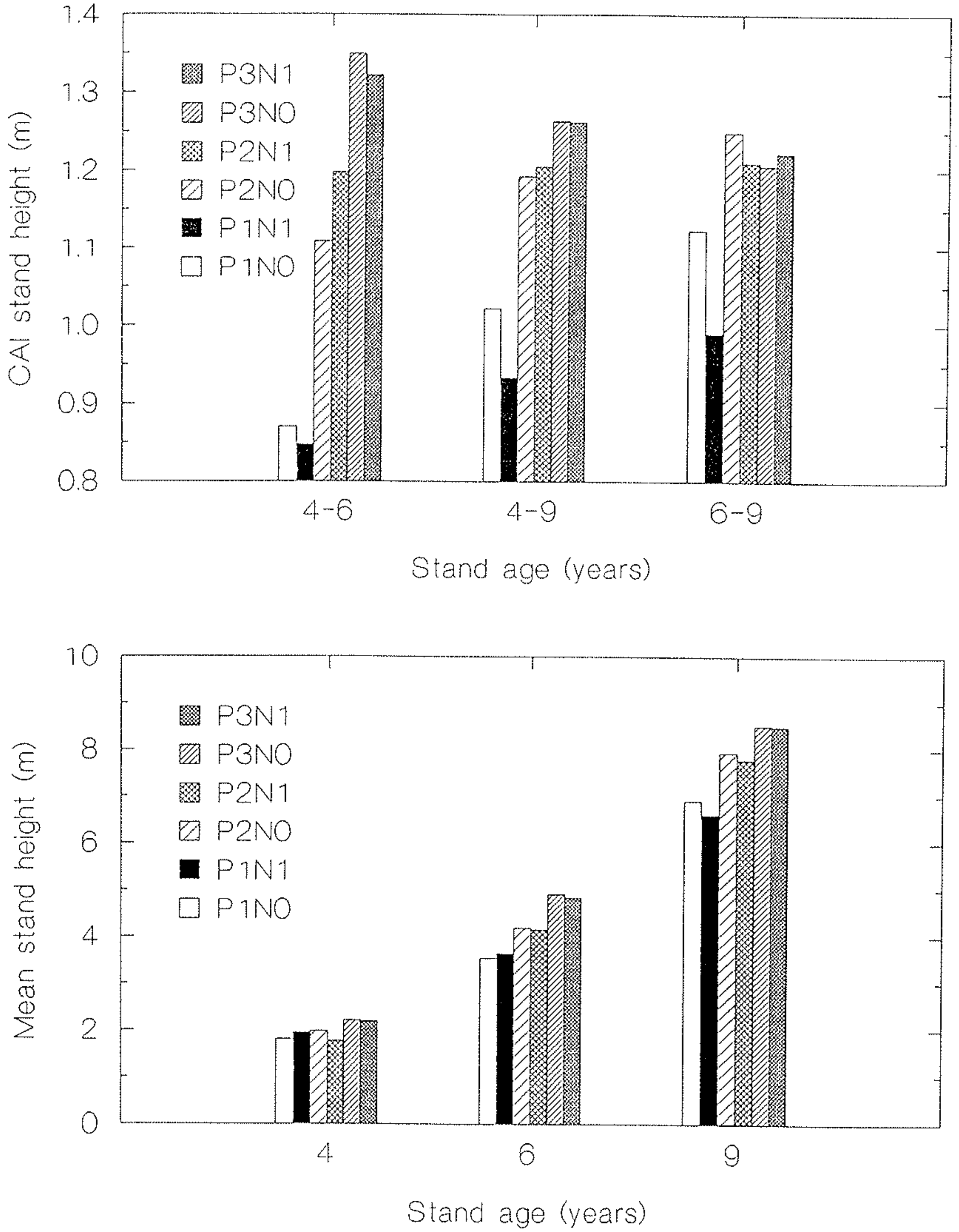

Figure 1. Mean stand height and current annual increment for height growth fertiliser treatments.

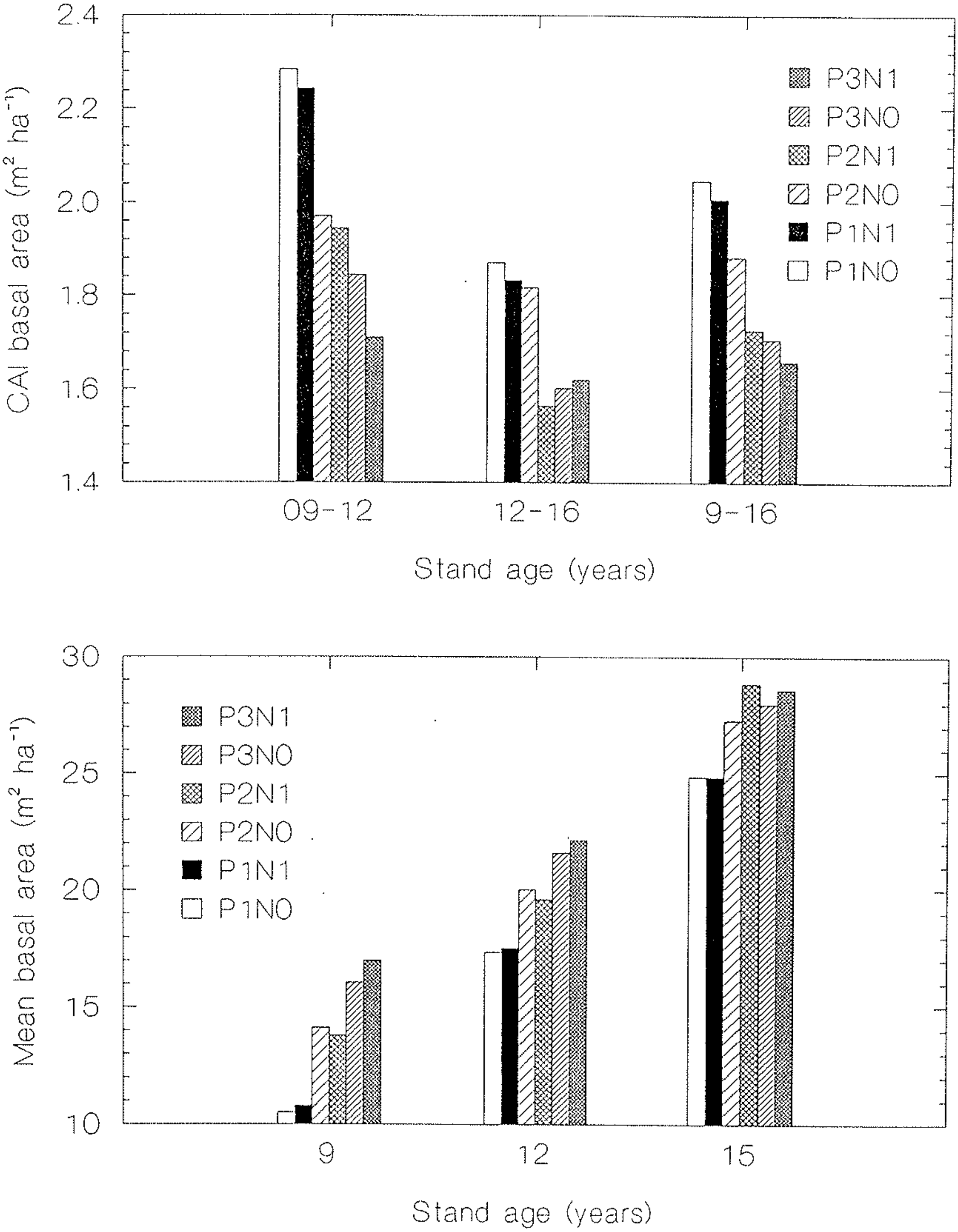

Figure 2. Mean standing basal area and current basal area increment for fertiliser treatments for measurements and intervals between measurements.

better than P2 which was significantly better than P1 (Tables 2 and 3). Mean basal areas for the P levels were 23.96 m^2 ha^{-1} (100 %), 26.06 m^2 ha^{-1} (109 %) and 28.40 m^2 ha^{-1} (119 %) for P1, P2 and P3, respectively.

Table 5. Analysis of variance summary for foliar concentrations of nitrogen, phosphorus and potassium. Probabilities are that the F value would be obtained by chance.

		Nitrogen*		Phosphorus**		Potassium	
Source	DF	F-ratio	P	F-ratio	P	F-ratio	P
P	2	52.61	0.000	9.21	0.000	1.10	0.371
N	1	11.22	0.007	0.09	0.295	0.01	0.943
N*P	2	17.48	0.000	0.01	0.920	0.10	0.925
Block	2	21.07	0.000	0.14	0.597	0.08	0.350
Error 1	10						
Family	14	0.98	0.472	2.55	0.002	1.20	0.280
Family*P	28	1.25	0.190	1.50	0.060	0.48	0.987
Family*N	14	0.54	0.908	0.80	0.666	0.37	0.981
Family*P*N	28	1.16	0.281	1.21	0.229	0.70	0.868
Error	152						

* Log transformation used for analysis.
** Arcsine (square root) transformation use in analysis

Table 6. Mean values obtained from foliar analysis in 1982 for per cent nitrogen, per cent phosphorus and per cent potassium.

	Nitrogen %			Phosphate %			Potassium %		
	N0	N1	Mean	N0	N1	Mean	N0	N1	Mean
P1	.653	.796	.725	.013	.011	.012	.319	.285	.302
P2	.599	.614	.607	.047	.044	.045	.415	.433	.424
P3	.612	.593	.603	.050	.047	.048	.388	.396	.392
Mean	.621	.668		.037	.034		.374	.371	

Foliar analysis - Analysis of variance for the foliar sampling in March 1982 gave highly significant differences for N, P, Block and N x P for nitrogen levels (Tables 5 and 6). The highest N concentrations were for the P1 and the N1 application (Table 6). The interaction resulted from depressed P3N1 values, relative to P1N1 and P2N1, which were higher than the respective P1N0 and P2N0 values. Phosphate concentrations were significant for P being lowest for P1. Potassium concentrations were lower for P1 but differences (Table 5) were not significant.

It was surprising that the more recent superphosphate additions to P1 (but not to P2) at ages 6 and 8 years did not bring the foliar levels of P1 up to, or to exceed that of P2. The levels recorded in Table 5 reflect the amount of P added only to age 4 years (Table 1).

Table 7. Mean concentrations of N and P from soil analysis of four treatments in March 1982.

		% N ($x10^{-2}$)	% P ($x10^{-3}$)
Block	N		
1	16	4.09	1.84
2	16	4.58	1.83
3	16	5.50	1.71
Fertiliser	N		
P1N1	12	3.52	1.84
P2N0	12	4.46	1.60
P2N1	12	4.56	1.71
P3N0	12	6.36	2.03

Table 8. Comparison of the families and genotypes for height and basal area increment over the periods 1975-80 and 1980-87, respectively. Families were ranked on basal area increment and families with similar letters were not significantly different at the .05 level by Scheffe comparisons.

Family	Female	Male	BA8087		HT7580	
100	E19	E182	2.311	a	1.12	a c
202	E40	E154	2.184	a	1.15	a c
215	E46	E182	2.173	a	1.10	b c
63	E40	E33	2.110	a c	1.20	a d
161	E46	E29	1.988	a c	1.15	a c
57	E19	E29	1.982	a c	1.18	a c
125	E40	E182	1.964	a c	1.14	a c
168	E46	E29	1.932	a c	1.15	a c
64	E46	E29	1.839	a c	1.22	a d
99	E19	E154	1.832	a c	1.15	a c
55	E19	E41	1.805	a c	1.12	a c
205	E46	E154	1.802	a c	1.14	a c
56	E19	E29	1.763	a c	1.17	a c
17	E40	E41	1.745	a c	1.20	a c
ROUTINE	ROUT	ROUT	1.386	b c	1.01	b d

Soil analysis - Samples were analysed for per cent nitrogen and phosphorus. Differences for N concentration (Table 7) between the treatments 2 (P1N1), 3 (P2N0), 4 (P2N1) and 5 (P3N0) were significant at the 0.02 level. The highest N concentration was associated with the highest application of P in P3. (Tables 1 and 7). For P concentration, differences in both the Block x Fertiliser application and P main effect were highly significant. The interaction (Table 7) makes little sense but the means for the P concentration in the table show greater concentrations for P1 and P3. These treatments were fertilised most recently in 1979 (Table 1) and the highest concentration in P3 corresponds with the highest applications of phosphate. The main value of this limited soil sampling was to document the low values of N and P in the sands of the planting sites.

Table 9. Results for analysis of variance of basal area for a balanced data set of 12 families to examine genotypes.

		Measurement date or interval					
Source	DF	Ht75	Ht77	Ht80	BA80	BA83	BA87
Block	2	0.001	0.000	0.000	0.000	0.044	0.531
P	2	0.009	0.000	0.000	0.000	0.002	0.023
N	1	0.718	0.975	0.504	0.694	0.364	0.491
N*P	2	0.262	0.767	0.940	0.897	0.955	0.867
Error 1	10						
Female	2	0.000	0.000	0.005	0.000	0.001	0.030
Male	3	0.034	0.238	0.777	0.071	0.047	0.017
Female*Male	6	0.020	0.000	0.000	0.000	0.001	0.000
Female*P	4	0.003	0.010	0.001	0.009	0.175	0.306
Female*N	2	0.437	0.612	0.641	0.657	0.441	0.371
Male*P	6	0.111	0.175	0.325	0.065	0.306	0.385
Male*N	3	0.251	0.435	0.420	0.235	0.600	0.518
Error 2	172						
		H7577	H7780	H7580	BA8083	BA8387	BA8087
Block	2	0.000	0.593	0.001	0.000	0.000	0.000
P	2	0.000	0.004	0.000	0.893	0.016	0.281
N	1	0.627	0.195	0.498	0.119	0.695	0.386
N*P	2	0.226	0.321	0.473	0.873	0.397	0.872
Error 1	10						
Female	2	0.001	0.000	0.031	0.372	0.019	0.728
Male	3	0.006	0.011	0.018	0.110	0.000	0.031
Female*Male	6	0.000	0.000	0.000	0.100	0.000	0.005
Female*P	4	0.196	0.204	0.024	0.690	0.542	0.695
Female*N	2	0.921	0.373	0.508	0.427	0.297	0.331
Male*P	6	0.482	0.354	0.697	0.678	0.591	0.771
Male*N	3	0.511	0.461	0.227	0.842	0.323	0.648
Error 2	172						

Families - Differences between the 15 family means were highly significant for all analyses (Table 4). Families are ranked on the basis of basal area increment in the 9 to 16 year period in Table 8. The significant differences determined between pairs by Scheffe analysis are designated by different letters. Current annual increments for height growth for the earlier 4 to 9 year measurement interval and the corresponding significance for difference between pairs of families are also included in the Table. From age 4 to 9 years the Routine, unselected seed was significantly inferior in height growth to all families from selected parents. Basal area growth of the best 3 families was superior to that of the unselected control family.

Genotypes - Probability values from the analysis of data for the balanced factorial with E19, E40 and E46 female parents each crossed with E29, E33, E154 and E182 male parents are set out in Table 9. The means for main effects and interactions are compared in Table 10. For standing values all Female main effects were significant or highly significant, while Male effects were significant at ages 4, 12 and 16 years. Female*Male interactions were significant. The Female x P interaction was significant at ages 4, 6 and 9, accounting for the Family*P interactions recorded in Table 4. The Male x P interactions were not significant. For growth in increment periods both the Female and Male main effects were not significant from age 9 to 12 years (Table 9). The Female x Male interaction was significant for all intervals. The Female x P interaction was significant over the 4 to 9 year period of height growth measurement.

Discussion

Sites - Blocks 1, 2 and 3 are sited on soil Types G, H and I, respectively, which are described by Havel (1976) as follows;-

Type G. Deep , dry pale sands which are strongly leached throughout and occur on lower slopes in the transition zone, and slopes and dune crests within the Bassendean Dune System.

Type H. Deep pale grey sands, dry at the surface, moist at depth, strongly leached throughout; occurring on sub-flats and around swamps in the transition zone and within the Bassendean Dune System.

Type I. Moist soils with dark grey humosoid surface and organic deposition horizon at depth occurring within the transition zone and Bassendean Dune System.

Plantation suitability is best on Type I and poorest on site G. Site index is not available for the trial but mean stand height for uniform stocking at stand age 9 years was 8.59, 7.86 and 6.97 m and mean basal area 15.17, 12.48 and 10.41 m^2 ha^{-1} for blocks 3(I), 2(H) and 1(G), respectively. It should be noted however, that without artificial thinning drought mortality was much greater on block 3, the moister site.

The percentage improvement of treatments P2 and P3 over P1 appeared to be considerably more effective in blocks 1 and 2 (i.e. on the drier sites) than in Block 3 (Table 11). Up to stand age 4 years the only difference in P addition was the second dose of 57 g per tree at age 2. This resulted in height increases of 15 to 24 per cent for P3. By age 6, P3 and P2 received a further 500 kg ha^{-1} of superphosphate more than P1 (Table 1) resulting in further increments over P1 of 48 per cent and 28 per cent, respectively. At this time the second application to P3 in year 2 resulted in 14 per cent better height growth in Blocks 2 and 3 and 30 per cent better growth in Block 1. The advantage of the second, early addition to height growth was still measurable at age 9 years, particularly on the driest site 1. The effects of these early fertiliser additions to P2 and P3 and not P1 was accentuated in the basal area data at age 9 with P2 approx 20 per cent better than P1 on sites 1 and 2, and

Table 10. Means for main effects and the Male x Female interaction for the genotype factorial.

Female Parent	Male parent E29	E33	E154	E182	Mean
	Height 1975-1980				
E19	1.20	1.12	1.17	1.18	1.16 a
E40	1.20	1.22	1.14	1.12	1.17 ab
E46	1.14	1.15	1.15	1.15	1.15 ac
Mean	1.18 a	1.17 a	1.15 a	1.15 b	1.16
	Basal area 1980-1987				
E19	1.982	1.764	1.832	2.311	1.972 a
E40	1.840	2.111	2.185	1.964	2.025 a
E46	1.988	1.933	1.803	2.174	1.974 a
Mean	1.937 a	1.936 a	1.940 a	2.150 a	1.991

Table 11. Percentage increase or decrease of P2 and P3 treatments over P1 within each block.

Block	Fert	Ht75	Ht77	Ht80	Ht7580	BA80	BA87	BA8087
	P1	0	0	0	0	0	0	0
1(G)	P2	0	16.4	20.5	32.4	37.9	9.3	-4.1
	P3	23.5	47.3	38.0	46.1	81.7	22.4	-5.1
	P1	0	0	0	0	0	0	0
2(H)	P2	0	28.0	22.8	27.4	39.9	11.0	-7.1
	P3	14.8	42.6	28.7	31.7	59.9	14.0	-14.6
	P1	0	0	0	0	0	0	0
3(I)	P2	0	8.3	7.8	11.1	17.2	6.0	-9.2
	P3	15.0	22.8	13.5	12.9	30.8	19.1	5.2

approximately half this amount on the wetter site 3. P3 was 30 to 40 per cent better than P1 on the drier sites and 14 per cent better on the wetter site. With the cessation of fertiliser additions in 1983 and stand adjustments due to drought mortality from age 9 to age 12, increments for P levels were more comparable at age 16. It is possible that regular fertiliser addition is more beneficial to the drier sites in the early 6 years. From age 6, one application of 500 kg ha^{-1} to P2 at year 12 was as effective as two in P1 and three in P3.

Fertiliser requirement

The overall result for fertiliser treatments is summarised by the growth means for height in 1975-80 (4-9 years) and basal area in 1980-87 (9-12 years) in Figures 1 and 2 and Table 3. Superphosphate added at 2 year intervals from stand age 2 to age 8 years to give P3 > P2 = P1 in amount added, caused a P3 > P2 > P1 growth response. This pattern in stand size, established by age 6 years, was largely the response to fertiliser additions at ages 2 and 4 years. Although P1 received additions at age 6 and 8 years and P2 did not, P1 did not make up the early advantage in stand development provided by the earlier fertiliser addition to P2 at age 4 years (Table 1). Additions from age 8 to age 12 did not influence growth response between treatments. Nitrogen addition tended to depress height growth up to age 9 years but favoured basal area development after age 9 years. The effect was not significant.

The trial covers main planting sites in the Bassendean Dunes sands and the transitional sands. Although a control was not present it can be accepted that the standard dose of 57 g of superphosphate at time of planting was effective. On the dry sites at least, it seems essential to broadcast a further 500 kg ha^{-1} by age 4 years. Further doses at approximately 4 year intervals should be beneficial.

Nitrogen was tested only at the rate of 250 kg ha^{-1} of ammonium sulphate. This had no useful effect and gave no indication that regular applications would be beneficial. If N is to be effective in association with P additions on these sites it is expected that amounts in excess of 400 kg ha^{-1} of urea are required. These could not be economical.

Families ands Genotype

An aim of the trial was to see if specific parents reacted differently to applied fertiliser. A Family x P interaction present in early standing height and basal area at age 9 years (Table 4) was further associated with a Female x P interaction amongst the genotypes (Table 9). The trend lines for the interaction depicted in Figure 3 show the interaction to be associated with a low response of parent E46 to the P2 level of fertiliser treatment. The differences which appeared at age 4 years are carried through in standing heights but are not reflected in increment data over the major trial period They are considered to be minimal and of no great concern to practice.

The Female x Male genotype interactions were pronounced throughout the trial (Table 9). In Table 12 changes in Family ranking over the period of stand development are compared. There is shuffling for ranking but not in general groupings of families within quartiles. Exceptions such family S17 being poorest in stand basal area in 1983 but second best in 1987 exist. For height at 4 years and basal area at 9 years, E182 formed the best cross with E19, E33 with E40 and E182 with the E46 female (Table 13). This was also the priority order for crossing throughout the 4 to 9 year period of height measurement (Fig. 4). From 9 to 16 years E154 was equally as effective as E33 for crossing with E40, the other priorities holding. Differences between male

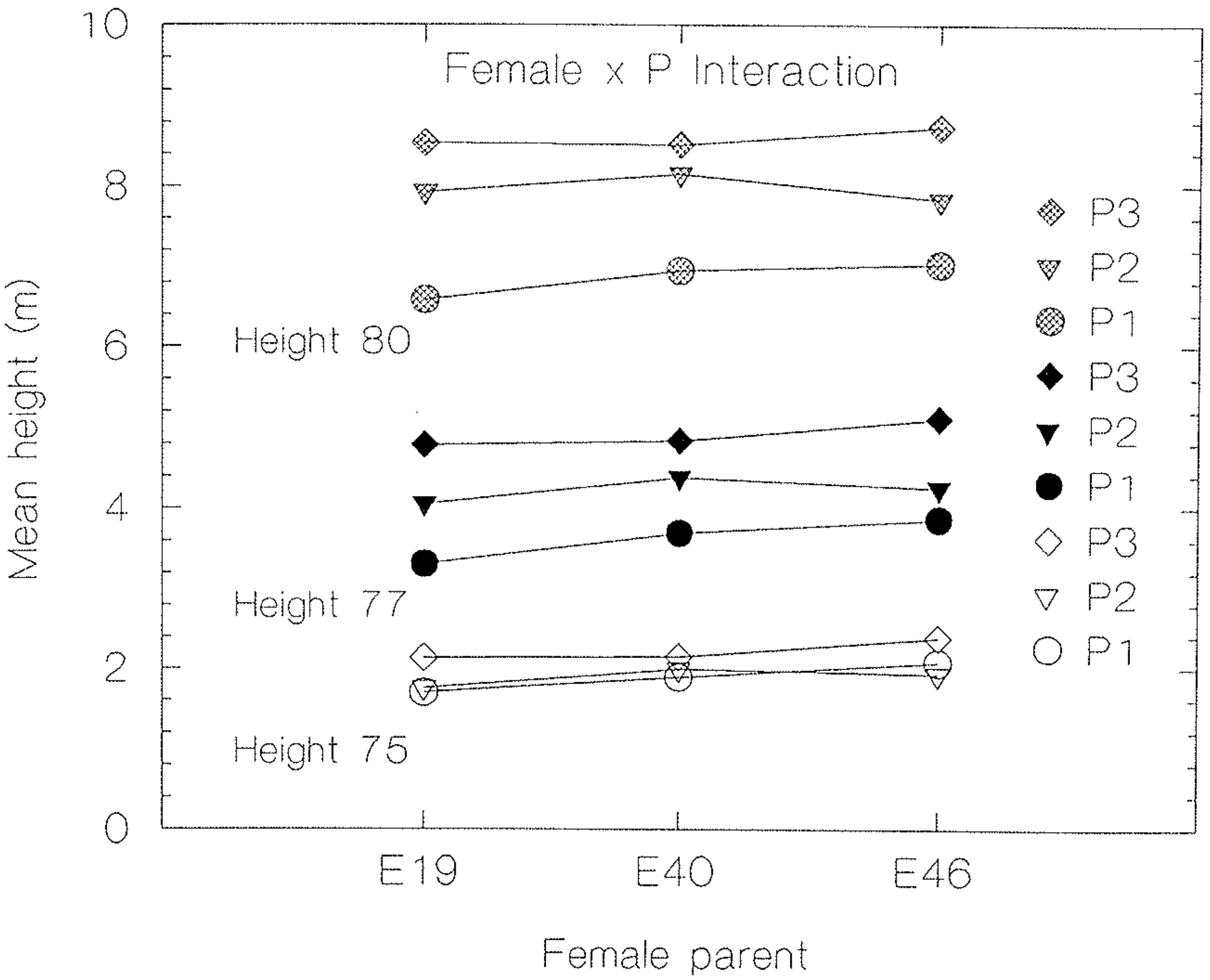

Figure 3. Trend lines for the Female x P interaction recorded in the trial.

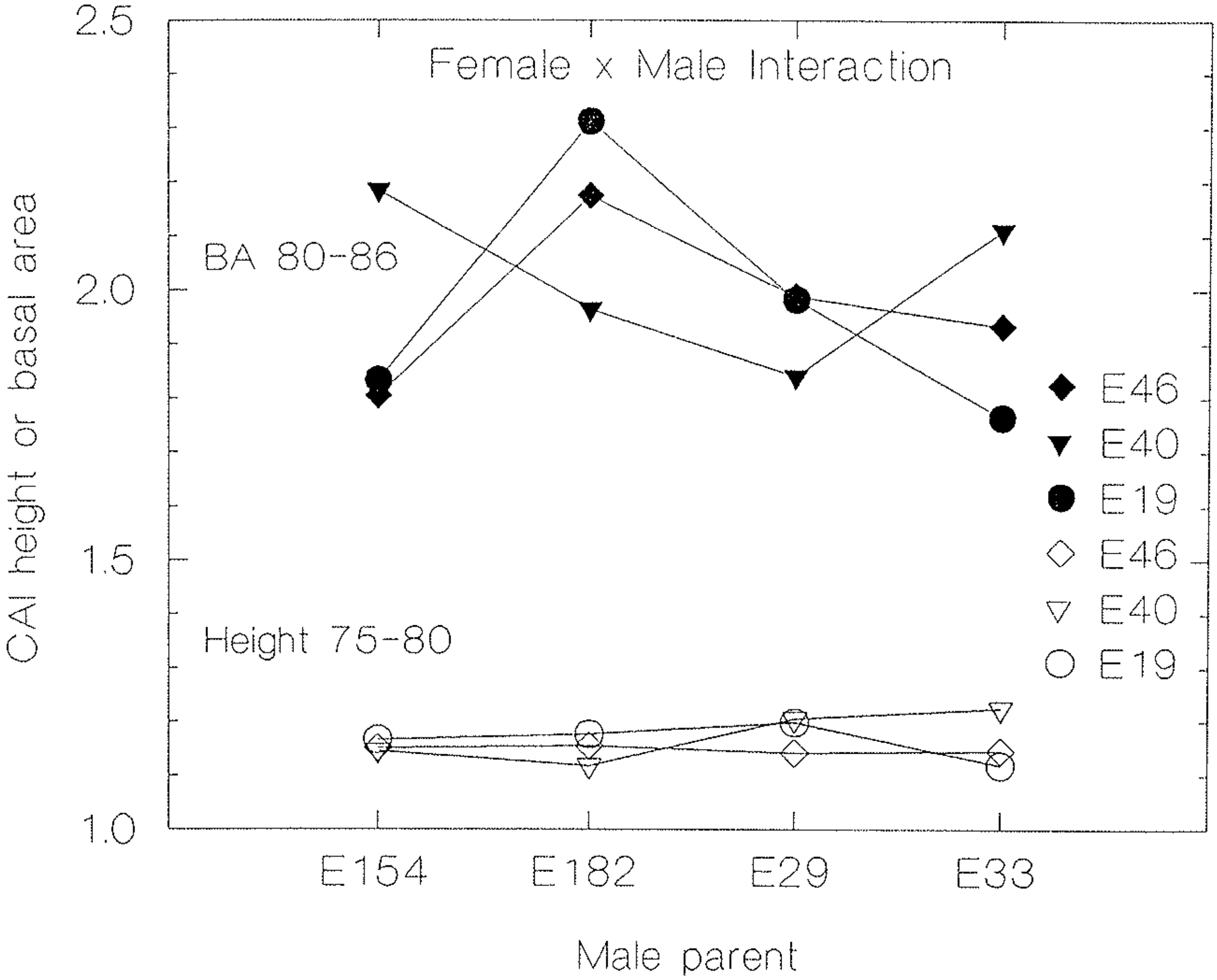

Figure 4. The nature of the Female x Male interaction present in the trial.

parents and female parents were not significant at the .05 level for both the 4 to 9 year and 9 to 16 year increment periods (Table 9).

Table 12 . Ranking of the performance of families with balanced genotypes for each measurement and growth interval to indicate variability during the trial. Ranking is from poorest (1) to best (12).

Family	Female	Male	Ht75	Ht77	Ht80	BA80	BA83	BA87
S17	E19	E 29	2	3	6	2	3	4
S55	E19	E 33	1	1	1	1	1	1
S56	E19	E154	3	2	3	3	2	2
S57	E19	E182	6	6	9	9	10	12
S63	E40	E 29	4	4	10	4	4	5
S64	E40	E 33	10	12	12	12	1	10
S99	E40	E154	7	7	4	7	8	9
S100	E40	E182	5	5	2	5	6	6
S125	E46	E 29	8	9	5	10	9	8
S161	E46	E 33	11	11	8	8	7	7
S168	E46	E154	9	8	7	6	5	3
S202	E46	E182	12	10	11	11	12	11

Family	Female	Male	H7577	H7780	H7580	B8083	B8387	B8087
S17	E19	E 29	10	10	10	7	6	7
S55	E19	E 33	2	5	2	1	8	1
S56	E19	E154	1	11	8	2	3	3
S57	E19	E182	4	8	9	12	12	12
S63	E40	E 29	9	12	11	3	2	4
S64	E40	E 33	12	9	12	8	10	9
S99	E40	E154	5	4	4	9	11	11
S100	E40	E182	3	2	1	5	7	6
S125	E46	E 29	8	3	3	10	4	8
S161	E46	E 33	11	5	5	6	5	5
S168	E46	E154	7	6	6	4	1	2
S202	E46	E182	6	7	7	11	9	10

The growth responses for height from age 4 to 9 years and basal area from age 9 to 16 years are considered to best depict genotype performance. No female or male parent was found to differ significantly at the .05 level for basal area growth while E40 was favoured as a superior female parent and E182 as a an inferior male parent for early height growth. The differences in means are however, minimal and not considered to be very relevant to a practical selection program

The major differences in growth between the 15 families examined in the trial were the differences in performance of seed from selected parents from the routine seed batch imported from Portugal (used for commercial establishment at that time). Selection and use of the best 3 families ranked on basal area (Table 8) would provide 60 per cent greater basal area growth and 11 per cent better height growth than the routine commercial mixture included in the trial.

WP 8/72 - Post establishment Fertiliser Application to *Pinus pinaster* on the Bassendean Sands.

Summary and Conclusions.

The trial tested the effects of N and N+P fertilisers, time of fertiliser application and quantity of fertiliser added on the subsequent growth of a 6 year old stand of *Pinus pinaster* on a typical grey, leached sand of the Bassendean Dunes system at Gnangara. Treatments also compared a thinning regime (T1) to 750 stems ha^{-1} at age 6 and to 250 stems ha^{-1} at age 13 years with (T2) thinning from the original 1800 to 750 stems ha^{-1} at age 13 years. Unfertilised controls were provided for each thinning regime and were compared with individual treatments in a randomised block design with 2 replications. Thinning, fertiliser type, application and quantity were compared as a 2x2x2x2 factorial with 2 replications in a randomised block design. Measurements were made from stand age 6 to age 22 years.

Contrasts of the mean total basal area for T1 fertiliser treatments against the control were highly significant for the stand at ages 17 and 22 years and for the 10-13, 13-17 and 6-22 year increment periods. For the T2 regime the fertiliser differences were significant at all measurements and for all increment periods, showing the dense stand to be most responsive to fertiliser addition. Significance of the P treatments against controls was similar to that for the total treatment comparisons but not as marked as that for the N+P treatments. The contrast of P = N+P was not significant.

Contrast analysis for a select crop of 247 stems ha^{-1} and a final crop of 100 stems ha^{-1} showed significance similar to that above but with greater sensitivity to the P treatments for both thinning regimes and for the N+P treatments of T1. Contrasts of N+P for select and final crop were not significant for the T2 treatments.

Factorial analysis confirmed that Thinning had the greatest and a highly significant main effect with Application time of second importance. There was no evidence in the main effects to suggest any important influences of using N fertiliser or doubling the amounts of fertiliser at time of application. Thinning was the only significant effect for total basal area over the whole period of the trial but Application (.031 level) and Replication (0.000 level) were also significant over the whole period for the select and final crop stands. A significant P x N interaction for total stand basal area in the initial 6-8 year period can be ignored but the A x N interaction was highly significant (.003) for the 6-8 year period and significant for the 8-10, 10-17 and 17-22 year increment periods for basal area and volume of the select crop. Although of a minor nature the interaction may mask some real impact of Nitrogen addition. Any N effect under conditions of the trial was of minimal influence.

Neither procedure for fertiliser application was superior over the period of the trial. A response to fertiliser was recorded for the application at age 6 years and the effect was maintained for up to 4 years. From the trial, fertilisation with 0.4 t ha^{-1}

superphosphate at age 6 years and at approximately 7 year intervals thereafter would appear to be satisfactory. It is possible that additions of less than 0.4 t ha^{-1} would suffice.

On such sites, which are at the low limit of what would generally be considered satisfactory for planting, the volume of a select crop may be increased by 60 to 70 per cent by the above fertiliser program

Introduction

The objective of the trial was to determine the limits of fertiliser requirements for *Pinus pinaster* stands on grey sands of the Bassendean Dunes, between the time of the early release thinning and the first commercial thinning.

The trial began in February 1972 in compartments 20 and 21, Section F of the Gnangara Plantation. It was established on 36 plots of .04 ha (20 m x 20 m) area. The pine was planted in 1966 with 60 g of superphosphate per seedling added as a spot application.

The type of fertiliser added, the quantity of fertiliser, the frequency of addition and the influence of stand thinning were all studied in a factorial design within 2 randomised blocks. Unfertilised controls were included for each thinning regime to allow contrasts between fertiliser and control to be evaluated in the randomised block design.

Procedure

Plot selection - Fifty plots of 20 m x 20 m dimension and separated by at least 7 m buffer were selected as the most uniform stands in stocking and quality. Heights and diameter over bark at breast height (dbhob) were measured for the best 10 stems per plot and the plots were ranked on the basis of mean height and basal area. The most uniform 36 plots were separated into two blocks and the treatments were randomly allocated to the 18 plots within each block.

Treatments - Details of the 18 treatments and the design are provided in Table 1.

Phosphate - Two levels of superphosphate (P) were applied as 0.4 tonne ha^{-1} and 0.8 t ha^{-1}.

Nitrogen - Two levels of nitrogen (N) were compared as zero urea and 0.15 t ha^{-1} urea.

Application - One regime (A1) applied fertilisers at 9 year intervals in 1972 and 1981. The second regime (A2) used a 7 year application period starting later in 1976 and repeated in 1983.

Thinning - One half of the plots were released to the best 750 stems ha^{-1} at age 6 and to the best 247 stems ha^{-1} at age 13 (T1). The alternative late thinned treatment (T2) reduced the original stand of 1800 stems ha^{-1} to the best 750 stems ha^{-1} at age 13 years.

Treatments were randomised as a 2x2x2x2 factorial experiment and the T1 and T2 unfertilised controls within the 2 uniformity blocks.

Table 1. Design and treatment schedule for WP 8/72. The trial was established in 1972 in stands planted in 1966 at 1800 stems ha^{-1} with 60 g of superphosphate $tree^{-1}$.

	Factor 1	Factor 2				Factor 3	Factor 4	Factor 5	
Treat.	Thinning	Application				Phosphate	Nitrogen	Replication	
No	s ha^{-1}(age)	72	81	76	83	t ha^{-1}	t ha^{-1}	1**	2
1	750 at 6 yr	6*	15			0.4t	nil	6	4
2	250 at 13 yr	6	15			0.4t	Urea 0.15t	25	15
3		6	15			0.8t	nil	16	33
4		6	15			0.8t	Urea 0.15t	5	11
5				10	17	0.4t	nil	30	1
6				10	17	0.4t	Urea 0.15t	17	21
7				10	17	0.8t	nil	23	9
8				10	17	0.8t	Urea 0.15t	29	36
9	1800 at 6 yr	6*	15			0.4t	nil	27	14
10	750 at 13 yr	6	15			0.4t	Urea 0.15t	10	19
11		6	15			0.8t	nil	22	20
12		6	15			0.8t	Urea 0.15t	26	32
13				10	17	0.4t	nil	28	8
14				10	17	0.4t	Urea 0.15t	7	13
15				10	17	0.8t	nil	35	31
16				10	17	0.8t	Urea 0.15t	34	18
17	750 at 6 yr, 250 at 13 yr					No added fertiliser		24	3
18	1800 at 6 yr, 750 at 13 yr					No added fertiliser		2	12

* Stand age at fertiliser application
** Plot number

Measurements - The trial was measured as follows:

August 1972, age 6.1 year - Dbhob and height.
March 1974, age 7.7 years - Dbhob and height.
February 1975, age 8.6 years - Dbhob and height.
July 1976, age 10.0 years - Dbhob and height.
August 1978, age 12.1 years - Dbhob
July 1979, age 13.0 years - Dbhob and select crop tree (247 stems ha^{-1}) height.
July 1980, age 14.0 years - Dbhob
July 1981, age 15.0 years - Dbhob
July 1982, age 16.0 years - Dbhob
July 1983, age 17.0 years - Dbhob and all heights
July 1984, age 18.0 years - Dbhob and select crop tree heights
August 1985, age 19.1 years - Dbhob and select crop tree heights
August 1986, age 20.1 years - Dbhob.
April 1987, age 20.7 years - Dbhob and final crop (100 stems ha

$^{-1}$) heights.
December 1988, age 22.3 years - Dbhob and final crop height.

Maintenance - Fertilisers were broadcast by hand to each plot in late winter following the schedule in Table 1. For the initial fertiliser applications (A1) in 1972 and (A2) in 1976 the rates of superphosphate were increased to 0.5 t ha^{-1} and 1.0 t ha^{-1} and the nitrogen source to 0.25 t ha^{-1} of ammonium sulphate.

Table 2. Results for total basal area of the 18 treatments in trial 8/72 analysed as a randomised block design. The values are the probabilities of treatment differences or selected contrasts occurring by chance.

Contrasts Key

1. T1 Fertiliser = control 1 (treat 1-8 = treat 17)
2. T2 Fertiliser = control 2 (treat 9-16 = treat 18)
3. T1 P = control 1 (treat 1,3,5,7 = treat 17)
4. T1 N+P = control 1 (treat 2,4,6,8 = treat 17)
5. T2 P = control 2 (treat 9,11,13,15 = treat 18)
6. T2 N+P = control 2 (treat 10,12,14,16 = treat 18)
7. T1 P = N+P (treat 1,3 5,7 = treat 2,4 6,8)
8. T2 P = N+P (treat 9,11,13,15 = treat 10,12,14,16)

Age	Treatment	Contrast							
(years)	p value	1	2	3	4	5	6	7	8
		Basal area							
8	.004	.244	.000	.291	.246	.944	.855	.860	.689
10	.004	.154	.000	.200	.152	.334	.736	.793	.318
13	.008	.061	.000	.291	.059	.099	.334	.722	.251
17	.000	.002	.000	.006	.001	.001	.000	.280	.507
22	.000	.008	.000	.021	.006	.023	.009	.343	.473
6-8	.001	.041	.000	.063	.042	.150	.263	.750	.587
8-10	.005	.084	.001	.126	.078	.006	.124	.676	.030
10-13	.012	.013	.000	.025	.013	.004	.017	.623	.260
14-17	.000	.002	.000	.006	.002	.007	.003	.443	.549
17-22	.002	.094	.000	.161	.074	.636	.358	.497	.474
6-22	.001	.054	.000	.101	.043	.027	.010	.477	.465

All trees were low pruned to height 2.1 m at the start of the trial in 1972. The marked 247 stems ha^{-1} select crop trees were further pruned to height 4.1 m in 1977 at age 11, and to 5.5 m in 1979 at age 13 years.

In 1979 at age 13 years all plots in T1 were thinned to the 247 stems ha^{-1} select crop trees and those in T2 were reduced to 750 stems ha^{-1}.

Foliar sampling - Foliar samples were taken from 6 final crop trees in each plot and analysed for N, P and K content in February 1973 and February 1976 following the first two fertiliser applications.

Table 3. Results of the 18 treatments in trial 8/72 analysed for select crop (247 stems ha^{-1}) basal area and volume as a randomised block design. The values are the probabilities of treatment differences or selected contrasts occurring by chance.

Contrasts Key

1. T1 Fertiliser = control 1 (treat 1-8 = treat 17)
2. T2 Fertiliser = control 2 (treat 9-16 = treat 18)
3. T1 P = control 1 (treat 1,3,5,7 = treat 17)
4. T1 N+P = control 1 (treat 2,4,6,8 = treat 17)
5. T2 P = control 2 (treat 9,11,13,15 = treat 18)
6. T2 N+P = control 2 (treat 10,12,14,16 = treat 18)
7. T1 P = N+P (treat 1,3 5,7 = treat 2,4 6,8)
8. T2 P = N+P (treat 9,11,13,15 = treat 10,12,14,16)

Age (years)	Treatment p value	Contrast 1	2	3	4	5	6	7	8
					Basal area				
8	.003	.013	.299	.028	.011	.051	.048	.461	.954
10	.000	.005	.007	.017	.013	.017	.026	.215	.744
13	.000	.001	.000	.003	.000	.005	.017	.089	.398
18	.000	.000	.000	.000	.000	.004	.010	.104	.502
22	.000	.000	.000	.001	.000	.031	.057	.163	.622
6-8	.000	.000	.003	.000	.000	.227	.090	.085	.399
8-10	.001	.001	.001	.004	.001	.631	.635	.244	.940
10-13	.000	.002	.000	.008	.001	.162	.734	.099	.095
13-18	.000	.000	.000	.001	.000	.043	.263	.320	.122
18-22	.000	.005	.000	.014	.004	.827	.822	.370	.486
8-22	.000	.000	.000	.001	.004	.127	.052	.127	.650
					Volume				
6-8	.000	.001	.244	.002	.001	.017	.005	.607	.407
8-10	.000	.007	.003	.015	.006	.014	.058	.490	.283
10-18	.000	.000	.000	.000	.000	.003	.023	.387	.181
18-22	.000	.002	.000	.006	.002	.164	.300	.390	.551
6-22	.000	.000	.000	.000	.000	.061	.019	.265	.369

Results

Treatment means for basal area of the total stand and select crop volume are depicted in Figures 1, 2 and 3. In Figures 1 and 2 the means for T1 and T2 thinning treatments are compared separately with their unfertilised controls. Figure 3 relates T1 treatments with T2 treatments. In the first 2 comparisons the A2 treatments are filled to facilitate treatment identification and comparison. The T2 treatments are filled in the third comparison which includes only those fertiliser treatments with N added. Total basal area standing at each measurement (top) and within successive increments periods (centre) are compared in each figure. Increment for measurement periods was the most

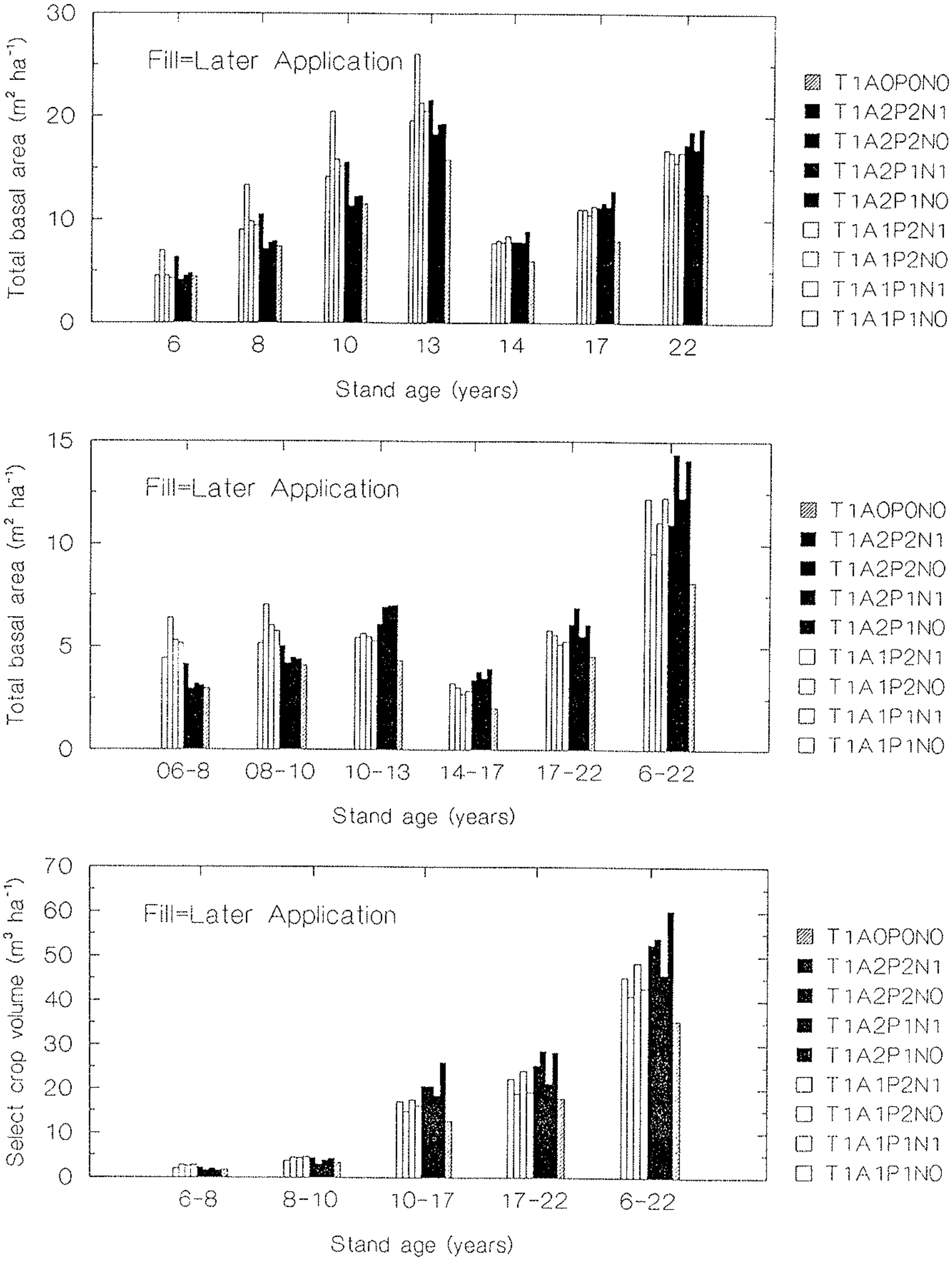

Figure 1. Comparisons of the early thinned treatments(T1) with the unfertilised control(T1A0P0N0) for total stand basal area for each measurement and increment period and for total volume of the select crop (247 ha^{-1}) for increment periods.

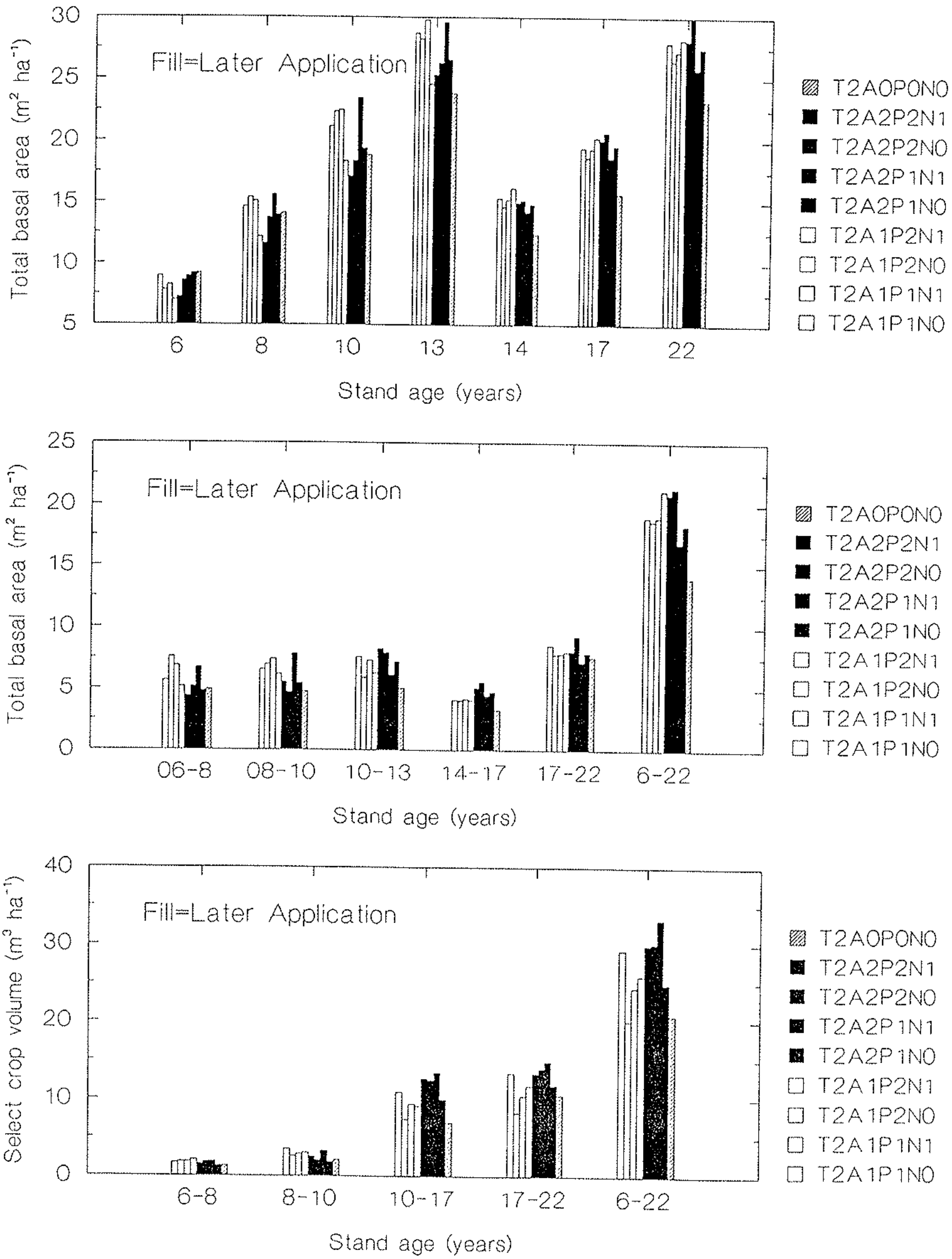

Figure 2. Comparisons of late thinned treatments (T2) with the non-fertilised control (T2A0P0N0) for total standing basal area for each measurement and increment period and for total volume of the select crop (247 stems ha^{-1}) for increment periods.

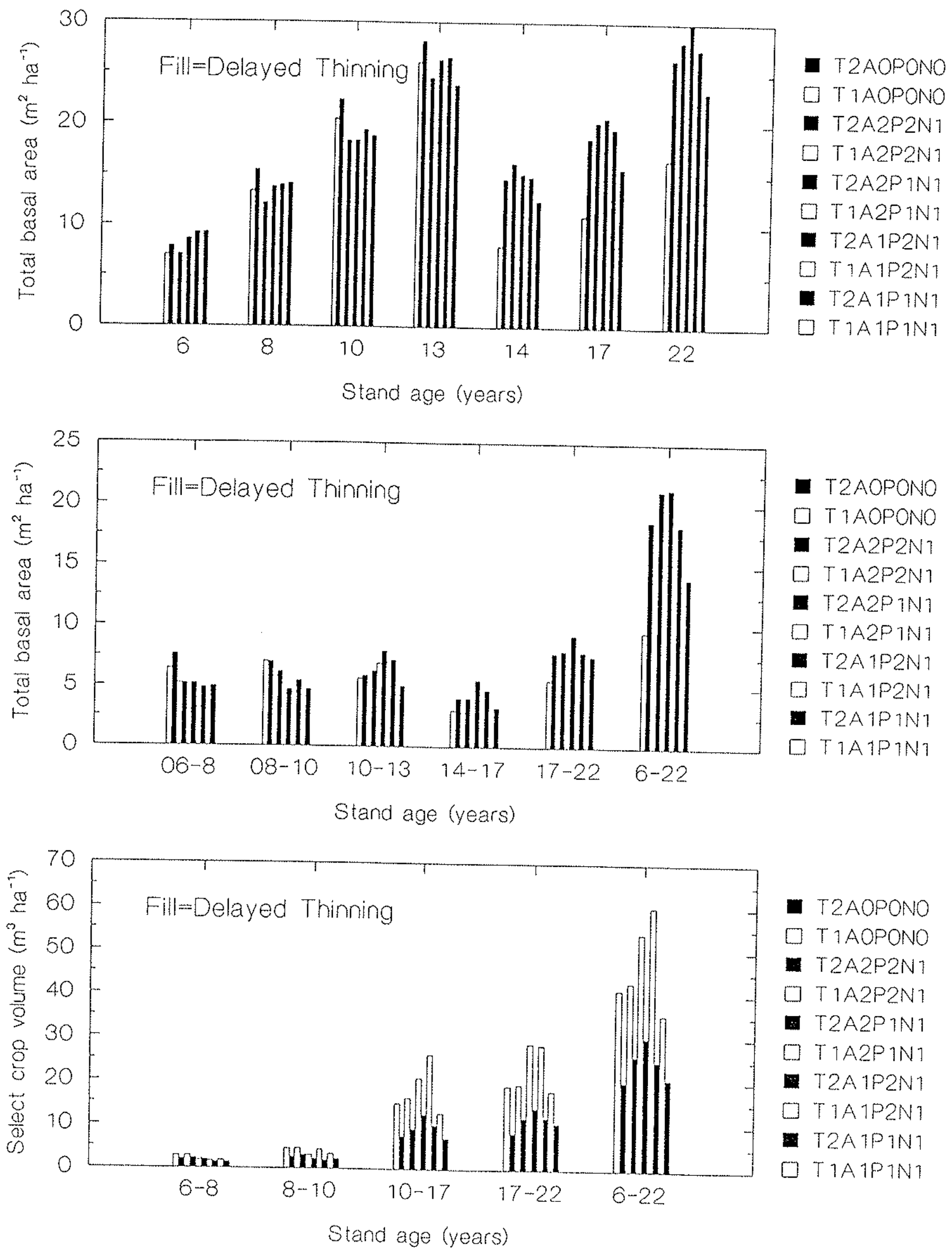

Figure 3. Comparisons of early thinning (T1) and late thinning (T2 - filled) regimes for treatments with nitrogen added (N2) with the non-fertilised controls. Means are presented for total standing basal area for each measurement and increment period and for total volume of the select crop (247 stems ha^{-1}) for increment periods .

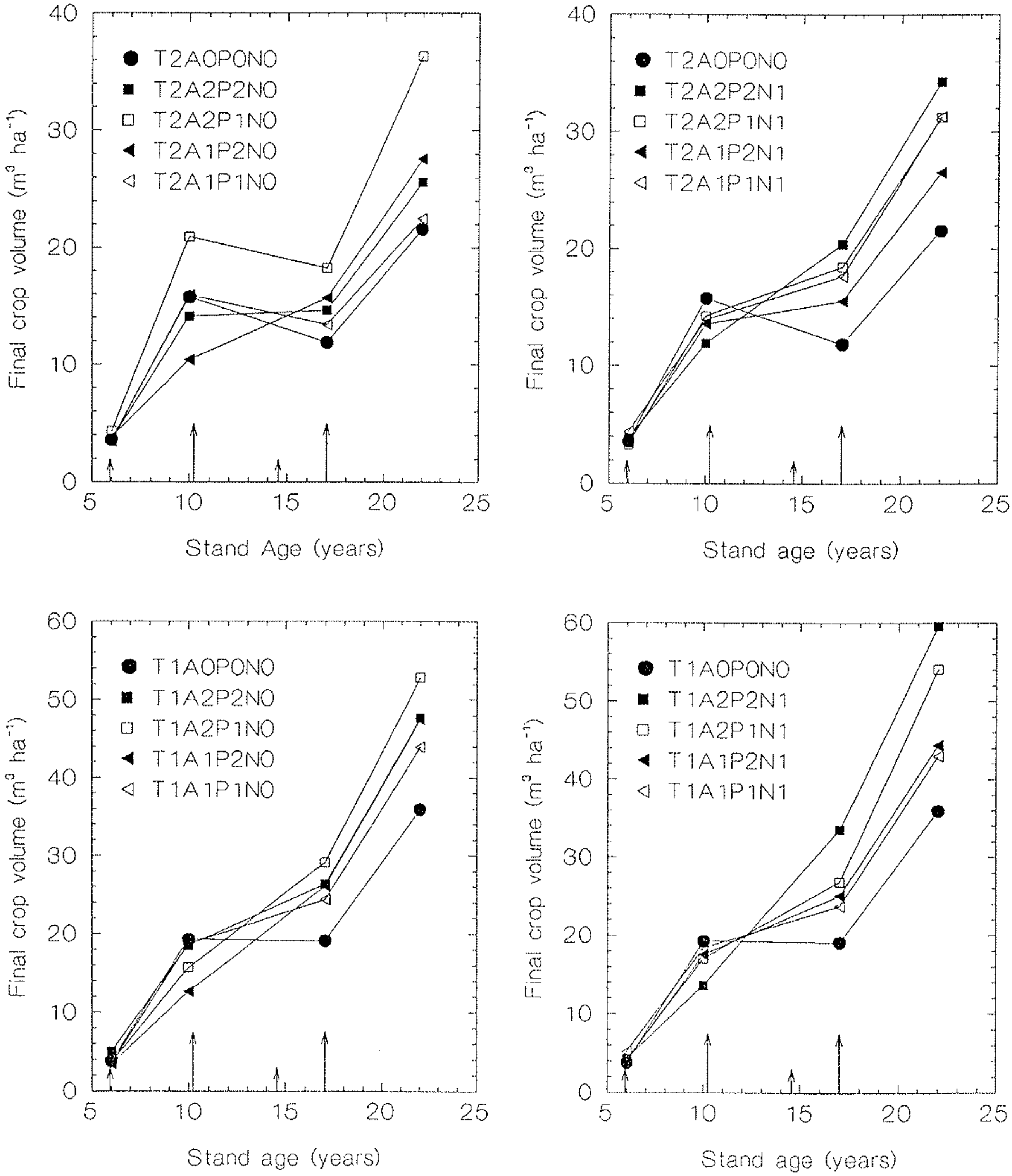

Figure 4. Comparison with and without nitrogen for late thinned treatments (top pair) and early thinned treatments (bottom pair). The means are volume of the final crop (100 stems ha^{-1}) selection.

responsive to treatment and is also presented for select crop volume (bottom) in each of the three figures. Comparisons of standing final crop volumes (100 stems ha^{-1}) with the controls are depicted in Figure 4.

Treatment analysis - The 18 treatments were analysed as a randomised block design for treatment effects and selected contrasts. This was carried out for both basal area and volume data at major measurements and for the increment between each measurement. Data was calculated for the total stand (Table 2), the select crop marked as 247 stems ha^{-1} (Table 3) and the final crop marked for the best 100 stems ha^{-1}.

Results showing the significance of the calculated F values for basal area of the total stand and basal area and volume analysis for the select crop are set out in Tables 2 and 3. The significance of probabilities at the .05 level for the values for the final crop did not differ from that of the select crop in Table 3, hence the data is not presented.

Total basal area - Treatment differences were significant for all measurements (Table 2). Contrast of the fertilised early thinned plots (T1) with the control was significant at ages 17 and 22 years and for the 6-8, 10-13 and 14-17 year increment periods. The T2 (late thinned treatments) contrast of fertilised treatments with control was much more responsive to fertiliser and highly significant at all measurements and increment periods.

Contrasts for P and N+P with the control for T1 treatments were again significant at the 17 and 22 year measurement and for the 10-13 and 14-17 year increment periods. The N+P contrast was also significant for the entire 6-22 year treatment interval.

With the delayed thinning T2 the P contrast within total basal area was significant at ages 17 and 22 years and for the 8-10 , 10-13, 14-17 and whole 6-22 year increment intervals. Significance for N+P was similar to P with the exception of non-significance in the 8-10 year interval. Contrasts of P against N+P for both T1 and T2 (Table 2, columns 7 and 8) were not significant during the trial.

Select and final crops - Response of the select stand was generally more sensitive to fertiliser additions (Table 3) than for the whole stand, particularly for the T1 treatments. The fertiliser contrast with control was significant throughout the trial except for the age 8, T2 measurement (Table 3). All P and N+P treatments for T1 were significant. For T2 the select crop P and N+P basal areas were significant for standing measurements but not significant for either fertiliser in increment periods from age 6 to age 22 years (Table 3, columns 5 and 6). The P contrast with N+P was not significant for the select or final crops throughout the trial.

Contrasts for the final crop did not vary from those obtained for the select crop above the .05 level of significance.

Factorial analysis - Treatments 1 to 16 were analysed as a 2x2x2x2 factorial within 2 randomised blocks. Analysis was for basal area for the total stand and basal area and total volume for both the select crop and the final crop (Tables 4, 5 and 6).

Table 4 Analysis of variance of total stand basal area (m^2 ha^{-1}) for the factorial design in trial 8/72 for three measurements.

		1976		1983		1988	
	DF	Mean square	p	Mean square	p	Mean square	p
Thinning	1	258.44	.000	537.98	.000	879.00	.000
Application	1	51.21	.027	2.52	.067	7.28	.056
Phosphate	1	0.21	.881	0.00	.984	3.27	.190
Nitrogen	1	2.26	.621	2.34	.077	6.07	.079
Replicate	1	47.29	.032	16.40	.000	30.01	.001
T*A	1	8.24	.348	0.51	.394	2.72	.230
T*P	1	13.78	.229	0.49	.403	0.71	.534
T*N	1	6.53	.403	0.14	.652	0.12	.795
A*P	1	15.76	.199	0.83	.279	2.81	.223
A*N	1	11.38	.272	0.77	.297	5.10	.105
P*N	1	22.51	.128	1.81	.116	2.28	.270
Error	20	8.93		0.67		1.77	
Total	31						

The major variation in the data was associated with the thinning treatment (Table 4, Fig. 5). The large mean square for application in the 10 year data (1976) results from the fact that the P and N treatments for A2 were not applied until after the 1976 measurement.

Table 5 Analysis of variance for total stand basal area within the factorial design in trial 8/72. The table shows the probability that the treatment effect obtained for successive increment periods could be due to chance. The error mean square for the increment period is in brackets.

Source	df	Stand age (years)					
		6-8	8-10	10-13	14-17	17-22	6-22
Thinning	1	.001	.002	.003	.000	.000	.000
Application	1	.000	.001	.003	.000	.101	.351
Phosphate	1	.876	.330	.373	.093	.010	.769
Nitrogen	1	.893	.176	.618	.199	.164	.263
Replicate	1	.434	.059	.006	.013	.039	.663
T*A	1	.218	.362	.219	.530	.163	.295
T*P	1	.518	.106	.148	.414	.829	.292
T*N	1	.608	.057	.219	.870	.970	.988
A*P	1	.331	.196	.486	.559	.251	.141
A*N	1	.129	.048	.072	.095	.045	.326
P*N	1	.017	.059	.729	.873	.805	.392
Error	20	(.968)	(.675)	(.634)	(.131)	(.418)	(5.413)
Total	31						

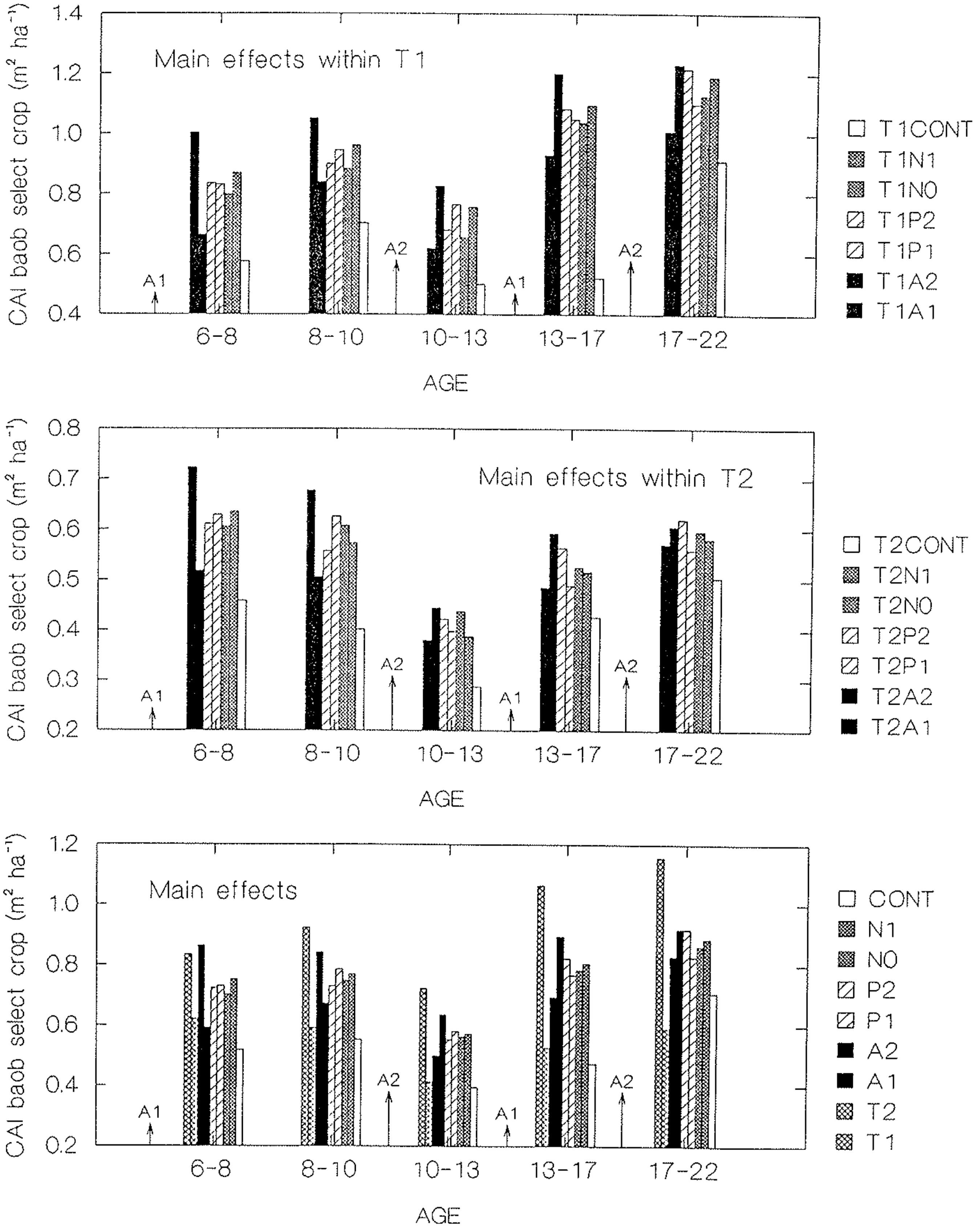

Figure 5. Mean values of main effects and control for basal area of the select crop for successive increment periods. Main effects are expressed within T1 early thinning (upper), within T2 late thinning (middle) and for the whole data set (lower). The relative positions of A1 early and A2 late fertiliser applications are marked by arrows to explain the Application response. Fertiliser was added by ages 6 and 15 years for A1 and 10 and 17 years for A2.

Probabilities for the F ratio from the analysis of variance of the factorials are set out in Tables 5 and 6 for the total stand and the select crop, respectively.

Table 6 Analysis of variance for the basal area of Select crop and Final crop stems within the factorial design in trial 8/72. The table shows the probability that the treatment effect obtained for successive increment periods could be due to chance. The error mean square for the increment period is in brackets.

Source	DF	Stand age (years)				
		6-8	8-10	10-17	17-22	6-22
		Select stand (247 stems ha^{-1})				
Thinning	1	0.000	0.000	0.000	0.000	0.000
Application	1	0.000	0.000	0.000	0.015	0.031
Phosphate	1	0.547	0.169	0.641	0.022	0.194
Nitrogen	1	0.275	0.745	0.923	0.823	0.859
Replicate	1	0.000	0.000	0.000	0.001	0.000
T*A	1	0.060	0.678	0.091	0.122	0.147
T*P	1	0.859	0.917	0.336	0.361	0.941
T*N	1	0.793	0.154	0.076	0.230	0.120
A*P	1	0.110	0.914	0.814	0.593	0.791
A*N	1	0.003	0.049	0.045	0.043	0.099
P*N	1	0.459	0.113	0.097	0.398	0.167
Error	20	(0.196)	(0.988)	(18.490)	(26.180)	(93.600)
Total	31					
		Final crop (100 stems ha^{-1})				
Thinning	1	0.000	0.000	0.000	0.000	0.000
Application	1	0.000	0.035	0.000	0.004	0.003
Phosphate	1	0.619	0.331	0.593	0.809	0.833
Nitrogen	1	0.990	0.200	0.575	0.641	0.534
Replicate	1	0.001	0.001	0.000	0.002	0.000
T*A	1	0.105	0.809	0.182	0.322	0.305
T*P	1	0.914	0.510	0.328	0.808	0.737
T*N	1	0.726	0.132	0.098	0.380	0.196
A*P	1	0.141	0.755	0.961	0.406	0.603
A*N	1	0.003	0.093	0.094	0.038	0.133
P*N	1	0.232	0.510	0.209	0.579	0.411
Error	20	(0.077)	(0.382)	(5.103)	(9.840)	(32.320)
Total	31					
		6-8	8-10	10-17	17-22	6-22

Thinning and replication effects were significant over all increment periods during the trial.

Application. - For total basal area (Table 5) the significant application effect at age 10 years and for the 6-8, 8-10, 10-13 and 14-17 year increment periods show the response to timing of fertiliser application. Only the A1 treatments were fertilised

```
  Treatment  Mean            Individual 95% CI
                  -------+---------+---------+---------+----
  1 T1A1P1N0 0.94          (-----*------)
  2 T1A1P1N1 1.32                         (-----*------)
  3 T1A1P2N0 0.94          (-----*------)
  4 T1A1P2N1 1.13                 (-----*------)
  5 T1A2P1N0 0.76   (-----*------)
  6 T1A2P1N1 0.91         (-----*------)
  7 T1A2P2N0 0.94          (-----*------)
  8 T1A2P2N1 0.99            (-----*------)
  9 T2A1P1N0 0.85      (-----*------)
 10 T2A1P1N1 0.92         (-----*------)
 11 T2A1P2N0 0.75  (-----*------)
 12 T2A1P2N1 1.03             (-----*------)
 13 T2A2P1N0 0.84      (-----*------)
 14 T2A2P1N1 0.76  (-----*------)
 15 T2A2P2N0 0.74  (-----*------)
 16 T2A2P2N1 0.84      (-----*------)
 17 T1A0P0N0 0.90        (-----*------)
 18 T2A0P0N0 0.80    (-----*------)
                  -------+---------+---------+---------+----
                     0.750     1.000     1.250     1.500
```

Figure 6. Means and confidence intervals for per cent N obtained in treatments for foliar sampling in February 1973. Fertiliser was applied for A1 six months prior to sampling but A2 is yet to be applied.

```
  Treatment  Mean            Individual 95% CI
                    --+---------+---------+---------+--------
  1 T1A1P1N0 0.209                     (--*--)
  2 T1A1P1N1 0.242                          (--*--)
  3 T1A1P2N0 0.312                                    (--*--)
  4 T1A1P2N1 0.318                                     (-*--)
  5 T1A2P1N0 0.073 (--*--)
  6 T1A2P1N1 0.084   (--*--)
  7 T1A2P2N0 0.074  (--*--)
  8 T1A2P2N1 0.070 (--*--)
  9 T2A1P1N0 0.179                 (--*--)
 10 T2A1P1N1 0.185                  (-*--)
 11 T2A1P2N0 0.238                         (--*--)
 12 T2A1P2N1 0.281                               (--*--)
 13 T2A2P1N0 0.085   (--*--)
 14 T2A2P1N1 0.075  (--*--)
 15 T2A2P2N0 0.092    (--*--)
 16 T2A2P2N1 0.093    (--*--)
 17 T1A0P0N0 0.074  (--*--)
 18 T2A0P0N0 0.075  (--*--)
                    --+---------+---------+---------+--------
                    0.070     0.140     0.210     0.280
```

Figure 7. Means and confidence intervals for per cent P obtained in treatments for foliar sampling in February 1973. Fertiliser was applied for A1 six months prior to sampling but A2 is yet to be applied.

in 1972 (6 years) hence there is no response in the A2 treatments in the 6-8 and 8-10 year period (Figs. 1, 2 and 5). The first A2 application was in 1976 (Table 1) at age 10 years and resulted in a marked response in all A2 treatments. The initial A1 treatment had ceased to be effective by this stage and the effect in the 10-13 year period was due to a superiority of the A2 treatments (Fig. 5). This was maintained in the 14-17 year period despite a further application in 1981 at age 15 years for the A1 treatments. Differences between A1 and A2 were not significant for total basal area in the 17-22 year period despite a further application to the A2 in 1983 at age 17 years. The select crop (Table 6) and the final crop (Fig. 4) were more responsive to application and the impact of A continued to be significant over the whole period of the trial. The final crop was most sensitive with significance for the entire 6-22 year increment period being at the .003 level. Delaying the application until age 10 and repeating at the more frequent 7 year interval provided the most benefit of the two options compared.

```
 Treatment  Mean            Individual 95% CI
                  --+---------+---------+---------+---------
 1 T1A1P1N0 0.58              (-------*-------)
 2 T1A1P1N1 0.52        (-------*-------)
 3 T1A1P2N0 0.61                (-------*-------)
 4 T1A1P2N1 0.70                       (-------*-------)
 5 T1A2P1N0 0.49      (-------*-------)
 6 T1A2P1N1 0.50       (-------*-------)
 7 T1A2P2N0 0.44  (-------*-------)
 8 T1A2P2N1 0.51        (-------*-------)
 9 T2A1P1N0 0.49      (-------*-------)
10 T2A1P1N1 0.54          (-------*-------)
11 T2A1P2N0 0.52         (-------*-------)
12 T2A1P2N1 0.47    (-------*-------)
13 T2A2P1N0 0.56            (-------*-------)
14 T2A2P1N1 0.49      (-------*-------)
15 T2A2P2N0 0.47    (-------*-------)
16 T2A2P2N1 0.51       (-------*-------)
17 T1A0P0N0 0.43 (-------*-------)
18 T2A0P0N0 0.47    (-------*-------)
                  --+---------+---------+---------+---------
                  0.360     0.480     0.600     0.720
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Figure 8. Means and confidence intervals for per cent K obtained in treatments for foliar sampling in February 1973. Fertiliser was applied for A1 6 months prior to sampling but A2 is yet to be applied.

Foliar analysis - Results of analysis for N, P and K in the 1973 data are summarised in Figures 6 to 8. Application 2 had not been applied and means for this factor level are comparable to the relevant control for each thinning level. The impact of adding urea and superphosphate in single or double dose is apparent. Foliar contents were also noticeably smaller in T2 than in T1

Analysis of the factorial design without the controls (Table 7) revealed significant interaction (Table 8) due largely to the fact that A2 acted as an unfertilised control. Increases in foliar N and P after the urea addition and the double dose of superphosphate were highly significant. Contents of foliar N and P were also significantly greater in T1 than in T2.

Table 7. Means value for N, P and K foliar contents in February 1973 for main effects and significant interactions within the factorial design. Only A1 was applied at that stage of trial development

	N (%)	P (%)	K (%)			N (%)	P (%)	K (%)
Thinning				Thin*Application				
1	0.995	0.173	0.546	1	1	1.086	0.270	0.603
2	0.843	0.153	0.507	1	2	0.903	0.075	0.490
				2	1	0.890	0.221	0.506
Application				2	2	0.796	0.086	0.508
1	0.988	0.245	0.555	Appl*Phosphate				
2	0.850	0.080	0.499	1	1	1.011	0.204	0.533
				1	2	0.965	0.287	0.576
Phosphate				2	1	0.820	0.079	0.512
1	0.915	0.141	0.523	2	2	0.880	0.082	0.486
2	0.922	0.185	0.531	Appl*Nitrogen				
				1	0	0.872	0.234	0.552
Nitrogen				1	1	1.103	0.256	0.557
0	0.847	0.157	0.523	2	0	0.822	0.081	0.493
1	0.990	0.168	0.531	2	1	0.877	0.080	0.505

Table 8. Summary of the factorial analysis for the 1973 foliar sampling. The p values are the probability that the F obtained would be exceeded by chance.

		N (%)	P (%)	K (%)
Source	DF	p	p	p
Thinning	1	0.001	0.002	0.129
Replication	1	0.536	0.105	0.338
Application	1	0.002	0.000	0.037
P	1	0.861	0.000	0.747
N	1	0.001	0.063	0.747
Thin*Appl	1	0.265	0.000	0.030
Thin*P	1	0.836	0.789	0.197
Thin*N	1	0.240	0.911	0.474
Appl*P	1	0.185	0.000	0.182
Appl*N	1	0.034	0.055	0.901
P*N	1	0.762	0.876	0.292
Error	20	0.01197	0.00024	0.00493
Total	31			

Foliar samples in 1976 were mixed when numbering and cannot be used to check field response.

Discussion

Treatments

The response to fertilisers was present 2 years after the first subsequent application at stand age 8 years. This resulted in significant increases in foliar N and P within 6 months of

fertiliser application (Figs. 6, 7, 8, Table 8). It was greatest for total basal area in the T2 late thinned stands (Figs. 1 and 2) and present for both P and N+P additions. The Select crop of the heavily thinned stand (T1) was more responsive to fertiliser than that of the late thinned, more dense stand (T2). This was associated with significantly higher foliar N and P levels (Table 8) in T1 but was probably causally associated more with the extra growing space provided the select trees. The maximum response was thus concentrated on the other than select portion of the dense (T2) stand. P and N+P treatments were similar in effect to suggest that there is no advntage to adding other that P to these stands.

Results of analysis for N, P and K in the 1973 foliar data (Figs. 6 to 8) were prior to Application 2 and means for the A2 levels are comparable to the relevant control for each thinning treatment. Differences for increased addition of P and N fertilisers are apparent and foliar composition (per cent) for each nutrient is less for T2 than for T1. The fact that T2 increment was greater than that of T1 for whole crop but not the select stand suggests that the lower contents measured for N and P in T2 result from dilution through spreading a fixed amount of fertiliser amongst a greater number of stems in T2 than in T1. Variation of foliar nutrient levels of the select crop with stand density was not observed in other trials (WP 20/65, WP 54/66).

Factorial analysis -

Analysis of the factorial design without the controls (Tables 4, 5 and 6) revealed significant interaction (Table 8) due largely to the fact that A2 acted as an unfertilised control. Significance for the T*A interaction for P and K was due to the higher nutrient percentages in the early thinned (T1) as opposed to the late thinned (T2) treatments. The A*P interactions for P content and for N content resulted from the high values for P2A1 and N1A1, respectively (Table 7).

The higher nutrient contents in the early thinning T1 and the application differences noted in Figures 6, 7 and 8 were highly significant for both N and P content (Table 8). The addition of 0.15 t urea (N1) produced a highly significant increase in foliar N and the double dose of superphosphate (P2) produced a highly significant increase in foliar P in comparison to the single dose of 0.4 t superphosphate.

Application - The intention of the application treatments was to assess whether an earlier application was more beneficial than a later application with more frequent treatments. The difference assessed over the whole measurement period from age 6-22 years was not significant for total basal area (Table 5) but increasingly significant for select and final crop stands (Table 6).

Results show that fertiliser effects occurred after the earliest subsequent application at age 6 years (Tables 5 and 6, Figs. 6, 7 and 8). The residual effect of the addition and the impact of successive applications is illustrated in Figure 5 which compares the responses of main effects and controls. Following application A1 at age 6 years the A1 treatments show significant increases in foliar N and P (Figs. 6 and 7) with increment over their A2 counterparts during the 6-8 year growth period for both the T1 and T2. For the 8-10 year increment period in Figure 5 the growth advantage from the application is maintained but at a decreased level. The 10-13 year comparison of means shows an immediate improvement in the A2 treatments following their first fertiliser addition at age 10 years. They outstrip the A1 treatments which maintained a minor but insignificant advantage over growth of the controls during the period.

The second addition of fertiliser for A1 at age 15 years had little impact in redressing the balance between A1 and A2 (Fig. 5). The reason for this is not obvious but it is suggested it is a result of severe drought on the sites from 1977-1978. The severe shortage of soil moisture (which resulted in some tree mortality over the period) may have retarded any growth response. By the time improved water relations returned the added fertiliser had been lost to the stand. In any case the A2 treatment maintained an advantage over the A1 for the 17-22 year period following the second addition for A2 at age 17 years.

The initial dose effect deteriorated significantly within 4 years and by the time the A2 application was applied at age 10 years the effect of the early A1 treatment had diminished. The influence of the 10 year application was greater and more sustained. As a significant response was obtained after application at age 6 years this could be considered as the latest desirable starting age for subsequent fertiliser application, to be followed by a further dressing at age 10 and thereafter at 7 year intervals.

Phosphate - The P main effect was significant only in the 17-22 year increment period for both total stand and select stand (Tables 5 and 6). Throughout the trial the P1 mean was marginally higher than the P2 and for the final increment period the difference in the total basal areas of 15.87 and 15.63 m^2 ha^{-1} for P1 and P2 respectively, proved to be significant.

There is no apparent reason for a more favourable growth from the lower amount of added phosphate. In fact, if the stands were deficient the reverse result would be the most probable outcome. The single significant response for P is hence not taken seriously and the factorial trial indicates that the lower application of 0.4 t ha^{-1} is as good as or superior to the

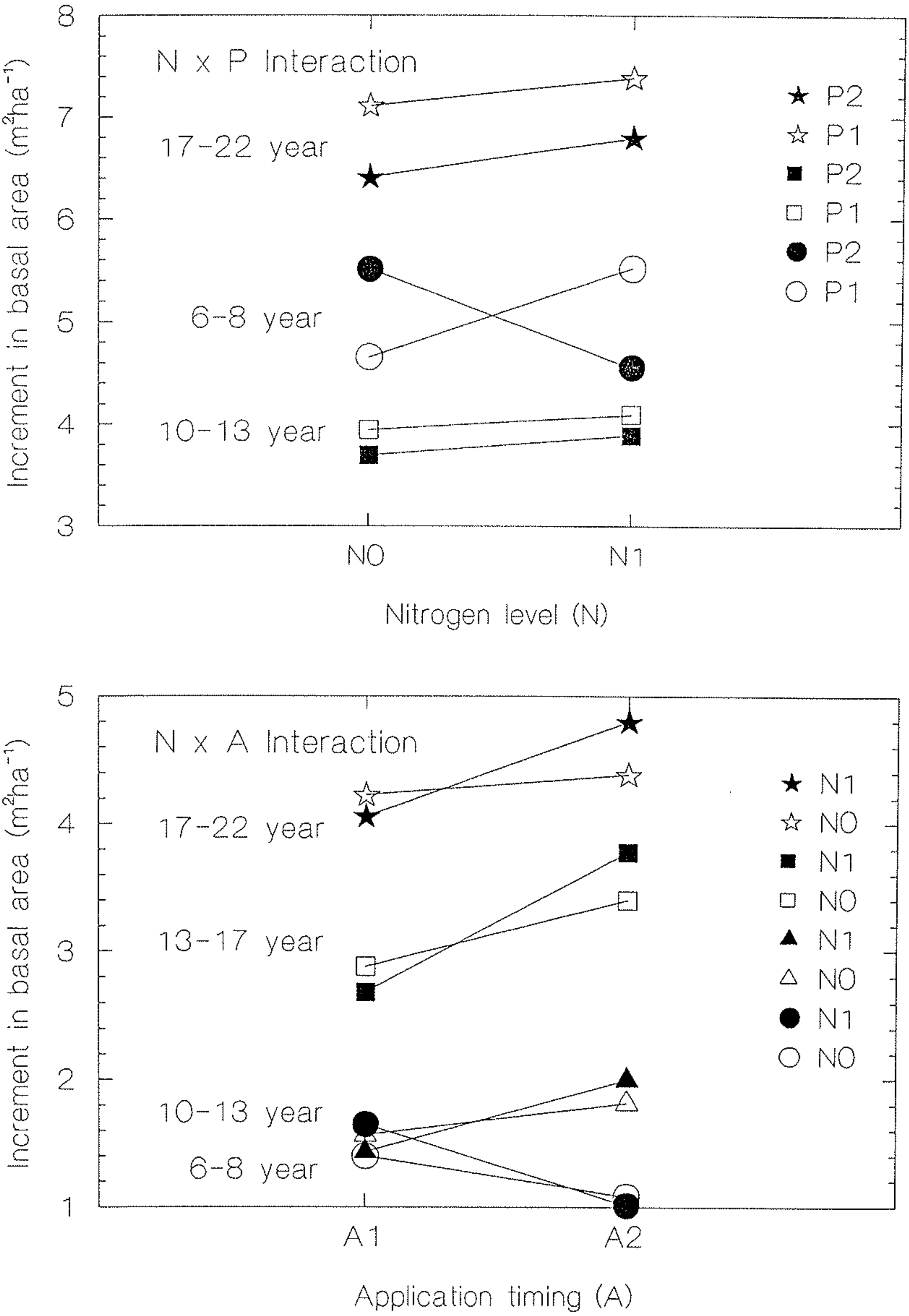

Figure 9. Trend lines for the interactions Nutritition by Application (N x A, bottom) and Nitrogen by Phosphorus (N x P, top).

larger, 0.8 t ha^{-1} dosage. It is quite possible that the 0.4 t ha^{-1} also represents a luxury level of phosphate addition and the optimum dosage may be less than this amount. This cannot be assessed from the trial.

Nitrogen. - There was no indication from the results for the main effect N that added nitrogen had any significant influence on stand growth during the trial (Tables 4, 5 and 6). However, the interaction A x N was significant in the 6-8, 8-10, 10-17 and 17-22 year periods for the select crop (Table 6), in the 8-10 and 17-22 year periods for total basal area (Table 5) and for the 6-8 and 17-22 year period for the final crop (Table 6). The interactions for the 6-8, 10-13, 13-17 and 17-22 year periods for the select stand are plotted in Figure 9. For the initial growth period the ammonium sulphate added at age 6 had a positive effect on growth in the A1 treatments. No N was added to the A2 treatments until age 10 years (Table 1) hence the interaction resulted. This was similar for the 8-10 year period which was excluded from the figure to assist interpretation. At age 10, ammonium sulphate added to the A2N1 treatments marginally improved growth over that of the N0 treatment with no added N fertiliser. For the A1 treatment the N effect deteriorated to the extent that the A1N1 treatments were less than the A1N0 treatments. The interaction depicted by trend lines in Figure 9 for the 10-13, 13-17 and 17-22 year periods remained for all increment periods after age 10 years, at which age A2 was first applied.

The reason for higher values for N1 in the A2 treatments and not for the A1 applications (Fig. 9) is not clear. Evidence indicates that the N1 addition did promote initial growth which is reasonably consistent in the T1 treatment (Figs. 1, 5 and 6) but generally absent in the T2 regime (Figs. 2, 5 and 6). The combined effects are masked in the main effect (Fig. 5, lower). The interaction was not significant for data over the total period and the N effect, whether present and obscured or not, is of a minor extent.

A further interaction for P x N was detected for total basal area in the 6-8 and 8-10 (.059 level) year increment periods (Table 5). This resulted from the P2 mean being slighter greater than the P1 mean for N0 and less than the P1 for N1 as shown in Figure 9. The circled trend lines in the figure show the interaction for the 6-8 year data. The result was identical for the 8-10 year data which has been omitted to allow comparison with the non-significant trends for the 10-13 year and 17-22 year increments. The result was transitory and balanced and is considered to be unimportant to the results shown by the main effects.

Foliar sampling

To a large extent foliar analysis was unsatisfactory. Samples collected in 1976 which would have provided a better record of treatment effects were confused prior to analysis and results could not be related back to field plots. The per cent P values for 1973 are also very high for the high additions of superphosphate. It is believed that this results from the standard graph used for P in analysis being considered as a straight line insted of a parabolla. Experience would suggest that P foliar levels would level at a maximum of 0.1 to 0.15 per cent. The high P values are hence non-realistic from the practical viewpoint but should not confuse interpretation of the trends resulting from superphosphate addition.

Analysis of foliar data for the factorial design without the controls (Table 7) revealed significant interaction (Table 8) due largely to the fact that A2 acted as an unfertilised control. Significance for the T x A interaction for P and K was due to higher nutrient percentages in the early thinned (T1) as opposed to the late thinned (T2) treatments. The A x P interactions for P content and for N content resulted from the high values for P2A1 and N1A1, respectively (Table 7).

The higher nutrient contents in the early thinning T1 and the application differences noted in Figures 6, 7 and 8 were highly significant for both N and P content (Table 8). Addition of 0.15 t urea (N1) produced a highly significant increase in foliar N and the double dose of superphosphate (P2) produced a highly significant increase in foliar P in comparison to the single dose of 0.4 t superphosphate. Improved basal area growth of the select stand following the fertiliser application in 1972 (Fig. 5) was associated with higher levels of N and P in the foliar sampling. In other studies of stand density and stand response in the region (Basal Area Control series, Free Growth Trial) significant differences in nutrient levels have not been associated with widely different stocking levels. Significant increases in growth of the select stand associated with decreasing stand density have however, consistently been recorded to suggest growth differences result from greater water availability and crown space for the released dominants rather than due to increased nutrient availability indicated by foliar levels.

Site Index - Mean heights for the select crop and final crop selection, corresponding to Predominant height and Top height respectively are plotted in Figure 10. Without subsequent fertiliser application the stand represents a Site Index of 14.5 m which is at the low end of the range of favourable sites available for planting in the area. Good fertiliser response would be expected for such sites. In fact total volume of the select crop of 247 stems ha^{-1} was improved 69 per cent by fertiliser application in the early thinned treatments over the 6-22 year trial period. The comparable improvement for the late thinned treatments was 59 per cent. For the 750 stems ha^{-1} remaining in the T2 treatment at age 22 years the MAI of the A2 treatments was 7.0 m^3 ha^{-1} total volume while the relative control had an MAI of 5.3 m^3 ha^{-1}. The actual MAI over the period of the trial cannot be determined as the volumes of the thinnings at age 13 years were not measured.

Water Stress - The height of the late thinned control (T2) progressively became less than that of the early thinned control over the course of measurement (Fig. 10). Such a difference could be related to improved water for tree growth in the early thinned treatments. This possibility was considered in planning

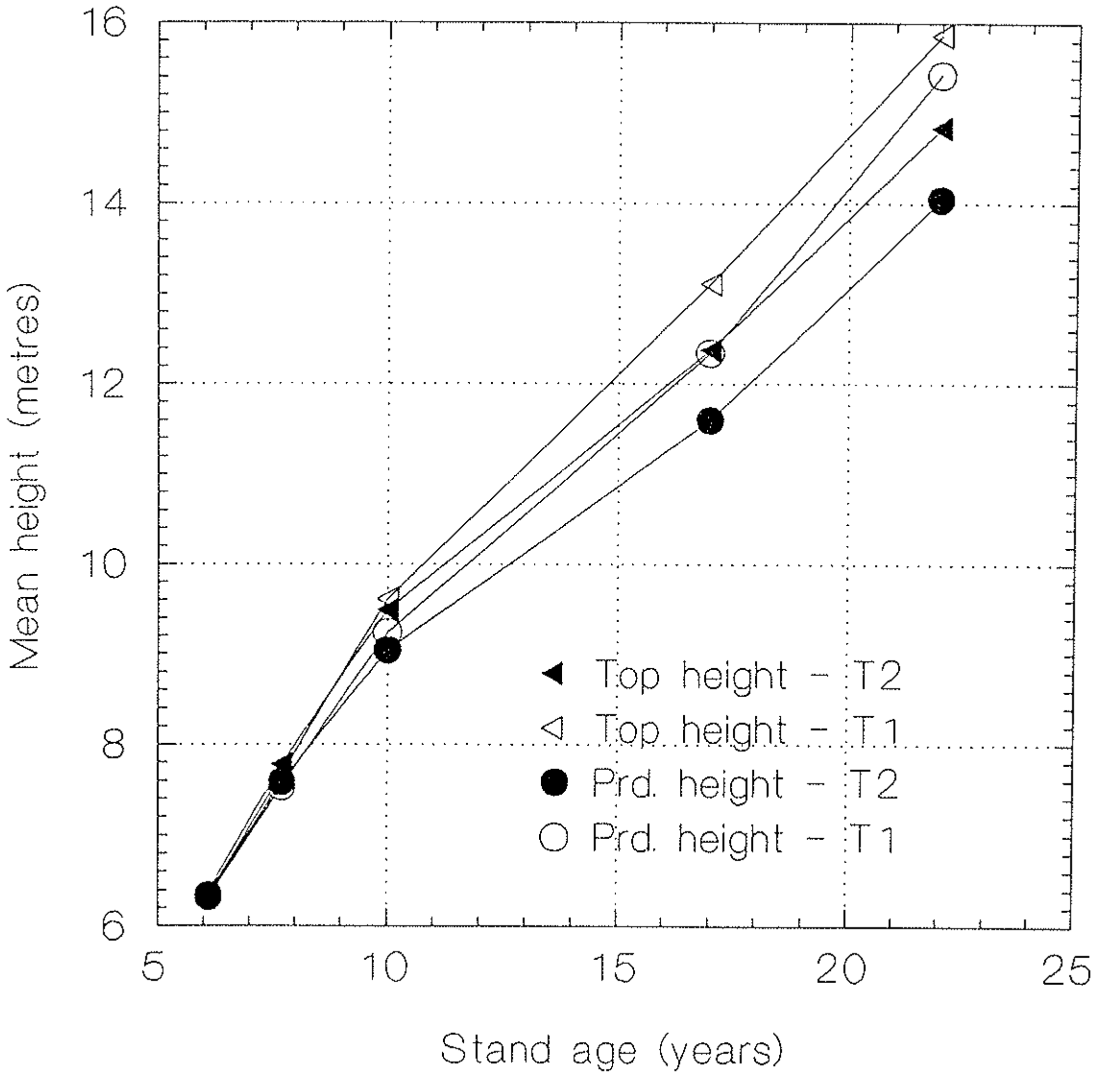

Figure 10. Mean heights for the early thinned (T1) and late thinned (T2) select stand (Predominant height) and final crop (Top height).

the trial and was a main cause for the incorporation of thinning in the trial design. The absence of significant interactions between N, P, and A and T in the analyses (Tables 5 and 6) has, however, discounted the importance of this influence on fertiliser use in the trial. To check, contrasts were calculated between the T1 control and T2 control for both Predominant height and Top height. No Top height differences were significant at measurements or within increment periods. The contrast for Predominant height was significant (.038 level) for the 22 year measurement and the 6-22 (.029 level) and 17-22 (.009 level) increment periods. The significance of these differences was not supported by Bonferroni comparisons of the treatment means. Some heights used to provide this mean were in fact calculated, as only the final crop (100 stems ha^{-1}) trees were measured in 1988. It is therefore suggested that any significance in the height differences between the thinning (T) treatments is associated with the assessment of Predominant height for the age 22 measurement.

WP 23/73 - Post establishment Fertiliser Application to *Pinus pinaster* on the Spearwood Sands.

Summary and Conclusions

The trial aimed to determine limits for fertiliser requirements of *Pinus pinaster* between time of early release thinning and the first commercial thinning for stands on yellow sands of the Spearwood Dunes system. It was established in 1973 in a stand planted in 1965 in Yanchep plantation. The stand was culled to the best 750 stems ha^{-1} at age 8 years.

Treatments to cover 10 and 6 year regimes for application of single and double doses of superphosphate (P), urea (N) and superphosphate and urea (N+P) fertilisers were compared in a 3x2x2 factorial design within 3 randomised blocks. An unfertilised control and a Luxury treatment with high N+P plus a trace element mixture were included within the randomised block design to compare treatment effects. Measurements were analysed for growth from age 8 to 22 years.

The trial was ambitious in attempting to evaluate both the required frequency of fertiliser application and the quantity of fertiliser required at each application. Within the circumstances it was found that the lower quantities at the wider spaced applications were adequate.

Experience with fertiliser applications on similar stands of the species on the leached grey sands of the Bassendean dunes system at Gnangara would suggest that the responses obtained to the amounts and types of fertiliser added were poor and very disappointing. Nitrogen added at the rate of 250 kg ha^{-1} of urea had no significant effect on stand production. There is little to indicate that the volume production of these stands can be maximised by fertiliser addition.

Without further work it is suggested that the use of super, copper, zinc fertiliser at approximately 400 kg ha^{-1}, applied at 10 year intervals is all that is warranted to maintain stands planted.

Introduction.

The trial aimed to determine limits for fertiliser requirements of *Pinus pinaster* between time of early release thinning and the first commercial thinning, for stands developed on yellow sands of the Spearwood Dunes system. It was established in 1973 in a stand planted in 1965 in Compartments 6 and 7 of Yanchep plantation group, Section E.

The trial was designed to compare 13 treatments against a control or as a 3x2x2 balanced factorial with 3 replications to compare effects of N, P and N+P fertilisers at different fertiliser quantities and at different application times.

Establishment

Plot selection - The stand was culled at age 8 years to leave the 750 best stems ha^{-1}. Fifty uniform plots of .04 ha area (20 m x 20 m) were selected to allow at least 11m separation between each plot. The plots were measured for height and diameter at 1.3 m stem height, ranked on the basis of mean height and basal area and separated into the most uniform 3 groups of 14. Fourteen treatments were randomly allocated to each block.

Within each plot the best selections for a final crop of 247 stems ha^{-1} and a select crop of 100 stems ha^{-1} were marked.

Table 1. - Design and schedule for treatments in Working Plan 23/73. The trial was established in 1973 in stands planted in 1965 at 2000 stems ha^{-1} with 60 g of zinc-super per tree.

Factor 1			Factor 2		Factor 3							Factor 4		
Fertiliser			Quantity**		Application							Replication		
1	2	3	1	2	73	83	93	73	79	85	93	1	2	3
Super			375		8*	18	28					17	12	21
Super			375					8	14	20	28	26	35	39
Super				750	8	18	28					18	8	50
Super				750				8	14	20	28	31	14	27
	Urea		125		8	18	28					7	9	34
	urea		125					8	14	20	28	25	15	13
	Urea			250	8	18	28					23	1	33
	Urea			250				8	14	20	28	30	36	46
		N+P	500		8	18	28					48	2	41
		N+P	500					8	14	20	28	16	20	29
		N+P		1000	8	18	28					11	49	32
		N+P		1000				8	14	20	28	5	3	38
Luxury			1000+125 Minorels					8	14	20	28	10	4	22
Control			No fertiliser addition									24	19	6

* Stand age at fertiliser application
** Rate in kg ha^{-1}

Treatments.

The Factorial Design- Three levels of fertiliser types, superphosphate (P), urea (N) and superphosphate + urea (N+P) were compared in a factorial design. Each was considered at single and double quantity levels and with application rates at 10 year or 6 year intervals spanning the stand development period. The design with fertilisers, quantities and application rates is detailed in Table 1. Analysis was on the basis of 36 plots containing a 3x2x2 factorial within 3 randomised blocks.

The Total Design. An unfertilised control and a Luxury fertiliser treatment were also replicated 3 times within the plot allocation to 42 plots (Table 1). This provided for a comparison of 13 treatments against a control in a randomised block design.

Table 2 Summary of values obtained from analysis of variance showing the significance of basal area and volume means for all treatments at different stand ages. Data for the whole crop and the select crop are included.

Stand age (yr)	D.F.	Basal area M.S.	Basal area F	Basal area p	Total volume M.S.	Total volume F	Total volume p
			Total stand				
8	13	0.075	0.44	0.940	-	-	-
9	13	0.249	0.98	0.499	3.483	0.91	0.558
13	13	1.821	1.79	0.100	58.60	1.84	0.091
14	13	0.377	1.43	0.211	-	-	-
18	13	1.730	2.12	0.051	79.29	1.83	0.092
23	13	3.491	1.69	0.123	274.8	1.51	0.179
			Select stand				
8	13	0.006	0.49	0.911	-	-	-
9	13	0.039	1.00	0.477	0.525	0.93	0.535
13	13	0.335	1.94	0.072	15.21	1.83	0.092
14	13	0.068	0.77	0.684	-	-	-
18	13	0.365	1.16	0.360	75.09	1.75	0.110
23	13	0.811	0.87	0.590	64.66	0.93	0.537

Maintenance - The fertiliser additions were made by hand in early spring according to the schedule set in Table 1.

In July 1978 at stand age 13 years the stands were thinned to leave the best 247 crop trees ha^{-1}.

Measurements - Measurements were made as follows:

August 1973 - height and diameter over bark at breast height (dbhob)
July 1974 - height and dbhob
July 1975 - dbhob and height of the select crop (100 stems ha^{-1}) tree.
July 1976 - dbhob and height of the select crop trees.
August 1977 - dbhob and height of the select crop trees.
June 1978 - dbhob and height of the select crop trees. Thinned to 247 stems ha^{-1}
July 1979 - dbhob.
August 1980 - dbhob.
July 1981 - dbhob.
July 1982 - dbhob.
July 1983 - dbhob and heights.
September 1984 - dbhob and select crop heights.
September 1985 - dbhob and select crop heights.
August 1986 - dbhob.
April 1987 - dbhob and select crop heights.
December 1988 - dbhob and select crop heights.

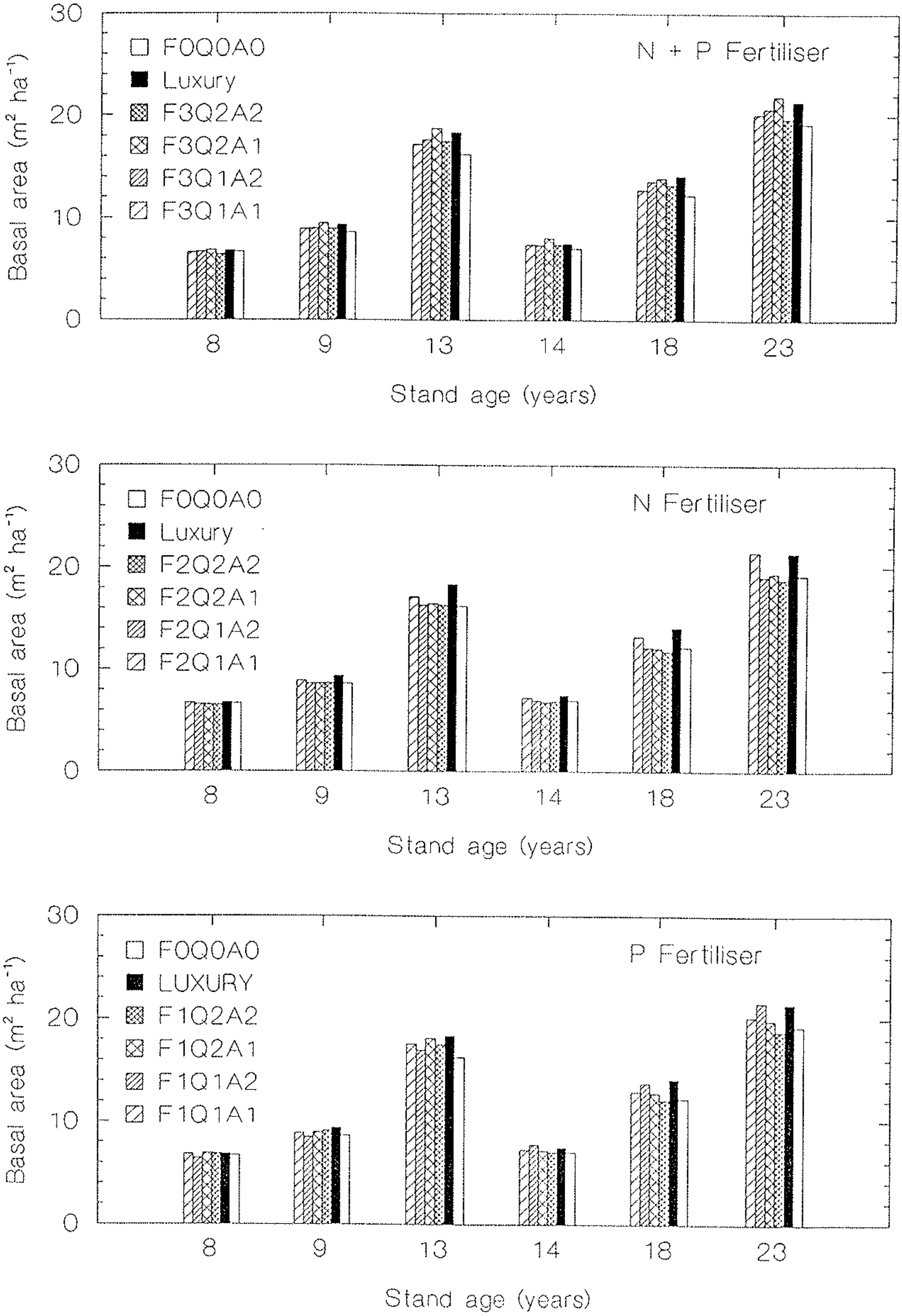

Figure 1. Treatment comparisons within each of the three fertiliser types tested in trial 23/73. Means are for standing basal area for the major measurements and can be related the performance of Luxury and control treatments.

Foliar sampling - In 1975 foliar samples were taken from the final crop selection of each plot and analysed for nitrogen (N), phosphorus (P), manganese (Mn) and zinc (Zn) content.

Results

Means for basal areas of all 13 treatments at 8, 9, 13, 14, 18 and 23 years stand age are plotted in Figure 1. The means are separated into fertiliser types to simplify comparison of each with the Luxury treatment and the unfertilised control.

The thinning in 1978 to 247 stems ha^{-1} at age 13 years reduced the basal area of some plots below that of the 1978 measurement. This provided some questionable results for volumes and the increment data for the 13-18 year period was not considered seriously on its own. Its later inclusion in Table 6 does not complicate analysis as the trends from the data were in accord with that for other measurements and increment intervals. Data was available for basal area at age 14 years, immediately after the thinning, to provide for analysis of the 14-18 year increment period, by-passing the 13-14 thinning interval.

Table 3 Summary of treatment values obtained from analysis of variance showing the significance of basal area and volume increment for different measurement periods. Data for the whole crop and the select crop are included.

Stand		Basal area			Total volume		
age (yr)	D.F.	M.S.	F	p	M.S.	F	p
			Total stand				
8-9	13	0.158	5.96	0.000	-	-	-
9-13	13	0.864	2.45	0.025	38.48	2.18	0.044
14-18	13	0.726	2.75	0.014	-	-	-
18-23	13	0.753	1.52	0.175	102.1	1.53	0.173
8-23	13	3.536	1.86	0.087	247.1	1.51	0.181
			Select stand				
8-9	13	0.033	1.99	0.079	-	-	-
9-13	13	0.167	2.48	0.024	6.643	2.16	0.046
14-18	13	0.165	1.94	0.073	-	-	-
18-23	13	0.219	1.29	0.282	25.13	1.37	0.241
8-23	13	0.902	1.09	0.410	67.56	1.09	0.407

Means for both standing values and the increments between measurements were analysed for basal area and stand volume for both the total stand and the select crop (247 stems ha^{-1}). The probabilities of the F ratios obtained by analysis of variance occurring by chance are listed in Tables 2 and 3.

Treatments had no significant effect on standing values but were significant for the increment in periods 8-9, 9-13 and 14-18 years for the total stand and for the 9-13 year period for the select stand.

Contrasts - Data for the 14 treatments were analysed (Table 4) to determine the probability of the following contrasts:

1. Treatments 1-4 = treatment 14 (P = control)
2. Treatments 5-8 = treatment 14 (N = control)
3. Treatments 9-12 = treatment 14 (N+P = control)
4. Treatments 9-12 = treatment 13 (N+P = luxury)
5. Treatments 9-12 = treatments 1-4 (N+P = P)
6. Treatments 9-12 = treatments 5-8 (N+P = N)
7. Treatment 13 = treatment 14 (luxury = control)
8. Treatments 1-12 = treatment 14 (fertiliser = control)

Table 4 Probabilities of contrasts for standing basal area and volumes.

Contrast	Stand age (years)							
	9	13	14	18	23	8-9	9-13	14-18
	Basal area (m^2 ha^{-1})							
P=control	.860	.063	.960	.273	.362	.085	.013	.250
N=control	.815	.632	.669	.885	.616	.138	.576	.763
N+P=control	.856	.027	.493	.059	.145	.000	.012	.086
N+P=luxury	.593	.386	.688	.207	.407	.248	.428	.017
N+P=P	.573	.531	.462	.189	.373	.000	.965	.348
N+P=N	.934	.018	.263	.008	.144	.000	.005	.019
Lux.=control	.779	.017	.274	.016	.075	.000	.010	.002
Fert.=control	.932	.239	.501	.244	.319	.006	.123	.374
	Total volume (m^3 ha^{-1})							
P=control	.444	.036	-	.275	.380	-	.015	.294
N=control	.633	.573	-	.774	.481	-	.593	.787
N+P=control	.150	.032	-	.090	.232	-	.030	.766
N+P=luxury	.413	.372	-	.211	.491	-	.387	.464
N+P=P	.274	.934	-	.316	.604	-	.631	.236
N+P=N	.302	.013	-	.028	.428	-	.010	.965
Lux.=control	.079	.019	-	.023	.141	-	.018	.728
Fert.=control	.778	.082	-	.267	.320	-	.062	.561
	9	13	14	18	23	8-9	9-13	14-18

Significant contrasts were obtained to show that the P effect was better than the control in the 9-13 year period only (Fig. 2), while the N+P effect was significantly better than the control at ages 13 and 18 years and for the 8-9 and 9-13 year growth periods (Table 4). The N effect did not differ from the control and the N+P effect was significantly better than the P effect in the 8-9 year period. The Luxury fertiliser addition (Treatment 13) was superior to the unfertilised control (Treatment 14) at stand ages 13 and 18 years and for increment of the 8-9, 9-13 and 14-18 year growth periods. The Luxury treatment behaved similarly to the

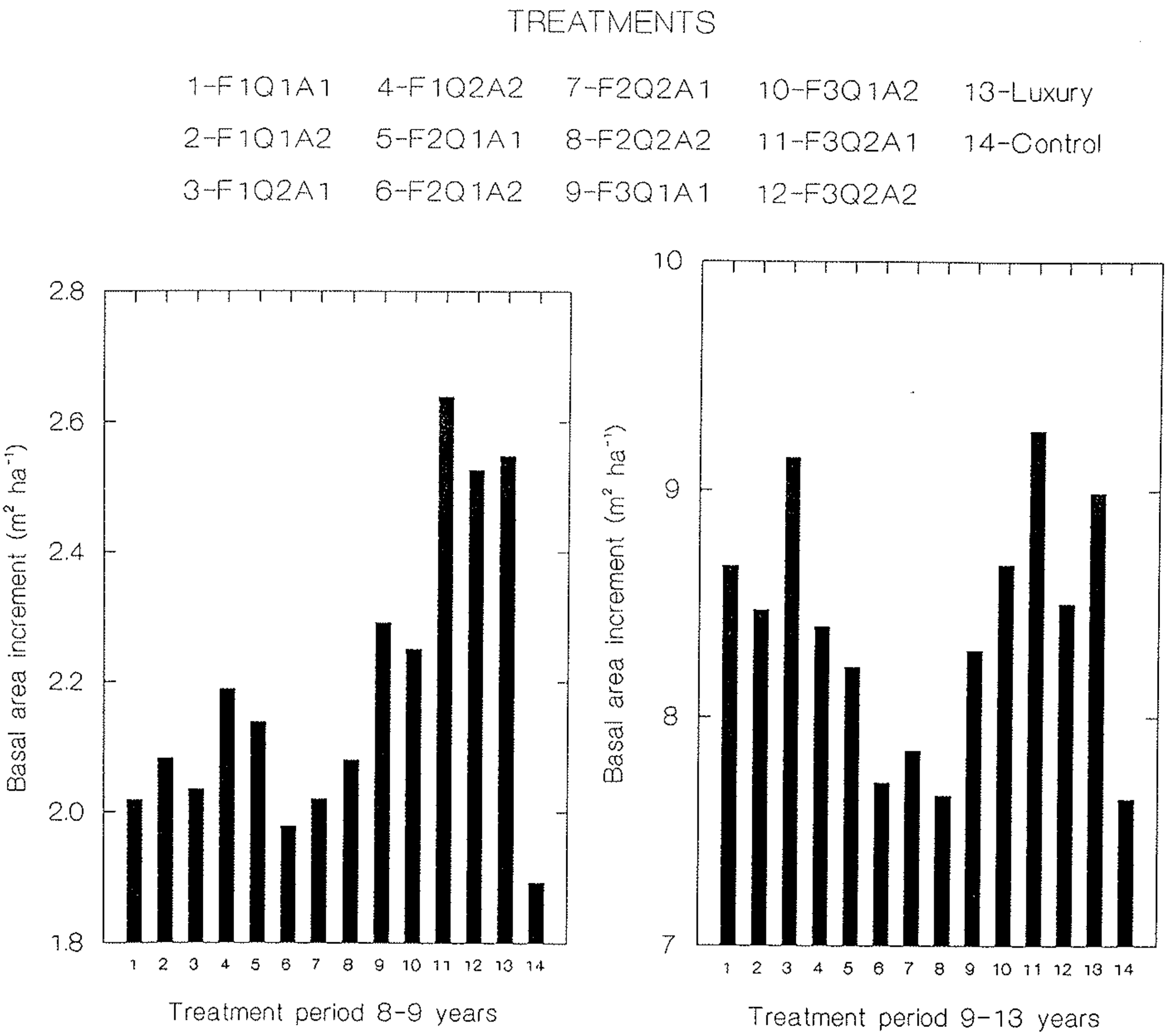

Figure 2. Bar diagrams of treatments for the 8-9 and 9-13 year increment periods showing the initial response of stand growth to fertiliser application.

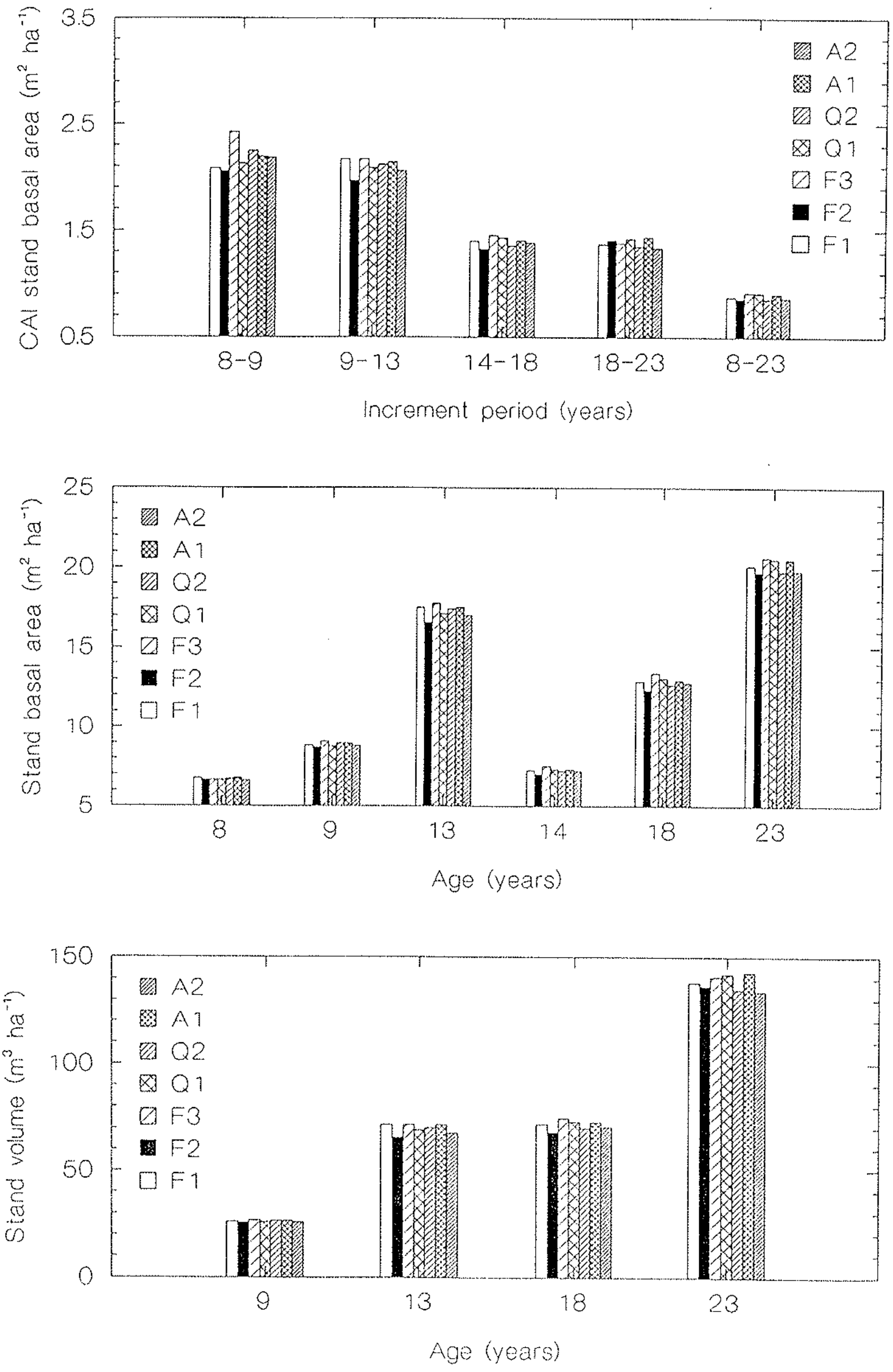

Figure 3. Response of the main effects for basal area and volume in the factorial arrangements of treatments.

N+P effect, the probabilities suggesting a slightly stronger effect and the Luxury treatment was significantly better than the N+P treatment in the 14-18 year increment period (2.54 versus 2.43 m^2 ha^{-1} $year^{-1}$). In this period both the N+P and Luxury effects were also significantly better than the N application (Fig. 2).

Factorial analysis - Data for the first 12 treatments were analysed as a 3x2x2 factorial randomised within 3 blocks. Interactions were not significant. Probabilities obtained for F values for basal area and volume data are set out in Tables 5 and 6.

Table 5 Probabilities for significance of main effects in the factorial analysis for standing basal area and increment periods.

Source	D.F	Stand age (years)					
		8	9	13	14	18	23
Fert	2	0.787	0.207	0.027	0.024	0.028	0.350
Quant	1	0.706	0.323	0.400	0.471	0.183	0.136
Applic	1	0.302	0.381	0.180	0.562	0.583	0.177
Replic	2	0.000	0.000	0.000	0.000	0.001	0.004
		Increment period (years)					
		8-9	9-13	14-18	18-23	9-23	
Fert	2	0.000	0.005	0.073	0.817	0.287	
Quant	1	0.036	0.546	0.098	0.136	0.085	
Applic	1	0.909	0.124	0.657	0.035	0.242	
Replic	2	0.001	0.033	0.039	0.094	0.101	

Significant basal area effects for Fertiliser were obtained for stand ages 13, 14 and 18 years and for the 8-9 and 9-13 year increment periods. A significant Quantity effect recording benefit of the double dose was recorded for basal area in the 8-9 year increment period and for volume in the 13-18 year period (Table 5, Fig. 3).

Table 6 Probabilities for significance of main effects in the factorial analysis for measurement of stand volume.

Source	DF	Stand age (years)							
		9	13	18	23	9-13	13-18	18-23	9-23
Fert	2	.291	.027	.091	.751	.011	.367	.821	.845
Quant	1	.295	.552	.198	.156	.753	.020	.158	.097
Applic	1	.215	.058	.307	.074	.052	.339	.027	.081
Replic	2	.000	.001	.001	.009	.046	.464	.069	.036

The Application effect was significant (.05 level) for both basal area and volume data in the 18-23 year increment period (Fig. 3). Replication or block effects were highly significant for standing data at each measurement.

Foliar analysis - Means for the foliar levels of P, N and Mn are compared in Figure 4. Treatment differences for N and Zn levels were not significant, those for P and Mn were highly significant. Means for Zn are not included in the table as several abnormal results, influencing mainly the Treatment 7 mean, could not be confirmed. For the difference in treatment P means Treatments 1, 2 and 3 with no added P were significantly less than Treatments 4 to 8 with P added in fertiliser (Fig. 4,lower). P levels in Treatments 4-8 did not differ significantly. For Mn (Fig. 4, middle), levels in Treatments 2, 3 and 7 were significantly lower than that in Treatment 8

Table 7. Means from the factorial arrangement of foliar nutrients sampled in 1975.

Effect	N (%)	P (%)	Mn (ppm)	Zn (ppm)	Effect	N (%)	P (%)	Mn (ppm)	Zn (ppm)
Fertiliser (F)					F*Q				
1(P)	0.942	0.078	18.3	14.3	1 1	0.950	0.072	17.0	15.4
2(N)	1.015	0.042	15.6	14.4	1 2	0.935	0.085	19.6	13.2
3(N+P)	0.954	0.075	16.5	9.9	2 1	0.988	0.044	15.5	13.2
					2 2	1.043	0.040	15.8	15.5
Quantity (Q)					3 1	0.965	0.072	17.3	12.1
1	0.967	0.063	16.6	13.6	3 2	0.943	0.078	15.8	7.8
2	0.973	0.068	17.1	12.2					
Replication									
1	0.998	0.065	17.0	12.4					
2	0.960	0.065	16.7	14.7					
3	0.954	0.066	16.7	11.6					

Means for factorial analysis of the foliar data are set out in Table 7. The application term is omitted since the foliar sampling only sampled the initial fertiliser application in 1973 and foliar values refer to levels 2 years after fertiliser application. No significant effects for treatment differences were found for N and Mn. For P, the fertiliser by quantity level was highly significant (.008) due to a depression in P levels associated with urea addition without added P (F2). P levels were also significantly higher for the higher level in the Quantity main effect and for the phosphatic fertilisers 1 and 3 in the Fertiliser main effect (Table 7). For the Zn levels difference in the fertiliser main effect were significant due to low values recorded for the N+P fertiliser additions.

Discussion

Treatments

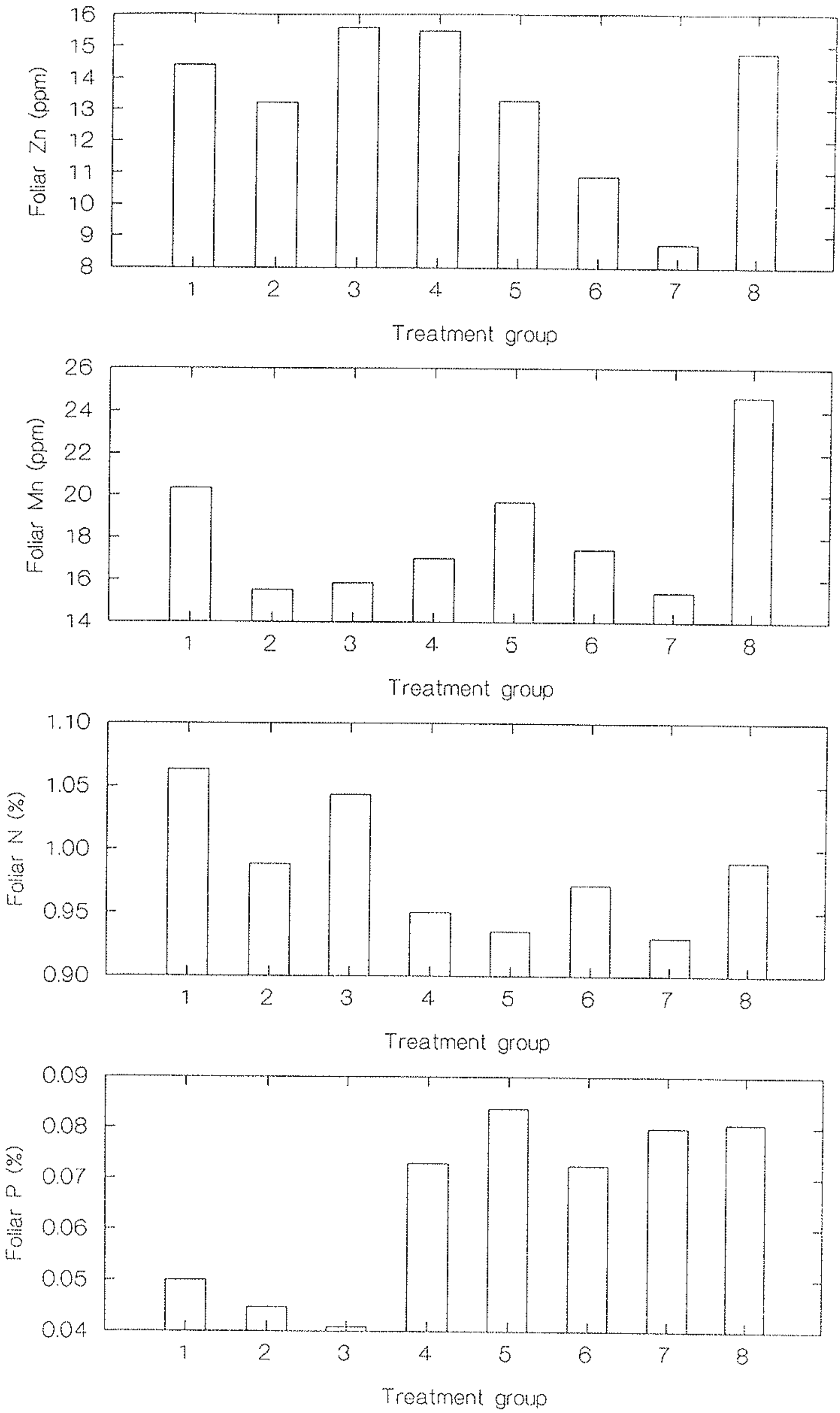

Figure 4. Comparison of mean levels for P, N and Mn obtained for treatments in the 1975 sampling. Treatment differences were not significant for N levels but were significant for P and Mn levels.

Contrasts - A highly significant response for basal area in the first year of treatment (Table 3) was associated with a highly significant contrast for N+P against control(.000 level) and for Luxury against control (Table 4, Fig. 2)). The contrasts of N+P against P and N were also highly significant indicating that the P and N separated produced limited immediate response (Fig. 2). The contrast of Luxury against N+P was not significant immediately after fertiliser addition. Maximum initial response was thus associated with the N+P and Luxury treatments. The P and N responses were of lesser magnitude and not significant. These trends can be seen in Figures 1 and 2.

The treatment response was also significant for the 9-13 and 14-18 year periods (Tables 3 and 4). This was associated with consistently high N+P and Luxury responses at ages 13 and 18 years (Figs. 1 and 2). The P response was also significant for the 9-13 year increment period but N responses were not significant during the trial. Treatment responses expressed in Table 8 as a percentage of the control suggest the best increment obtained for the 9-23 year increment period was of the order of 20 per cent .

Initially the significant contrast of Luxury against N+P was regarded as a possible positive effect of the 125 kg ha^{-1} of minor elements added as Minorels. Minorels is a commercial minor element mix containing calcium 5.0 %, copper 1.0 %, Zinc 0.7 %, manganese 2.25 %, iron 3.5 %, molybdenum 0.04 %, boron 0.1 % and aluminium 1.0 % The Luxury treatment was the most effective of all additions up to age 18 years (Fig. 1, Table 8) and it was expected that minor element deficiency present in the developing stand limited the effect of the N and P additions. Zinc deficiency is observable and critical in the young stands unless treated on these sites. Over the trial however, the effect of the Q2, N+P (Treatments 11 and 12) was not significantly inferior to the Luxury which received the same applications of 750 kg ha^{-1} of superphosphate and 250 kg ha^{-1} urea. In Figure 4 it can be seen that the Minorels addition resulted in the highest Mn levels recorded in treatments. This level was significantly higher than Treatments 2, 3 and 7 which suggest that urea addition lowered natural Mn levels in the stands. The Zn analysis was suspect but the value recorded in Treatment 8 was within the range of 14-16 ppm recorded for the other stands.

Factorial effects

Fertiliser - Within the factorial design fertiliser effects were significant for basal area increment for the 8-13 year interval and in the basal area for standing crops at ages 13, 14 and 18 years, for both the whole stand (Table 5) and the select crop. N+P was significantly better than both P and N for the first year only. For the interval 9-13 and 14-18 the P effect was equivalent to the N+P effect and for the 9-13 year period, significantly better than the N effect (Fig. 3).

Quantity. - During the first year of treatment in the 8-9 year period the double quantity applications were significantly better (.036 level) than the single dose for basal area increment (Table 5, Fig. 3). This was reflected in significantly higher P values for Q2 than for Q1 (Table 7). For the total increment period however, there is no substantial evidence to suggest that heavier fertiliser applications than Q1 are warranted.

Table 8 Stand volume for different ages and the trial increment period. Means are expressed as a percentage of the unfertilised control and ranked.

	Treatment	Stand age (Years)									
		9		13		18		23		9-23	
		R	%	R	%	R	%	R	%	R	%
1	F1Q1A1	9	103	4	115	6	107	6	106	6	107
2	F1Q1A2	13	99	8	108	3	114	3	114	3	117
3	F1Q2A1	5	105	3	117	7	107	8	105	8	105
4	F1Q2A2	3	106	6	109	13	98	14	96	14	94
5	F2Q1A1	6	105	10	107	5	111	2	117	1	120
6	F2Q1A2	14	99	14	99	10	100	10	100	10	100
7	F2Q2A1	11	102	11	103	11	100	9	103	9	104
8	F2Q2A2	10	102	12	101	14	95	13	97	13	96
9	F3Q1A1	4	106	6	109	9	105	7	106	7	106
10	F3Q1A2	7	104	5	110	4	113	5	108	5	109
11	F3Q2A1	2	115	1	122	2	118	1	118	2	119
12	F3Q2A2	8	104	8	108	8	107	12	99	12	98
13	Luxury	1	111	2	118	1	119	4	112	4	113
14	Control	12	100	13	100	11	100	11	100	11	100

Application - The first regime for application timing (A1) produced superior volume increment for the 18-23 year increment period (Tables 5 and 6, Fig. 3). This result is contrary to expectations. For the 18-23 year period A2 had two applications at ages 14 and 20 years while A1 involved only one application at stand age 18 years (Table 1). The reasons for superiority of A1 as opposed to the A2 regime are not obvious. The results combined with those for the quantity factor indicate that application of the lower quantity at 10 year intervals, rather than more frequently at 6 year intervals, was most favourable to stand development.

Improvement - The increment obtained from fertiliser application in the trial rarely exceeded 20 per cent of the unfertilised control (Table 8). The Luxury treatment was the best, it was better than the P but equivalent to the N+P treatment. It differed from the N+P treatment only in the addition of 125 kg ha^{-1} of the Minorels trace element mixture. One must suspect the need for further trace element amendment with stand development if growth on the soil types is to be effectively promoted by P or N+P addition. The contrast for Luxury against N+P for the 14-18 year increment period (Table 4) supports this suggestion and the higher Mn levels recorded in the 1975 foliar analysis indicate a need for additions of this element with urea application. Analysis of the data did not detect any sustained effect for quantity applied or frequency of application to warrant other than the lower quantity and less frequent application.

From the overall results the site shows very limited response to fertiliser. This limited response to fertiliser was also common to other extensive trials (WP 54/66, WP 48/66) on similar hight quality sites on the Spearewood Dunes sands. It is believed that future treatment should follow Treatment 2 (Fig. 2) of 375 kg ha^{-1} of superphosphate broadcast at approximately 5 to 6 year intervals. Any improvement over this requires an approximation of Treatment 11 of 750 kg ha^{-1} super plus 250 kg ha^{-1} urea at 10 yearly intervals. It is anticipated that the first option would be the most cost effective.

The wisdom of using urea as a nitrogen source cannot be ascertained from the trial design. However, N applied as ammonium sulphate with superphosphate in a further large scale trial on these sands (WP 54/66) was also only associated with very modest increments.

Trace elements - The possibility of a trace element solution was followed up by treatments to an established progeny trial YS7. This was one of the first progeny trials established in the 100 acre plot at Yanchep in 1966, adjacent to WP 54/66. It compared 12 full-sib families, in 3 tree units, randomised within 10 uniformity blocks. In 1972 at age 6 years half the blocks were treated with 500 kg super, copper, zinc fertiliser ha^{-1} and the other half were treated with 500 kg super, copper, zinc plus 3 kg manganese sulphate ha^{-1}. Blocks were paired for the comparison to reduce variation. Manganese was a trace element often required for pasture trials on similar soils. Observations in the initial years following treatment suggested that the manganese recipients looked much healthier than those without. Analysis of volume measurements following the application revealed no evidence of any manganese effect.

Site index - The presence of the unfertilised control allows determination of the site index used in the trial. The three blocks had almost identical height means with a top height of 16.5 m at age 20 years. This represents the best site class measured in the Yanchep plantations on the yellow sands of the Spearwood dune system.

WP-20/76 - Early applications of nitrogen and phosphate fertilisers to *Pinus pinaster* on Bassendean Sands of low site quality.

Summary and Conclusions.

The trial tested four different fertiliser applications against an unfertilised control on a three year old stand of pine on marginal grey sands of the Bassendean Series.

A height response was obtained within 2 years following application and the response was highly significant for all treatments for height, basal area and volume growth for a further 5.5 years. The control was fertilised at age 10 years and provided equivalent growth to the refertilised treatments up to age 15.5 years. There was no difference in response between the P and N+P treatments. A dressing of 500 kg ha^{-1} of superphosphate was as effective as any fertiliser tested.

Volume growth was trebled in 7 years after treatment to produce a MAI of 8 m^3 ha^{-1} up to age 15.5 years.

Introduction

The trial aimed to test the effect of subsequent fertiliser additions on young stands of *Pinus pinaster* on poor site qualities of the grey Bassendean sands at Gnangara plantation. All plants receive 60 g superphosphate at time of planting. It was required to determine if further fertiliser applications broadcast to the established plants at approximately three years of age could promote favourable growth on such poor sites. The suitability of superphosphate alone or superphosphate plus nitrogenous fertilisers was also examined.

Location - The trial was established on stands established in 1973 at Gnangara Plantation, Sections J13 and J19, on low quality sands (Havel Type H).

Establishment - The stand was planted in 1973 at 3.5 m x 2.5 m spacing with improved stock from the seed orchard. Twenty plots of 14.0 m x 12.5 m (.0175 ha) within a surround of 38.0 m x 27.5 m (.077 ha) were selected to enclose 20 trees. Fertiliser was applied at time of planting as a spot application of 60 g superphosphate per plant. The stand was thinned from 1150 to 685 stems ha^{-1} at age 7 years in August 1980 and treated for scrub control in September 1983 at age 10.

Design - The trial was designed as a randomised block of 5 treatments within 4 uniformity blocks based on mean height.

Treatments - Five treatments were established at stand age 3 years in August 1976.

1. Control - No subsequent fertiliser.
2. 500 kg ha^{-1} superphosphate.
3. 250 kg ha^{-1} superphosphate + 80 kg ha^{-1} urea.
4. 500 kg ha^{-1} superphosphate + 150 kg ha^{-1}urea.

5. 250 kg ha^{-1} superphosphate + 150 kg ha^{-1} urea.

Table 1. Analysis of variance of progressive measurement data for stand height, stand basal area and stand volume.

Date	Stand age (years)	Treatment p	Block p	Error Mean square	Total Sum squares
		Height (m)			
1976	3.0	0.326	0.000	0.006	0.383
1978	4.6	0.075	0.000	0.040	2.894
1980	6.6	0.007	0.014	0.299	15.499
1982	8.6	0.000	0.005	0.278	28.054
1983	9.6	0.000	0.009	0.341	31.917
1984	10.6	0.000	0.031	0.517	36.868
1985	11.6	0.001	0.020	0.563	36.645
1986	12.6	0.006	0.042	0.852	41.330
1989	15.5	0.027	0.044	1.147	49.714
		Basal area (m^2 ha^{-1})			
1980	6.6	0.006	0.011	0.353	18.970
1982	8.6	0.001	0.178	1.635	94.357
1983	9.6	0.001	0.234	2.641	149.439
1984	10.6	0.001	0.313	3.548	198.115
1985	11.6	0.002	0.367	4.570	218.225
1986	12.6	0.006	0.386	6.075	246.096
1989	15.5	0.023	0.470	9.488	299.380
		Volume (m^3 ha^{-1})			
1980	6.6	0.040	0.019	1.96	79.8
1982	8.6	0.003	0.069	16.37	840.9
1983	9.6	0.003	0.113	36.94	1795.3
1984	10.6	0.004	0.186	67.18	3008.9
1985	11.6	0.007	0.164	101.10	4222.9
1986	12.6	0.020	0.189	185.10	6541.9
1989	15.5	0.057	0.197	395.50	11831.2
D.F.		4	3	12	19

In November 1983 at stand age 10 years 500 kg ha^{-1} of superphosphate was applied to the treatment 1 control plots.

Treatments were again fertilised in August 1984 at age 11 as follows

1. Nil.
2. 500 kg ha^{-1} superphosphate.
3. 300 kg ha^{-1} superphosphate.
4. 500 kg ha^{-1} superphosphate + 250 kg ha^{-1} ammonium sulphate.
5. Nil in 1984.

Measurements. Twelve trees per plot were marked and the following measurements were made -

December 1976 Tree heights.
January 1978 Tree heights.
January 1979 Tree heights.
February 1980 Diameter breast height over bark (dbhob) and heights.
February 1981 Dbhob and heights.
February 1982 Dbhob and heights.
March 1983 Dbhob and heights.
March 1984 Dbhob and heights.
February 1985 Dbhob and heights.
March 1986 Dbhob and heights.
April 1986 Dbhob and heights.
February 1988 Dbhob and heights.
March 1989 Dbhob and heights.

Table 2. Analysis of variance of progressive measurement data for current annual increment in stand height, stand basal area and stand volume

Date	Stand age (years)	Treatment p	Block p	Error Mean square	Total Sum squares
		Height (m)			
1976-78	3-5	0.054	0.005	0.014	0.672
1978-80	5-7	0.006	0.234	0.050	2.101
1980-82	7-9	0.000	0.122	0.006	0.873
1982-83	9-10	0.128	0.657	0.014	0.323
1983-84	10-11	0.286	0.691	0.026	0.499
1984-85	11-12	0.207	0.064	0.014	0.383
1985-86	12-13	0.418	0.563	0.060	1.095
1986 89	13-16	0.446	0.320	0.007	0.138
				Basal Area (m^2 ha^{-1})	
1980-82	7-9	0.000	0.847	0.125	8.3914
1982-83	9-10	0.003	0.453	0.163	7.0953
1983-84	10-11	0.001	0.673	0.074	3.7591
1984-85	11-12	0.769	0.773	0.088	1.3073
1985-86	12-13	0.485	0.640	0.154	2.6795
1986 89	13-16	0.775	0.860	0.053	0.7636
		Volume (m^3 ha^{-1})			
1980-82	7-9	0.001	0.138	1.800	106.881
1982-83	9-10	0.005	0.264	4.353	185.378
1983-84	10-11	0.012	0.487	4.739	167.443
1984-85	11-12	0.098	0.128	4.087	118.351
1985-86	12-13	0.202	0.300	41.360	332.220
1986 89	13-16	0.421	0.251	4.958	103.487
D.F.		4	3	12	19

Results.

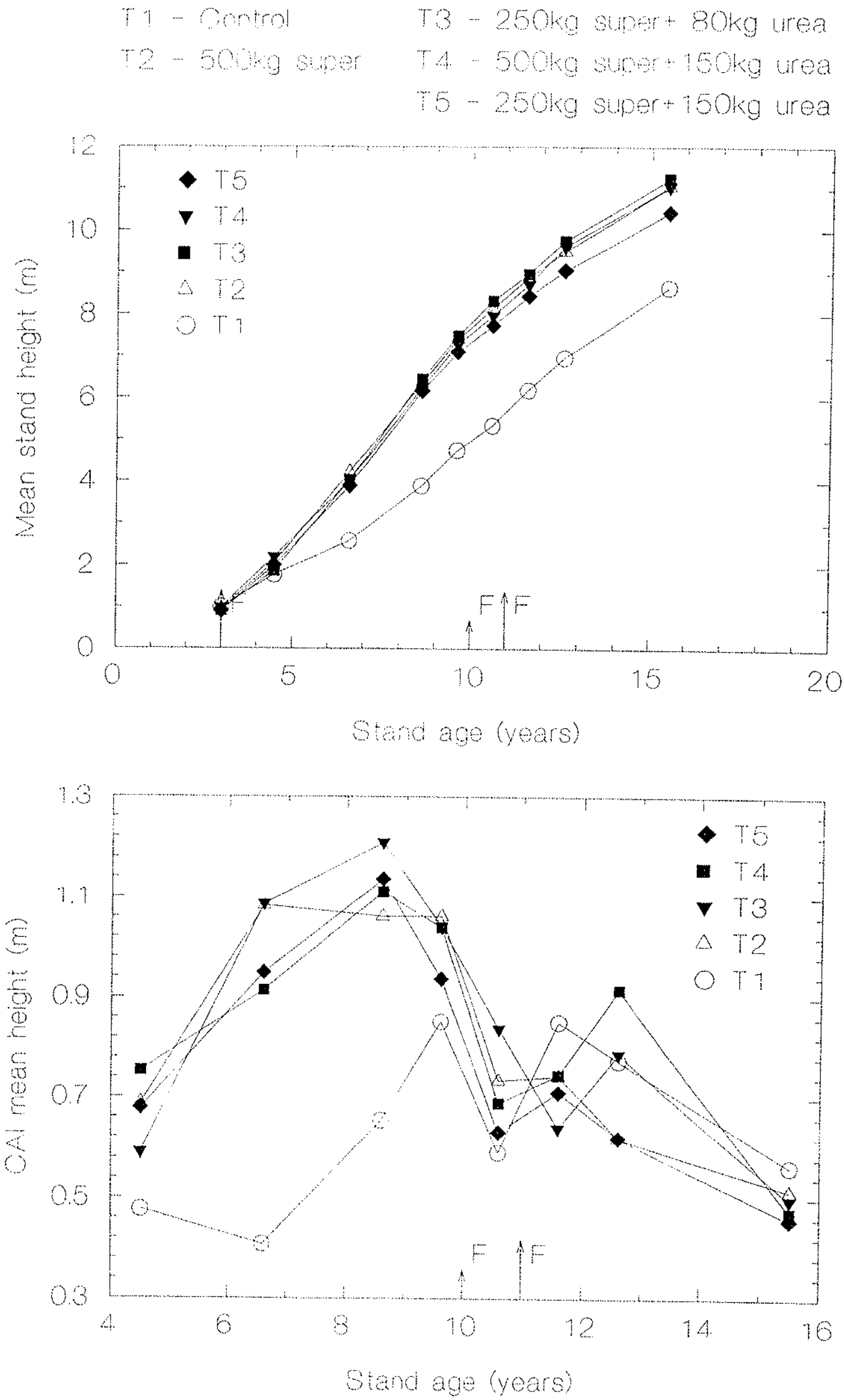

Figure 1. Mean standing height and current annual increment in stand height for the control and treatments over the period of the trial. The times of fertiliser application are marked.

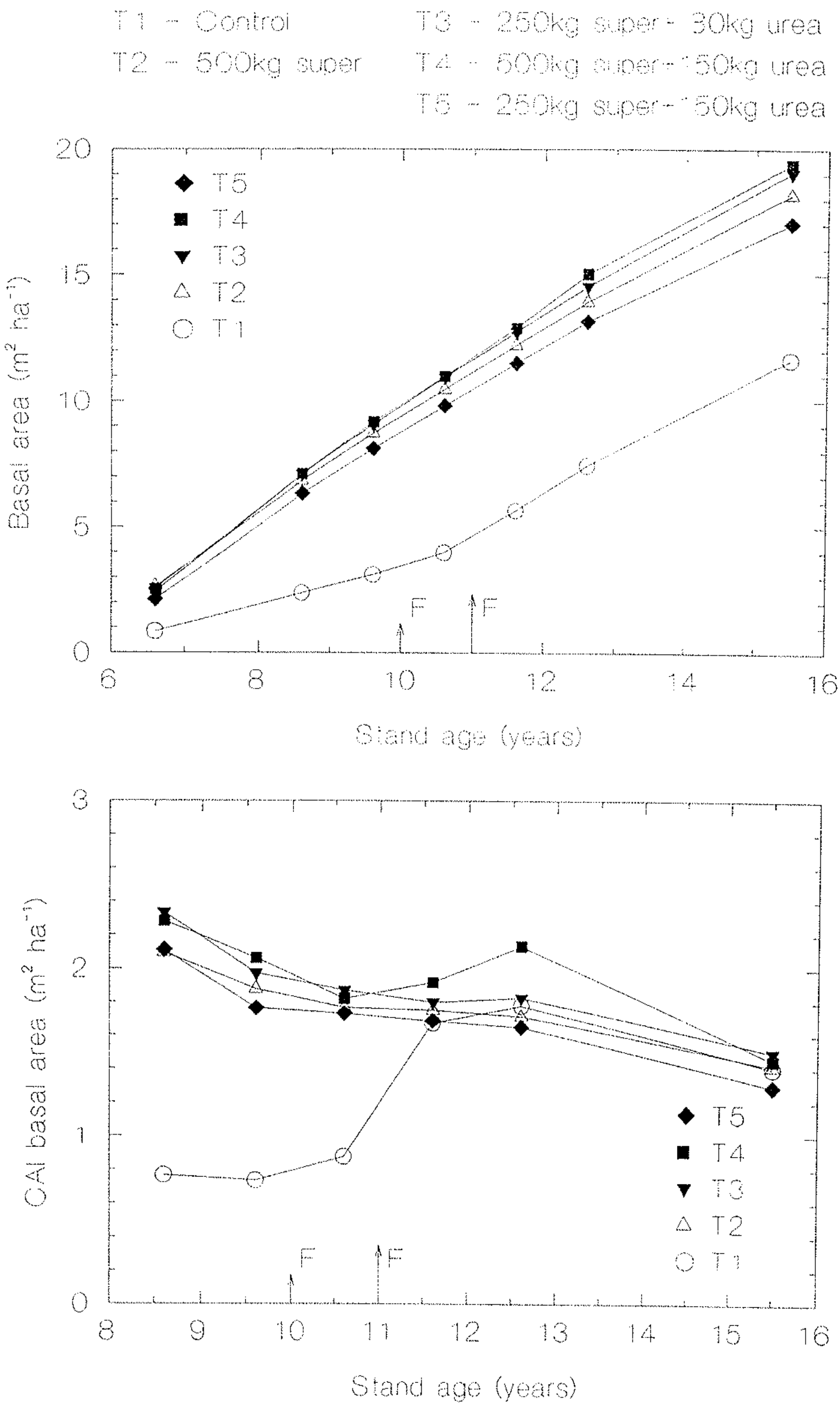

Figure 2. Mean basal area and current annual increment in basal area for the control and treatments over the period of the trial. The times of fertiliser application are marked.

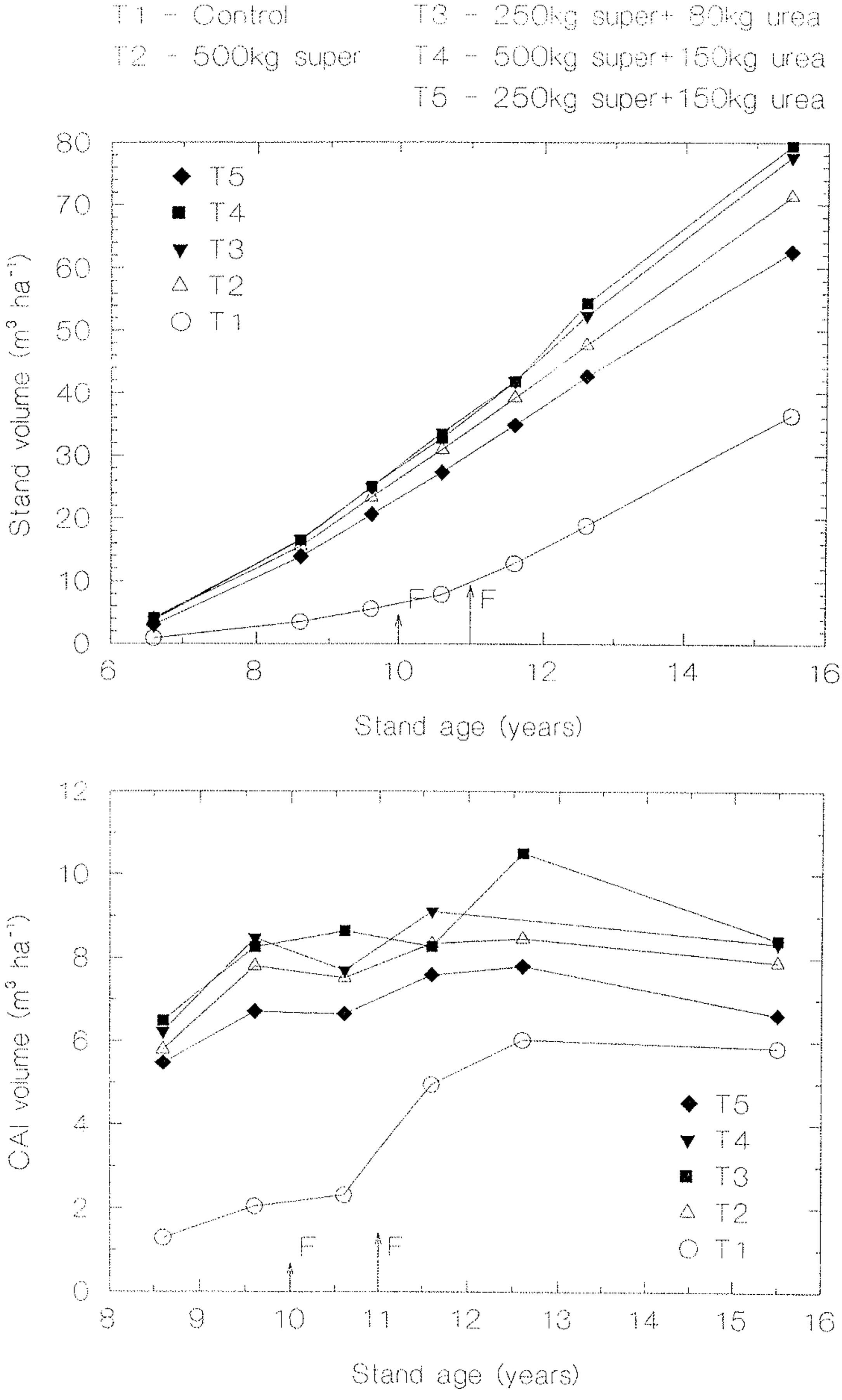

Figure 3. Mean standing volume and current annual increment in volume for the control and treatments over the period of the trial. The times of fertiliser application are marked.

Data for both standing values and current annual increment for the interval between measurements (CAI) were subject to analysis of variance as five treatments randomised within three uniformity blocks. Means for standing height, basal area and volume are plotted against stand age in Figures 1, 2 and 3. Early development from 1976 to 1980 was only recorded in height measurements and is shown as CAI height in Figure 1 (lower). Growth in basal area and volume is presented in Figures 2 and 3.

Growth of treatments following fertiliser application in August 1976 at stand age 3 years was measurably greater than that of the untreated control and the difference was just not significant at the .05 level at age 5 years (Table 2). The fertiliser effect on growth increased greatly following 1978 to be highly significant up to age 9 for height and to age 11 for basal area and volume data (Table 2, Figs. 1, 2 and 3). Initial differences in the first two years after treatment were between the control and treatment 4 but thereafter all treatments were greater than the control (Table 3, Figs. 1 to 3.). At no time during the trial were differences between treatments found to be significant (Table 3). At stand age 10.6 years, 7.6 years after treatment, there was no evidence for differing effects for treatments (Table 2, Tables 1 to 3), even with the second addition of fertiliser at age 11 years.

The single fertiliser addition to the control at age 10 years raised the growth of the control by age 11.6 to the equivalent of the four applied treatments. It remained at this level until the end of the trial (Figs. 1 to 3).

Discussion.

Response - There was a significant response to added fertiliser by the 3 year old stand. This continued in the annual growth differences until age 9.5 years for height growth and until age 11 for basal area and volume. By age 11.5 years the fertilised control had improved to nullify previous growth differences. The impact of the second fertiliser application at age 10 years cannot be assessed but it was no better than the fertiliser addition of 500 kg ha^{-1} of super to the control at age 10 years (Tables 2 and 3, Figs. 1 to 3). It can be seen from Figures 1 and 3 that growth in treatment 5, which was not refertilised in 1984 at age 11 years, is falling off with respect to treatments 2 to 4. The decline in growth rate was not significant within the trial design and measurement period but it is expected that it would be so if measurement was continued.

Superphosphate alone or super plus the urea dressing were equally effective in increasing growth. In the seven years following application the treated stand increased volume to be 4.25 times greater than that of the unfertilised control.

Site - Top height growth of the control stand to ages 10 and 15.5 years was equivalent to site index 12.0 m at age 19 years determined from the Gnangara and Yanchep Basal area control study. This is the poorest site studied with an MAI of approximately 2-3 m^3 ha^{-1}. With fertiliser additions this has been increased to the order of 8 m^3 ha^{-1}.

Table 3. Bonferroni pair-wise tests of means for measurement intervals to show the significance of differences between treatments. Table values are the probability that the difference examined would occur by chance.

Source and Period	Treatment	Treatment 1	2	3	4	5
Height	1	1.000				
	2	0.285	1.000			
1976-78	3	1.000	1.000	1.000		
	4	0.068	1.000	0.792	1.000	
3-5 yr	5	0.348	1.000	1.000	1.000	1.000
Height	1	1.000				
	2	0.011	1.000			
1978-80	3	0.011	1.000	1.000		
	4	0.078	1.000	1.000	1.000	
5-7 yr	5	0.052	1.000	1.000	1.000	1.000
Volume	1	1.000				
	2	0.005	1.000			
1980-82	3	0.001	1.000			
	4	0.002	1.000	1.000	1.000	
7-9 yr	5	0.009	1.000	1.000	1.000	1.000
Volume	1	1.000				
	2	0.021	1.000			
1982-83	3	0.012	1.000	1.000		
	4	0.009	1.000	1.000	1.000	
9-10 yr	5	0.083	1.000	1.000	1.000	1.000
Volume	1	1.000				
	2	0.055	1.000			
1983-84	3	0.014	1.000	1.000		
	4	0.044	1.000	1.000	1.000	
9-10 yr	5	0.156	1.000	1.000	1.000	1.000
Volume	1	1.000				
	2	0.358	1.000			
1984-85	3	0.391	1.000	1.000		
	4	0.132	1.000	1.000	1.000	
9-10 yr	5	0.914	1.000	1.000	1.000	1.000

The site (Havel type H) is characteristic of deep pale grey sands, dry at the surface, moist at depth and strongly leached throughout. They occur on sub-flats and around swamps in the transition zone and within the Bassendean Dunes system. They are marginal to unsuitable for plantation purposes.

WP 21/76-Refertilisation of *Pinus pinaster* at Pinjar.

Summary and Conclusions

The trial aimed to test the effectiveness of fertiliser additions in increasing growth on 20 year old *Pinus pinaster* stands of poor site quality at Pinjar plantation. Time elapsed between the first thinning (from approx. 1000 stems ha^{-1} to 250 stems ha^{-1}) and fertiliser application was also considered as a factor in the trial. In the initial trial (A) a control and 6 treatments were compared to test the effect of a base dressing of 500 kg ha^{-1} superphosphate and increasing additions of urea up to 625 kg ha^{-1}, from stand age 21.2 to 28.5 years. At age 28.5 years the plots were further thinned to 100 stems ha^{-1} and resorted into 5 similar groups. A second series of fertiliser treatments (B) ranging from a control to 400 kg ha^{-1} superphosphate plus 600 kg ha^{-1} urea were tested from age 29.5 to age 33.5 years.

Response to fertiliser was significant in the first two years after application A and increased in the third and fourth years. There was no detectable effect of fertiliser addition in the fourth and fifth years after application. Treatments receiving more than 300 kg ha^{-1} urea on the base dressing of super were significantly better than the control in growth. The most effective treatments received 625 kg ha^{-1} of urea and were superior (.001 level) to any treatment with less than 300 kg ha^{-1} of urea. There was no advantage in increasing the base phosphatic dressing from 500 to 1000 kg ha^{-1} with the 625 kg ha^{-1} urea. The trial does not allow examination of nitrogenous fertiliser addition without a basic phosphatic dressing. The second application B produced a highly significant response with 400 kg ha^{-1} super plus 600 kg ha^{-1} urea but none with super alone or super plus 150 kg ha^{-1} urea. This confirms the requirement for the high level of urea to obtain an effective response. The average increase in current annual increment in total volume in application B was 4 m^3 ha^{-1} on the 100 stems ha^{-1} of a select crop.

Responses in stands thinned 1 and 2 years before fertiliser application were superior to those thinned 4 years prior to fertiliser application. Fertiliser can be added effectively immediately after thinning and no time interval for adjustment to the new stand density is required.

Results indicate that fertiliser dressings using greater than 300 kg ha^{-1} urea on a base dressing of 400 kg ha^{-1} superphosphate will effectively increase growth on 20 year old thinned stands at Pinjar plantation. Applications require to be repeated after 4 years, at least in the first instance.

Introduction.

The trial aimed to find a suitable fertiliser treatment to stimulate stand vigour in 20 year old stands thinned to 250 stems ha^{-1}. The stands had been fertilised with superphosphate at time of planting and were of low site quality at Pinjar. Both phosphatic and nitrogenous fertilisers were considered to be relevant. Time for stand recovery since thinning was also investigated as a factor important to stand response on fertiliser addition.

Procedure.

Location. - The trial was established in September 1976 in four separate stands planted in 1955 at Pinjar.

Compartment A2 - Thinned to 250 stems ha^{-1} in December 1971 (Plots 17, 18, 19, 20, 21, 22, 23, 24)
Compartment A4 - Thinned to 250 stems ha^{-1} in December 1974 (Plots 25, 26)
Compartment A6 - Thinned to 250 stems ha^{-1} in December 1974 (Plots 9, 10, 11, 12, 13, 14, 15, 16, 27, 28, 29, 30)
Compartment A5 - Thinned to 250 stems ha^{-1} June 1975 (Plots 1, 2, 3, 4, 5, 6, 7, 8).

Plots were 20 m x 20 m square surrounded by a 10 m wide buffer providing a gross area of 0.09 ha and a net area of 0.04 ha.

Treatments. - Uniform areas to provide a single balanced design were not available. Thirty plots were selected in three stands differing with respect to thinning time and absence from areal supering effects (Plots 25, 26). These were distributed within four uniformity blocks (Table 1). Plots 25 and 26 were the only areas suitable for treatment 1, the unfertilised control. The other treatments were allocated randomly.

Table 1. Initial allocation of plots to treatments and blocks

Treatment	Block			
	1	2	3	4
1				25,26
2	3,6	12,14	18,22	
3	1,5	9,13	17,20	
4	2,7	11,28	21,23	
5		16,30		
6	4,8	15,29	19,24	
7		10,27		
Thinned	1975	1974	1971	1974

In 1976 the following treatments were tested -

Treatment 1 Nil fertiliser
Treatment 2 500 kg ha^{-1} superphosphate.
Treatment 3 500 kg ha^{-1} superphosphate + 150 kg ha^{-1} urea.
Treatment 4 500 kg ha^{-1} superphosphate + 300 kg ha^{-1} urea.
Treatment 5 500 kg ha^{-1} superphosphate + 470 kg ha^{-1} urea.
Treatment 6 500 kg ha^{-1} superphosphate + 625 kg ha^{-1} urea.
Treatment 7 1000 kg ha^{-1} superphosphate + 625 kg ha^{-1} urea.

The design provided for the analysis of at least two replications of the seven treatments within a completely randomised experiment and for a balanced trial of treatments 2, 3 and 6 replicated in blocks 1, 2 and 3 representing thinning at ages 20, 19 and 16 years of age (Table 1).

Plots were measured from 1976 to 1984. They were thinned to 100 stems ha^{-1} in October 1984. In August 1985 the plots were resorted into five similar groups and a second set of fertiliser treatments (Application B) was applied (Table 2).

Table 2. Plot allocation and treatments for second fertiliser addition in 1985.

	Treatment	Plot
1	Nil	5,1,9,13,17,20.
2	400 kg ha^{-1} superphosphate	4,8,15,19,24,29.
3	400 kg ha^{-1} Coastal super	6,3,12,14,18,22.
4	400 kg ha^{-1} super + 150 kg ha^{-1} urea	2,7,11,21,23,28.
5	400 kg ha^{-1} super + 600 kg ha^{-1} urea	10,16,25,26,27,30.

Measurement.

The 30 plots were measured for height and diameter breast height over bark (dbhob) and the initial fertiliser application A was applied in September 1976 at a stand age of 21 years. Subsequent measurement and treatment was as follows

January	1978	Dbhob measured.
January	1979	Dbhob measured.
February	1980	Dbhob measured.
February	1981	Dbhob measured.
February	1982	Dbhob measured.
March	1983	Dbhob and height of crop trees (100 stems ha^{-1}) measured.
February	1984	Dbhob and height of crop trees measured.
October	1984	Plots thinned from 250 to 100 stems ha^{-1}.
February	1985	Dbhob and all heights measured.
September	1985	Fertiliser treatment 2 applied.
February	1985	Dbhob and heights measured.
January	1987	Dbhob and heights measured.
February	1988	Dbhob and heights measured.
January	1989	Dbhob and heights measured.

Analysis

Responses from fertiliser application A for the trial period September 1976 to September 1985 were analysed as a randomised experiment with 7 treatments. The measurements displayed variable dbhob and volume means (Table 3) for the initial plot grouping and covariant analysis, using the original diameters as the covariant, was also examined.

Table 3. Analysis of initial data for basal area and volume and a comparison of the mean values to demonstrate the initial variability between treatment groups.

Analysis of variance on Basal Area 1976

Source	DF	SS	MS	F	p
Treat1	6	10.13	1.69	0.51	0.792
Error	23	75.61	3.29		
Total	29	85.74			

```
                                    Individual 95 PCT CI'S for Mean
                                              Based on Pooled StDev.
 Level   N  Mean  StDev.---------+---------+---------+-------
   1     2 10.7   1.62             (----------*----------)
   2     6  9.1   2.02            (-----*-----)
   3     6  9.6   1.78              (-----*-----)
   4     6  9.4   1.78             (-----*-----)
   5     2  8.7   1.18     (----------*----------)
   6     6  9.8   1.75              (-----*------)
   7     2  8.0   1.99  (----------*----------)
                        ---------+---------+---------+-------
Pooled StDev.= 1.813           7.5      10.0      12.5
```

Analysis of variance on Volume 1976

Source	DF	SS	MS	F	p
Treat1	6	595	99	0.68	0.664
Error	23	3330	145		
Total	29	3924			

```
                                      Individual 95 PCT CI'S for Mean
                                                Based on Pooled StDev.
 Level   N   Mean   StDev.--------+---------+---------+--------
   1     2   58.3   11.6              (----------*----------)
   2     6   46.5   13.6            (-----*-----)
   3     6   48.9   12.1             (------*-----)
   4     6   47.2   11.2            (------*-----)
   5     2   43.1    9.0     (----------*----------)
   6     6   51.4   11.1               (-----*-----)
   7     2   37.0   14.1  (----------*----------)
                          --------+---------+---------+--------
Pooled StDev.= 12.03            32        48        64
```

Treatments 2, 3, 4 and 6 were analysed as a balanced randomised block experiment within blocks 1, 2 and 3 (Table 1).

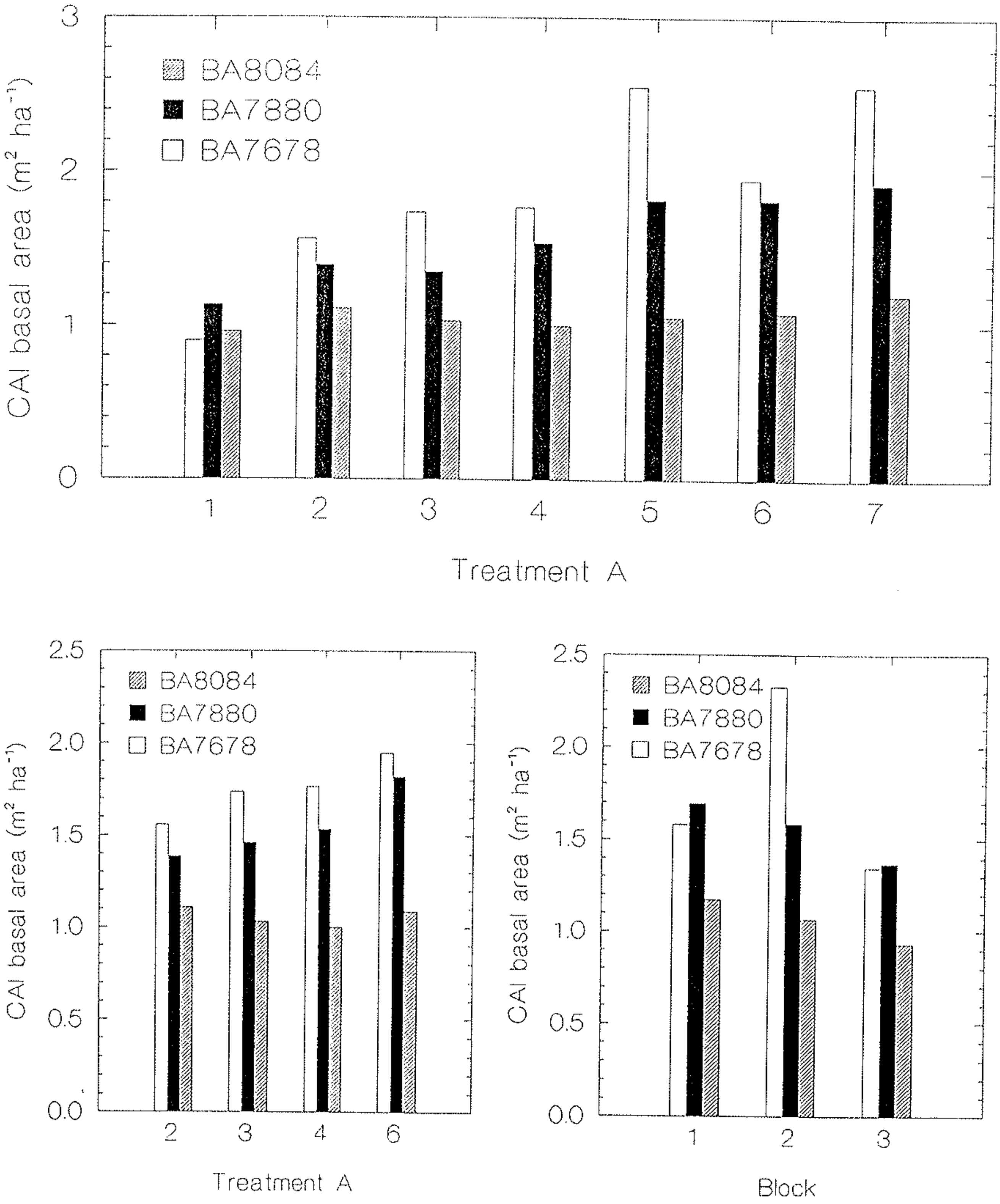

Figure 1. Treatment responses for application A for growth in basal area. The top figure is for all seven treatments as described in the key. The lower plots are for the four treatments and the block effects in the balanced design.

Application A
1. Nil
2. 500 kg super
3. 500 kg super + 150 kg urea
4. 500 kg super + 300 kg urea
5. 500 kg super + 470 kg urea
6. 500 kg super + 625 kg urea
7. 1000 kg super + 625 kg urea

Blocks
1. Thinned in 1975
2. Thinned in 1974
3. Thinned in 1971

The 30 plots subject to the second fertiliser application B were analysed as a completely randomised experiment with five treatments and six replications. The analysis was checked by ANCOVA to ensure re allocation of plots for application B did not bias any treatment.

Results

Completely randomised Treatments A1. - Variation in means for diameter and height in the treatment groups prior to fertiliser application indicated bias, particularly to treatment 1 (Table 3). On analysis the standing values for diameter and height were not significantly different and diameter was used as a covariant in analysis of covariance of the fully randomised data (Table 4). Results in Table 4 indicate significant (.02 level) treatment differences for adjusted basal area means in 1980 and 1984. Analysis of current annual increment (CAI) for basal area growth showed the 1976 to 1978 growth to be significant at the .016 level and 1978 to 1980 increment to be highly significant (Table 4). Increment for the 1980-1984 period was not significant. Basal area increment for the entire 1976 to 1984 period of application A was significant at the .007 level. Unadjusted means for 1976-78, 1978-80 and 1980-84 periods for the seven treatments are depicted in the top diagram of Figure 1.

Table 4. Analysis of variance and covariance for basal areas and volume for all plots in a completely randomised design with the initial fertiliser application A.

Source	DF	BA7678	BA7880	BA8084	BA76	BA80	BA84	Vol84	Vol76
Treat1	6	.016	.000	.490	.792	.245	.225	.517	.664
Error	23								
Total	29								
Analysis of Covariance									
Treat1	6					.023	.021	.052	
D76	1					.000	.001	.002	
Error	22								
Total	9								

Analysis to assess the significance of differences between treatments for basal area increment over the 1978-80 period showed growth in treatment 1 to be significantly different to growth in treatments 5,6, and 7 and treatments 2 and 3 to be significantly inferior in growth to treatments 6 and 7 (Table 5).

Balanced randomised block comparisons A2. - Analysis of variance for treatments 2, 3, 4 and 6 in the three thinning blocks found no significant differences for treatments for standing basal areas at each measurement (Table 6). Block differences were significant for the 1976, 1978 and 1980 measurements. For basal area increments (Fig. 1) treatment differences for BA7880 were significant (Table 6). Block differences were significantly different for BA7678, BA7880 and BA8084 (Fig. 1). Basal area increment favoured the stands thinned 2 years prior to fertiliser application for the two years after fertiliser application but thereafter, increment was greatest in the stands with least delay between thinning and fertiliser application (Blocks 1 and 2)

Table 5 Bonferroni adjustment for the matrix of pair-wise comparison probabilities for treatment differences in basal area for the increment period 1978-1980.

Treatment	Treatment 1	2	3	4	5	6	7
1	1.000						
2	1.000	1.000					
3	1.000	1.000	1.000				
4	0.201	1.000	1.000	1.000			
5	0.014	0.125	0.065	1.000	1.000		
6	0.001	0.006	0.002	0.197	1.000	1.000	
7	0.003	0.020	0.010	0.240	1.000	1.000	1.000

Treatments B - Analysis of variance for basal areas and volumes for the second fertiliser addition, application B, in 1985 showed a significant effect for treatments for basal area and volume in 1989 and a highly significant effect on increment in the period 1985-89 (Table 7). Examination of the means for BA85 at the outset of the trial B (Table 8) indicated that treatments 2 and 5 could be out of accord with the means for the other treatment cells. Ancova using stem diameters in 1985 as the covariate increased the significance of adjusted treatment differences for BA89 and Volume89. The unadjusted values for BA8589 increment are plotted in Figure 2, left lower diagram

Table 6. Analysis of variance for the initial fertiliser application as a balanced trial with treatments 2, 3, 4 and 6 on Blocks 1, 2 and 3.

Source	DF	BA76	BA80	BA84	Vol76	Vol84	BA7678	BA7880	BA8084
		Probability of F.							
Treat1	3	.765	.091	.187	.651	.148	.129	.000	.157
Block1	2	.000	.031	.319	.000	.044	.000	.011	.000
T*B	6	1.000	.998	.964	.997	.965	.985	.449	.119
Error	12								
Total	23								

Discussion

Fertiliser Response - There was a measurable stand response to the initial fertiliser application A during the first 15 months following application in September 1976. Response was highly significant during the second and third years after treatment but was not discernible from 1980 to 1984 (Table 4, Fig. 1). The

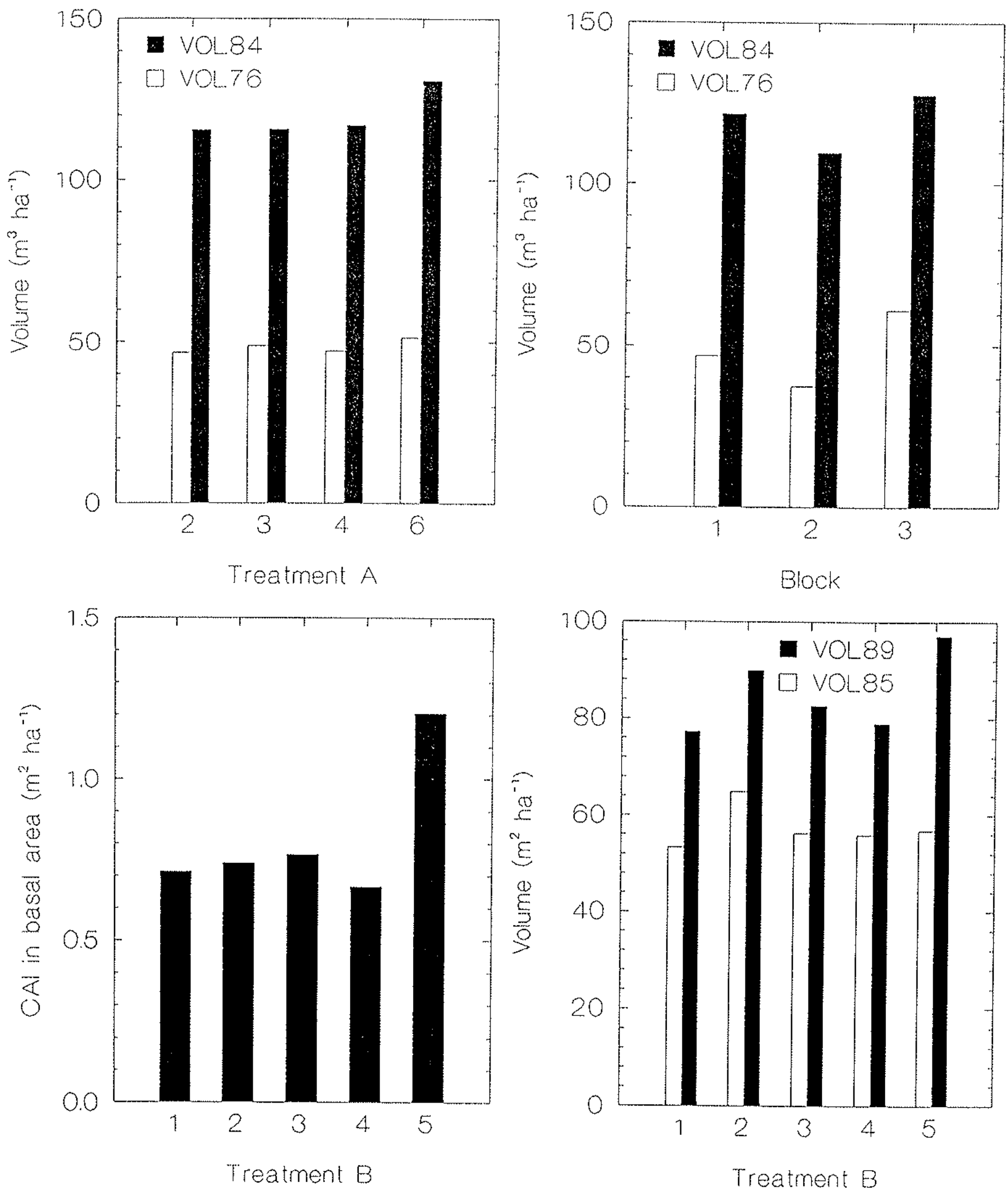

Figure 2. Responses in volume for treatments of Application A in a balanced trial and to basal area and volume for Application B.

Application A

1. Nil
2. 500 kg super
3. 500 kg super + 150 kg urea
4. 500 kg super + 300 kg urea
5. 500 kg super + 470 kg urea
6. 500 kg super + 625 kg urea
7. 1000 kg super + 625 kg urea

Application B

1. Nil
2. 400 kg super
3. 400 kg Coastal super
4. 400 kg super + 150 kg urea
5. 400 kg super + 600 kg urea

major differences were between the control and treatments 6 and 7 and between treatment 2 and treatment 7 (Fig. 1, Table 5). Response over the non-fertilised controls required the addition of at least 625 kg ha^{-1} of urea and 500 kg ha^{-1} superphosphate and influenced the stand for about 4 years. The improvement in basal area increment was 107 per cent over the control for the period 1976 to 1980. Over the 6 years of the trial volume improvement averaged 37 per cent.

Table 7. Analysis of variance and covariance for basal area and volume for the second fertiliser application B on the regrouped plots.

		BA85	BA89	Vol85	Vol89	BA8589	Vol8589
Source	DF			Probability of F			
Treat2	4	.141	.010	.123	.039	.001	.001
Error	25						
Total	29						
Analysis of Covariance							
D85	1		.000		.000	.366	.067
Treat2	4		.001		.006	.001	.000
Error	24						
Total	29						

Analysis of the balanced design with treatments 2, 3, 4 and 6 and times since thinning of 1, 2 and 4 years compared the effect of applications of nil (T2), 150 (T3), 300 (T4) and 625 (T6) kg ha^{-1} of urea on a base of 500 kg ha^{-1} superphosphate. The increment in the period 1978 to 1980 was highly significant (Table 6, Fig. 1). Bonferroni pair-wise comparisons of the means found the treatment 6, the highest application of urea, to be significantly superior to superphosphate alone or up to 300 kg ha^{-1} urea. In the above unbalanced comparison of 7 treatments it was also shown that 300 kg ha^{-1} urea plus 500 kg ha^{-1} was significantly better than no fertiliser at all (Table 5). The design did not allow for testing of the effect of urea additions separately but previous studies indicate that nitrogenous fertilisers are effective on the coastal sands only when used in conjunction with phosphatic fertilisers.

Analysis of the second trial with fertiliser application B on the regrouped plots (Table 2) confirmed that at least 600 kg ha^{-1} of urea was required with 400 kg ha^{-1} superphosphate to produce a significant growth response (Table 7, Fig. 2) on the soils and in the stands tested. The effect was measured as a 68 per cent improvement in volume growth over the control for the four years of testing application B.

Both trials clearly demonstrate that growth can be effectively stimulated in 20 year or older stands on the Pinjar soils provided that at least 300 kg of urea is applied. It is probable that a base dressing of the order of 400 kg ha^{-1} of superphosphate is required to obtain the benefit of the nitrogenous fertiliser.

Table 8. Analysis of initial and final data for basal area with a comparison of the mean values for fertiliser application B to demonstrate the initial variability between treatment groups.

Analysis of variance on BA85

Source	DF	SS	MS	F	p
Treat2	4	5.244	1.311	1.90	0.141
Error	25	17.214	0.689		
Total	29	22.458			

```
                                    Individual 95 PCT CI'S for Mean
                                             Based on Pooled StDev.
Level  N   Mean     StDev.  -------+---------+---------+---------
  1    6   8.6      0.48    (---------*---------)
  2    6   9.7      0.78                   (---------*---------)
  3    6   8.6      1.05    (---------*---------)
  4    6   8.7      0.70      (---------*---------)
  5    6   9.1      0.99         (---------*---------)
                           -------+---------+---------+---------
Pooled StDev.= 0.830             8.40      9.10      9.80
```

Analysis of variance on BA89

Source	DF	SS	MS	F	p
Treat2	4	27.40	6.85	4.15	0.010
Error	25	41.24	1.65		
Total	29	68.64			

```
                                    Individual 95 PCT CI'S for Mean
                                             Based on Pooled StDev.
Level N   Mean    StDev.  --+---------+---------+---------+---
  1   6   11.4    0.81     (------*-------)
  2   6   12.6    0.85             (-------*------)
  3   6   11.6    1.65       (------*------)
  4   6   11.3    1.41     (------*------)
  5   6   13.9    1.47                      (-------*------)
                          --+---------+---------+---------+---
Pooled StDev.= 1.284      10.5      12.0      13.5      15.0
```

WP 22/76 - Late refertilisation of *Pinus pinaster* at Gnangara.

Summary and Conclusions.

The trial aimed to test the effectiveness of further addition of fertilisers on the growth of 25 year old stands thinned to 250 stems ha^{-1} at Gnangara. For an initial period of 8 years, applied nitrogen levels ranging from Nil urea to 600 kg ha^{-1} urea, superimposed over a basic dressing of 500 kg ha^{-1} superphosphate, were compared. The stands were then thinned to 100 stems ha^{-1} and nil further phosphate treatment was compared with 400 kg ha^{-1} of coastal superphosphate, 5 superphosphate tablets beneath the crown perimeter of each tree and 400 kg ha^{-1} superphosphate applied to plot groups at stand age 34 years.

There were no significant effects of applied nitrogen in the first comparison. The growth was excellent and even over the treatment range. There was no unfertilised control and the contribution of the added phosphate on the good stand growth could not be ascertained. For the second application the added P had a minor and non-significant effect on increasing growth. There was no indication that any of the forms of added P were better than the others.

Introduction

The trial aimed to find a suitable fertiliser treatment to stimulate stand vigour in 25 year old stands of *Pinus pinaster* on grey sands at Gnangara. A similar trial (WP 21/76) was applied to stands at Pinjar.

Procedure.

Location. - The trial was established in September 1976 in two separate stands at Gnangara, Section B, Compartment 26. The area was planted in 1951. Stand A considered as Block 1 was thinned to 250 stems ha^{-1} in December 1973, stand B or Block 2 was thinned to 250 stems ha^{-1} in December 1975. The area was re-fertilised with 500 kg ha^{-1} superphosphate in 1962 (age 11 years), 1971 (age 20 years) and by areal means in September 1976 (stand age 25 years).

Treatments. - Eight uniform plots 30 x 30 m (.09 ha) in area were selected in each stand. Uniformity was checked by comparing the stem numbers and basal areas of trees within the enclosed 20 x 20 m (.04 ha) measurement areas.

In September 1976 at stand age 25 years the following treatments were randomly allocated to plots in each block.

1. 500 kg ha^{-1} superphosphate.
   (Plots 1,6,9,11)
2. 500 kg ha^{-1} superphosphate + 150 kg ha^{-1} urea
   (Plots 4,7,10,12)
3. 500 kg ha^{-1} superphosphate + 300 kg ha^{-1} urea.
   (Plots 2,5,14,15).
4. 500 kg ha^{-1} superphosphate + 625 kg ha^{-1} urea.
   (Plots 3,8,13,16)

The plots were thinned to 100 stems ha^{-1} in February 1984 (stand age 33 years) and the following treatments applied in September 1984.

1. Nil fertiliser.
   (Plots 2,5,14,15).
2. 5 super tablets at the edge of each crown.
   (Plots 1,6,9,11).
3. 400 kg ha^{-1} Coastal superphosphate.
   (Plots 3,8,13,16).
4. 400 kg ha^{-1} superphosphate.
   (Plots 4,7,10,12).

Table 1. Results from analysis of variance of standing basal areas and increments for treatment Application 1. Data for Treatments, Blocks and the interaction are the probability that the F value would have been obtained by chance. The error mean square is included. Data refers to 250 stems ha^{-1}.

		Year of measurement				
Source	DF	BA76	BA78	BA80	BA82	BA84
Treat1	3	0.990	0.999	0.894	0.888	0.889
Block	1	0.219	0.320	0.434	0.857	0.798
Treat1*Block	3	0.922	0.886	0.795	0.623	0.647
Error MS	8	2.266	3.1416	4.288	6.354	8.805
Total	15					

		Increment period			
Source	DF	BA7678	BA7880	BA8082	BA8284
Treat1	3	0.642	0.235	0.727	0.837
Block	1	0.814	0.830	0.061	0.026
Treat1*Block	3	0.708	0.816	0.191	0.701
Error MS	8	0.1698	0.1505	0.0807	0.0532
Total	15				

Measurement. - Measurement was as follows.

September 1976 (25.2 years)	DBHob and height.
January 1978 (26.5 years)	DBHob.
January 1979 (27.5 years)	DBHob.
February 1980 (28.5 years)	DBHob.
February 1981 (29.5 years)	DBHob
February 1982 (30.5 years)	DBHob.
March 1983 (31.5 years)	DBHob + crop tree heights.
February 1984 (32.5 years)	DBHob.
February 1985 (33.5 years)	DBHob and heights.
April 1986 (34.7 years)	DBHob and heights.
January 1987 (35.5 years)	DBHob and heights.
February 1988 (36.5 years)	DBHob and heights.

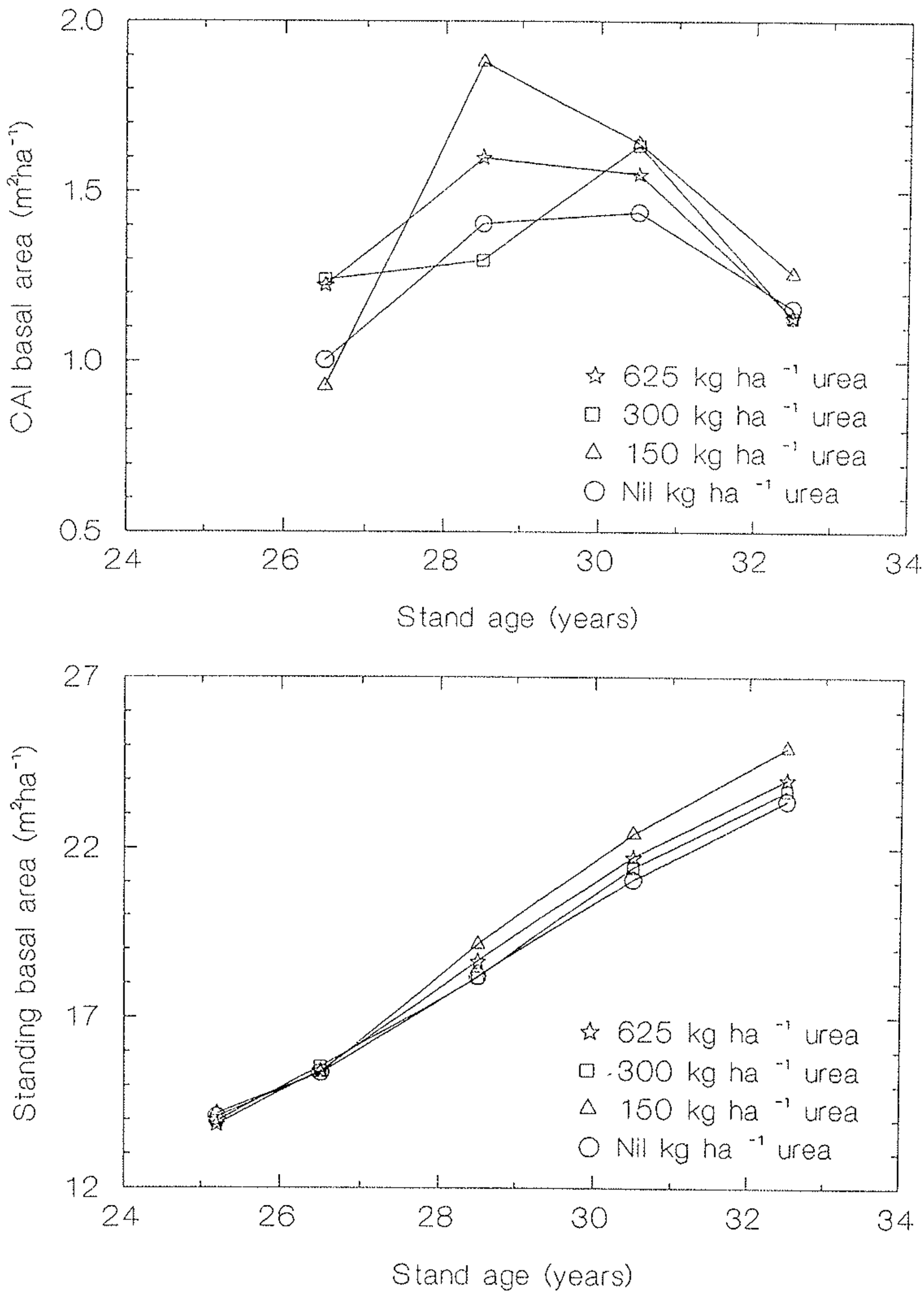

Figure 1. Development trends for standing basal area (bottom) and increment within 1 or 2 year periods (top) for Treatment application 1, applied in 1976 at stand age 25 years. The nitrogen treatments superimpose a general application of 500 kg ha^{-1} superphosphate in 1976.

January 1989 (37.5 years) DBHob and heights.

Analysis. - Two plots of each treatment were present in each block and the trial was analysed for main effects of treatments and blocks and for the treatment x block interaction. The interactions were not significant and analysis was repeated with the interaction included in the error term in an attempt to improve the precision.

Results

The progress of development for the means of the first application treatments and the increments for measurement period are set out in Figure 1. Stand basal area was similar for each treatment at age 24.5 years and only the 150 kg ha^{-1} treatment showed any improvement over the non-nitrogen treatment. Increment data (Fig. 1) indicate that this treatment experienced greater growth from age 26.5 to age 30.5 years. Differences between means for standing basal area and basal area increment for the different applications of urea were not significant (Table 1) up to stand age 33 years in 1984 at which time the stand was thinned.

Table 2. Results from analysis of variance of standing volumes and increments for treatment Application 2. Data for Treatments, Blocks and the interaction are the probability that the F value would have been obtained by chance. The error mean square is included. Data refers to 100 stems ha^{-1}.

		Year of measurement				
Source	DF	Vol84	Vol85	Vol86	Vol88	Vol89
Treat2	3	0.358	0.420	0.410	0.417	0.402
Block	1	0.934	0.664	0.421	0.371	0.314
Treat2*Block	3	0.787	0.607	0.708	0.820	0.847
Error	8	484.7	480.9	603.8	911.3	989.1
Total	15					

		Increment period			
Source	DF	Vol8485	Vol8586	Vol8688	Vol8889
Treat2	3	0.292	0.594	0.272	0.082
Block	1	0.000	0.023	0.299	0.011
Treat2*Block	3	0.057	0.824	0.947	0.320
Error MS	8	5.62	10.6	15.0	2.42
Total	15				

Development of stand volume and volume increment following thinning to 100 stems ha^{-1} and refertilising are plotted in Figure 2. There was an indication that the applications of 400 kg ha^{-1} superphosphate and superphosphate tablets accelerated volume growth. This was not apparent until the 34.7 to 36.5

measurement period. Analysis showed that standing basal areas and increments were not significantly different at any stage up to 4 years after thinning and refertilising (Table 2).

The start points for standing volume of treatment groups in 1985 (age 33.5 years) in Figure 2 show some divergence. Analysis of covariance using basal areas at the 1985 measurement did not show treatment effects for volumes to be any more significant than at the 0.195 level. This is to be expected from results for increment obtained in Table 2.

Discussion

Although there is no significant effect of the different levels of nitrogen in the first application and the different levels of phosphate in the second application, the volume increments for 100 stems ha^{-1} from age 34 to 38 years of age are reasonably impressive. A current annual increment of approximately 10 m^3 ha^{-1} (Fig. 2) is in the medium to high range for the plantation area. It is not possible to assess the effect of the regular additions of phosphate fertiliser over the life of the stand on this growth. It is however, surprising that there is no indication of a beneficial influence of added nitrogen in such a stand with favourable P levels to promote reasonable growth. It is obvious from the results that N+P fertiliser offers no benefit above P on such sites.

Mean heights of the 100 select stems ha^{-1} (Fig. 3) were not significantly different for treatment groups. The predominant heights verify that the stand is amongst the top volume producers measured within the plantation.

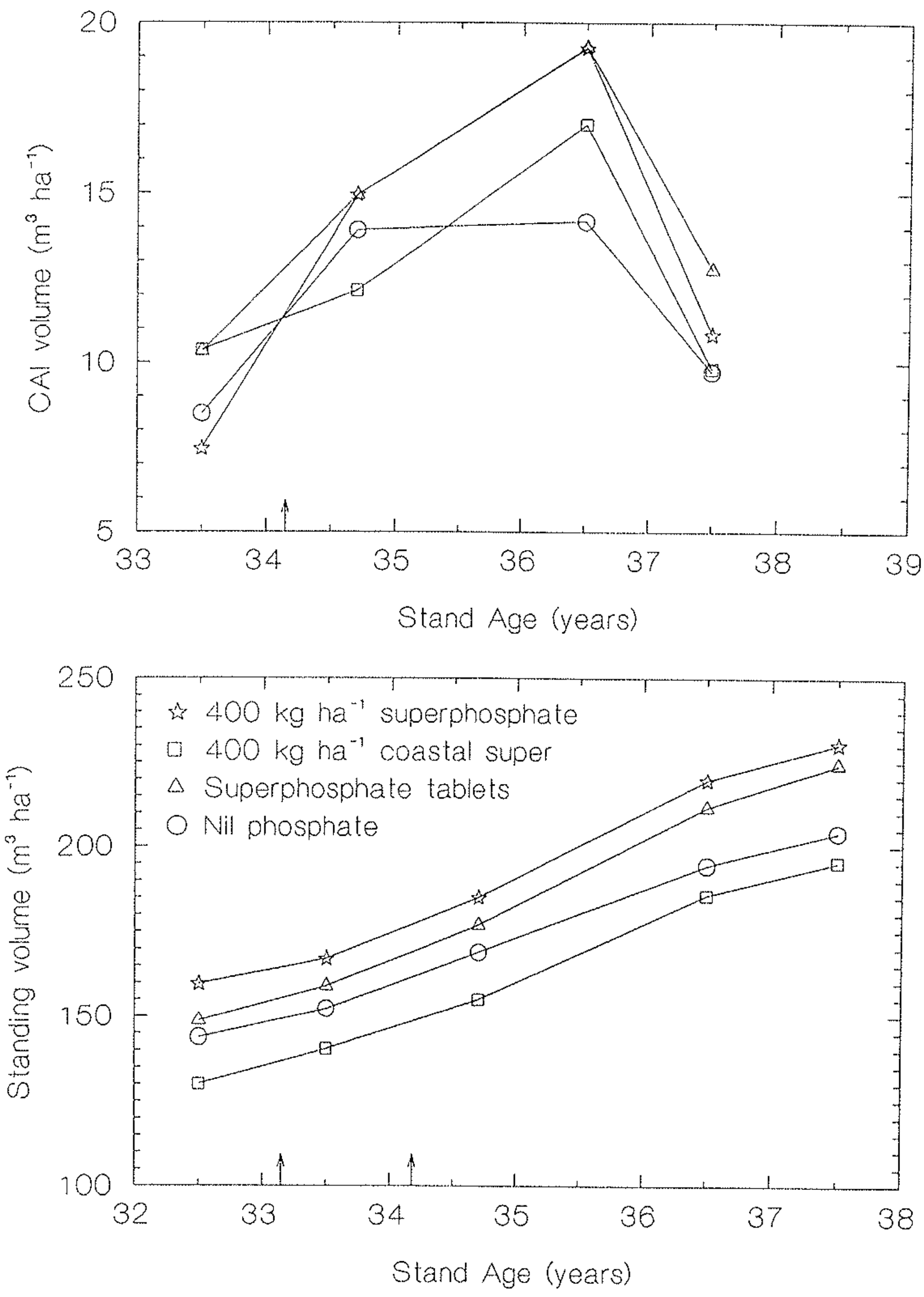

Figure 2. Development trends for standing volume (bottom) and volume increment (top) for Treatment application 2, applied in September 1985 at stand age 34 years. The stands were thinned from 250 to 100 stems ha^{-1} in September 1984.

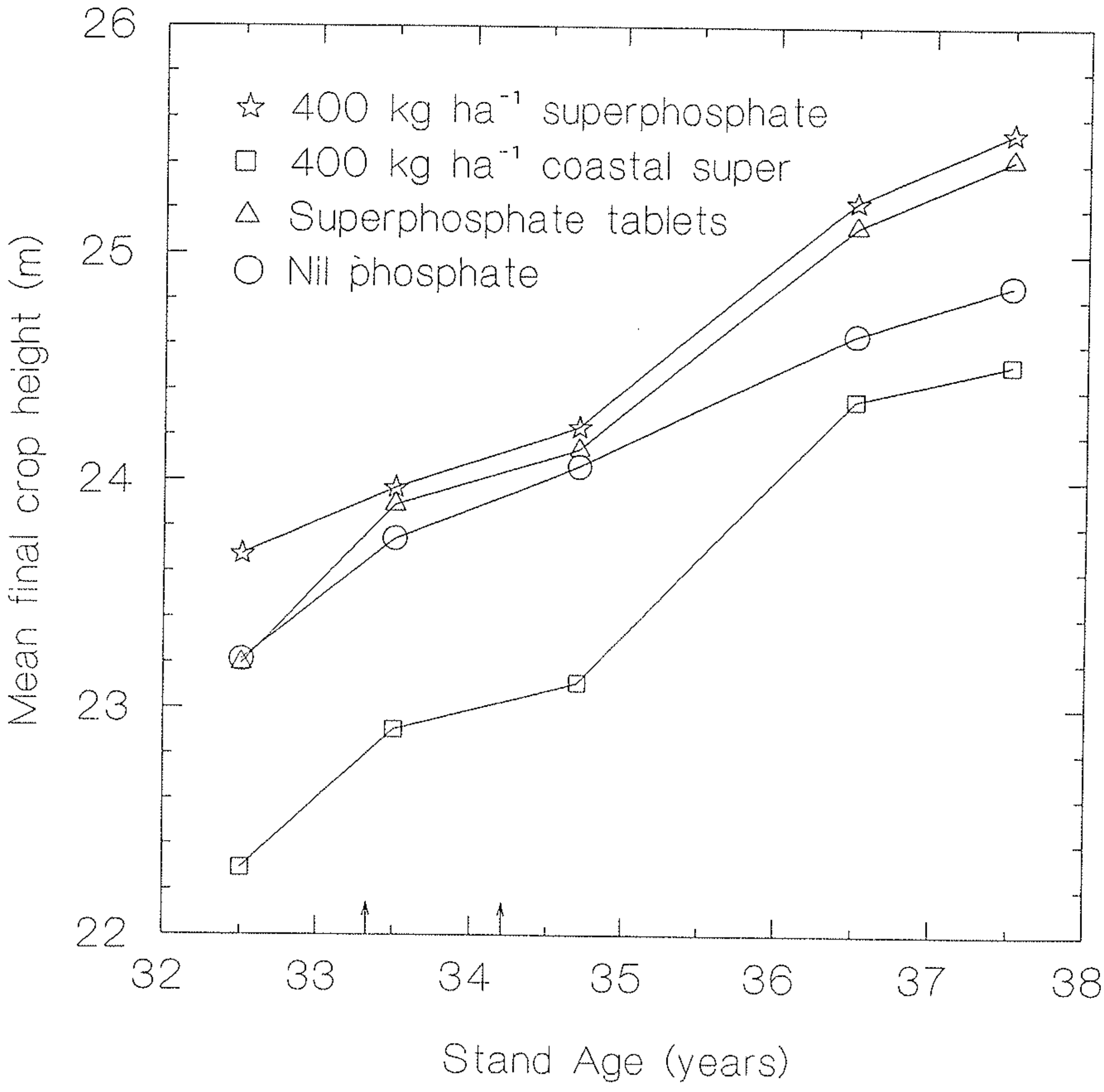

Figure 3. Mean heights of the 100 stems ha-1 for treatments refertilised at stand age 34 years.

Gnangara E44 - Fertiliser application to 21 year old *Pinus pinaster* at Gnangara E44.

Summary and Conclusions

Four different combinations of phosphatic and nitrogenous fertilisers were tested against a control in a 21 year old stand of *Pinus pinaster* on Bassendean sands at Gnangara plantation. The site was adjacent to a ground water bore managed by the Water Authority and the aim was to monitor the impact of water withdrawal on the control and heavily fertilised stands.

The five treatments were replicated in three blocks separated on the basis of high, moderate and low basal area production. The minimum application was 500 kg ha^{-1} superphosphate and the maximum 800 kg ha^{-1} Agras No 1.

The trial commenced in 1978 and terminated in 1989. During this period no impact of the added fertilisers on stand growth could be detected

Introduction

The trial area is adjacent to a Water Authority bore. The objective was to monitor the response of the pines with maximum fertiliser treatment to continued water pumping.

Location

The trial was established in Gnangara plantation, Compartment E44, east of Silver Road and north of Blackboy Road. The stand was planted in 1957.

Procedure

Fifteen plots of 20 m x 20 m net area and 40 m x 40 m gross area were selected. Each contained or were reduced to 10 trees (250 ha^{-1}), 5 of which were marked as the final crop. The plots were ranked on the basis of basal area over bark (baob) and separated into three groups of 5 plots with progressively decreasing basal area.

Treatments - Five treatments were compared -

1. Control - Nil fertiliser.
2. 500 kg ha^{-1} superphosphate (9.1 % P).
3. 500 kg ha^{-1} superphosphate + 150 kg ha^{-1} urea (46 % N).
4. 500 kg ha^{-1} Agras No 1 (17.5 % N, < 7.6 % P).
5. 800 kg ha^{-1} Agras No 1.

The fertilisers were applied in September 1978 and repeated in August 1983.

Measurements - Diameter breast height over bark (dbhob) was measured in the following years.

August 1978. Age 21.0 years.

February 1980. Age 22.6 years.
February 1981 Age 23.6 years.
February 1982. Age 24.6 years.
March 1983. Age 25.6 years.
February 1984. Age 26.6 years.
January 1985. Age 27.6 years.
January 1986. Age 28.6 years.
January 1987. Age 29.6 years.
January 1988. Age 30.6 years.
January 1989. Age 31.6 years.

Table 1. Results of analysis of variance for standing plot basal areas and current annual increments in basal area.

Measurement Period	Age (years)	Treatment p	Block p	Treatment Mean square	Error Mean square
		Stand basal area (m^2 ha^{-1})			
1978	21.0	0.355	0.030	3.484	2.726
1981	23.6	0.569	0.146	0.844	1.083
1983	25.6	0.631	0.175	1.851	2.763
1985	27.6	0.550	0.322	5.914	7.265
1987	29.6	0.606	0.446	8.950	12.570
1989	31.6	0.582	0.388	12.500	16.550
		CAI basal area (m^2 ha^{-1})			
1978-81	21-24	0.355	0.485	0.118	0.087
1981-83	24-26	0.523	0.529	0.217	0.245
1983-85	26-28	0.420	0.434	0.317	0.289
1985-87	28-30	0.700	0.904	0.135	0.242
1987-89	30-32	0.504	0.199	0.082	0.091
D.F		4	2	4	8

Results

Mean values for stand basal area and current annual increment (CAI) in basal area at approximately two yearly measurement intervals are plotted in Figure 1. There was little difference from the unfertilised control treatment, the highest Agras application treatment 5 performing the poorest. There is little evidence of a response to the second fertiliser addition at age 26 years although it is expected that a superiority in growth by treatments 2-5 over the control was maintained and slightly increased by this latter addition. The addition of 500 kg ha^{-1} of superphosphate (T2) was as effective as any other treatment in promoting growth.

Analysis of variance for stand basal areas and CAI,s were carried out and no treatment was found to be significant from any other (Table 1).

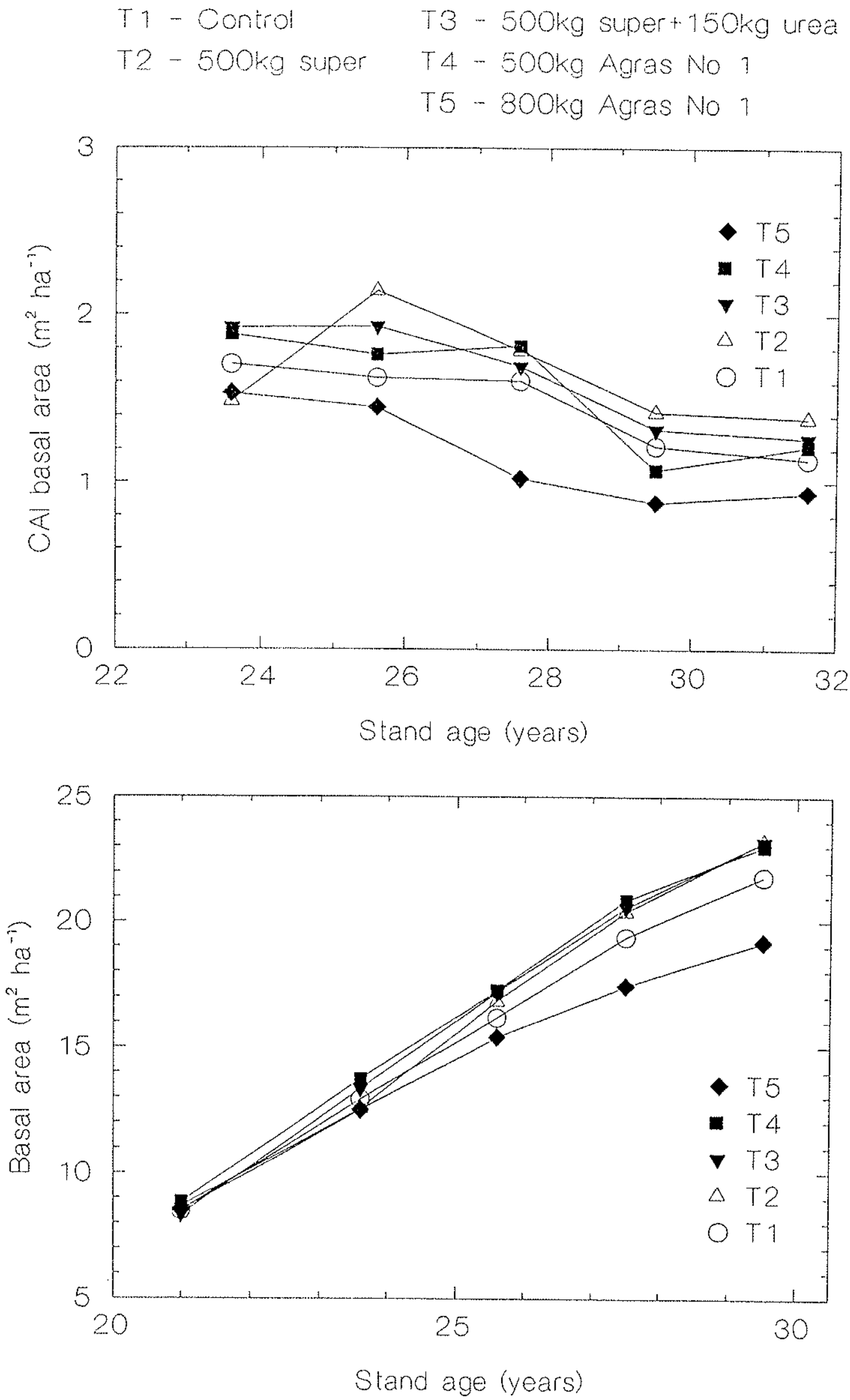

Figure 1. The development of standing basal area and current annual increment in basal area for the five treatments over the course of the trial.

Discussion

The lack of any appreciable treatment response for either of the 1978 or 1983 applications over the measurement period (Fig. 1) is surprising. The unexplained growth depression for Treatment 5 of 800 kg ha^{-1} Agras and the small number of degrees of freedom for the error term in the analysis (Table 1) due to the limited design may account for the lack of significance in results. Measured differences from the control would not lead one to anticipate improved results from a more comprehensive trial.

The limited response to relatively high and frequent fertiliser additions cannot be logically associated with water withdrawal from the ground water bore in the vicinity. At the commencement of the trial many trees in Compartment E44 were scorched in a prescribed burn in June 1978 but it was recorded that an adequate number of healthy trees remained for plot selection and establishment of the trial. Increment cores were taken and no obvious variations in growth which could be associated with water table variation, fire effects or fertiliser additions were observed.

Fertiliser addition was not effective in increasing growth for stands of this age on such sites.

Research WP 2/81 - Seasonal timing for fertiliser application to *Pinus pinaster* stands on coastal plain sands.

Summary and Conclusion

The trial investigates the effects of P and N+P fertiliser applications on stands of *Pinus pinaster* of 8 and 17 years of age on both grey sands of the Bassendean Dunes series and yellow sands of the Spearwood Dunes series. Applications of each fertiliser type were applied in April, July, August, September and October to determine if application in any month promoted superior growth response.

At each of four sites 11 plots of 0.4 ha net area were selected to allow 5 monthly applications of 0.5 tonne ha^{-1} of superphosphate, 5 monthly applications of 0.5 t ha^{-1} superphosphate plus 0.15 t ha^{-1} of urea and an unfertilised control plot. The trial was commenced in April 1981 and tree height and dbhob were measured annually for 5 years. Foliar samples were collected from 3 select crop trees per plot in April 1982, 1982, 1983 and 1984 and analysed for N and P content.

A supplementary study extended to a further four stands with a control and applications in August and September for each fertiliser treatment .

Differences in stand response to the different months of application were not significant. Both fertiliser treatments had significant effects on growth with the N+P being superior to the P alone. The response was measurable within 12 months after application and lasted for five years. Response was greater in stands on the grey sands than in those studied on the yellow sands.

Foliar P content responded immediately to added P and remained high five years after fertiliser application. On the grey sands volume response could be related to the foliar P levels. Most response occurred in stands with control P levels of .02 to .04 per cent, maximum levels were between .07 and .08 per cent and satisfactory growth was associated with foliar levels for P of .06 to .07 per cent. Foliar analysis provided a sound diagnostic technique for managing superphosphate additions to developing stands.

Foliar N contents were depressed with respect to the control values but tended to remain in balance with P levels through the added urea with N+P additions. Foliar N per cent fluctuated considerably from year to year and would require a comparative control if to be of assistance in diagnosing fertiliser requirements of stands. It appears that stand growth on the yellow sands is better related to foliar N levels than to foliar P per cent.

Needle length was analysed as a means of assessing fertiliser response. Variation made sampling difficult but response to added fertiliser was rapid. The procedure is of limited use unless a suitable control is available for comparison.

Introduction.

Local research groups have considered that fertiliser additions to tree plantations were most effective when applied at the start of the spring season. In 1980 and again in 1981 the operational broadcast application of subsequent fertiliser to established plantations north of Perth was during the period May to June. A trial was commenced in 1981 to determine whether these applications could be less effective than later applications.

Objective - The aim of the trial was to assess whether there was an optimum period between early winter and late spring for effective response to fertiliser application in developing pine stands in plantations on the northern Swan Coastal Plain. Both P and N+P fertilisers were considered and it was largely with the use of nitrogenous fertilisers that the concern with timing of application was felt. An opportunity was taken in planning the trial to assess the utility of foliar analysis of N and P levels to diagnose stand fertiliser requirements.

Location - The trial was established at two locations in the Gnangara plantation and two at Yanchep, embracing stands from 8 to 17 years of age and sampling both leached, grey sands and yellow, limestone sands. Partial treatments were established at a further four additional sites to sample a wider range of site effects.

Establishment

Treatments and Design - the basic trial was designed as a 5x2 factorial to examine 5 periods of fertiliser application and 2 fertiliser types. This trial was randomised within each of 4 stand types. A control was included at each site to contrast the 10 fertiliser-period combinations.

Fertilisers types -

1. Superphosphate at 0.5 tonne ha-1, broadcast.
2. Super at 0.5 t. ha^{-1} plus 0.15 t. ha^{-1} urea, broadcast.
3. Nil fertiliser (not included as a factorial level but as a control to assess the overall response).

Fertiliser timing -

1. Applied in period 10-20 April 1981.
2. Applied in period 10-20 July 1981.
3. Applied in period 10-20 August 1981.
4. Applied in period 10-20 September 1981.
5. Applied in period 10-20 October 1981.

Site type and stand development -

1. Bassendean series, grey sands, planted in 1964 and thinned to 225 stems ha^{-1}. Gnangara E31.
2. Bassendean series, grey sands, planted in 1973 and thinned to 300 stems ha^{-1}. Gnangara J16.

3. Karrakatta series, yellow sands, planted in 1967 and thinned to 250 stems ha^{-1}. Yanchep B29.
4. Karrakatta series, yellow sands, planted in 1973 and thinned to 300 stems ha^{-1}. Yanchep C12 and C15.

Four additional stands were employed in the supplementary study.

5. Bassendean series, grey sands, planted in 1964 and thinned to 225 stems ha^{-1}. Gnangara E30. This site is close to 1 above.
6. Bassendean series, grey sands, planted in 1964 and thinned to 225 stems ha^{-1}. Gnangara E33, again associated with sites 1 and 5.
7. Bassendean series, grey sands, planted in 1973 and thinned to 750 stems ha^{-1}. Gnangara J15.
8. Karrakatta series, yellow sands , planted in 1974 and thinned to 300 stems ha^{-1}. Yanchep B101.

Supplementary study - To sample a wider range of site and stand conditions 4 extra sites were selected with 6 plots. Treatments were restricted to a control, superphosphate applied in July, August and September and superphosphate and urea applied in August and September.

Procedure - Plots of 40 m x 40 m (0.16 ha gross area) were selected to represent stands of full stocking and uniform growth at each site. Heights and diameter breast height over bark (dbhob) were measured on all trees in the central 20 m x 20 m (net area .04 ha). Plots with means outside a one standard deviation range were rejected until 11 acceptable plots were located at each site. Treatments were randomly allocated to the plots in March 1981.

The fertiliser treatments were applied by hand on April 22, July 22, August 24, September 24 and October 26.

Measurement and Analysis

Heights and dbhob were measured in March 1981, April 1982, March 1983, March 1984, March 1985 and March 1986.

Foliar samples were collected from each of 3 crop trees per plot (75 stems ha^{-1}) in April of years 1981, 1982, 1983 and 1984. These were analysed for N and P content.

For the main trial mean total volume, per cent P and per cent N for the eleven treatments were subject to an analysis of variance with the four sites as blocks. Contrasts were examined between the 10 treatments and the control, the P treatments (1 to 5) against the control, the N+P treatments (6-10) against the control and the P treatments against the N+P treatments.

The controls were removed from the data sets and volumes and percentage N and P were analysed as a 5x2 factorial within the four randomised sites.

The supplementary plots were included in a separate analysis of a 2x2 factorial plus controls for the total of 8 sites.

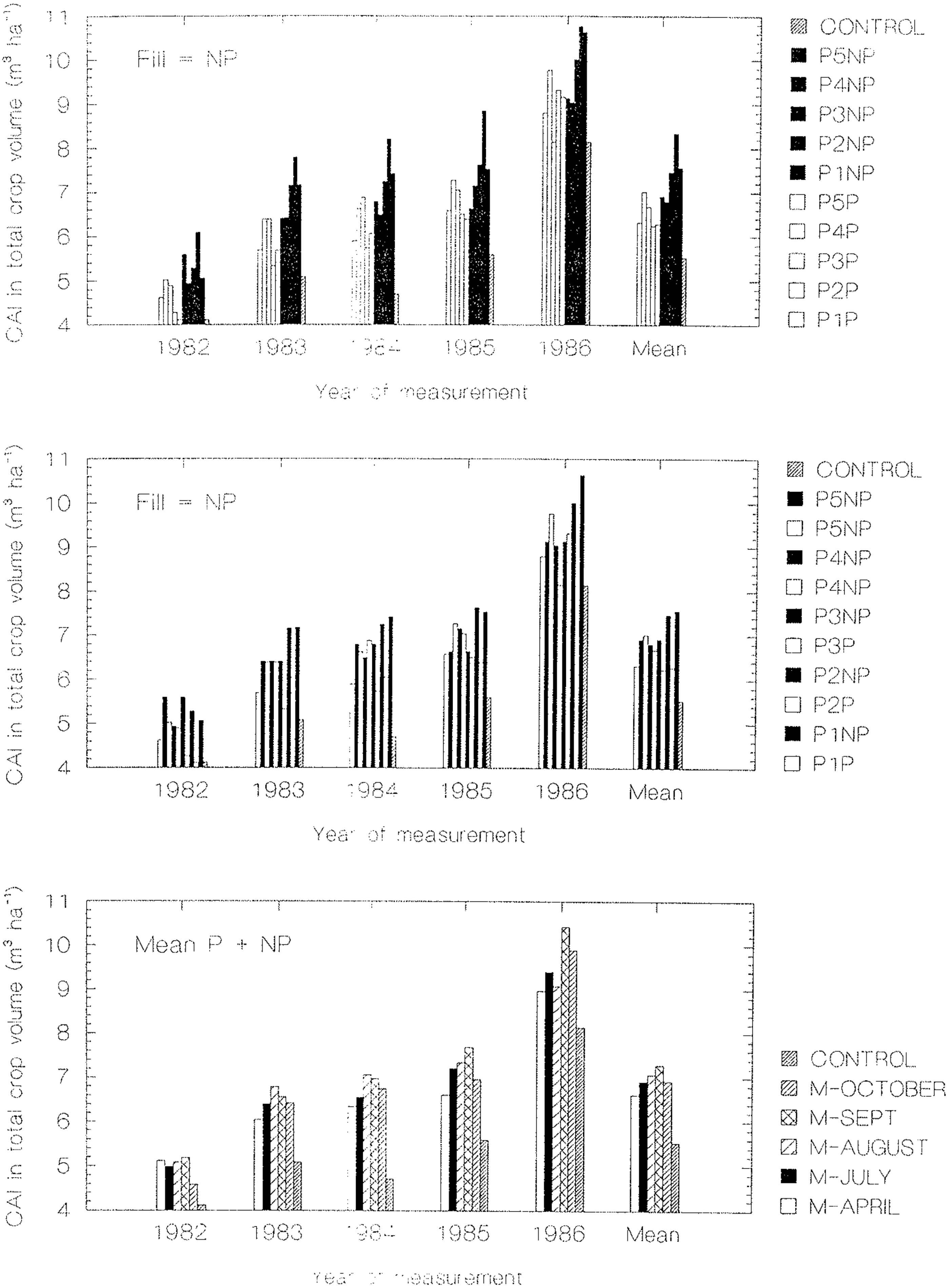

Figure 1. Current annual increment in total volume for the 11 treatments used in the basic trial showing differences between P, N+P and the control and the monthly application times (lower).

Table 1. Mean values for standing volume of total and select crop for treatments at each measurement.

Treatment		Year of Measurement 1981	1982	1983	1984	1985	1986
		Standing total volume (m^3 ha^{-1})					
1	P-April	15.6	20.2	25.9	31.8	38.4	47.2
2	P-July	18.2	23.3	29.6	36.3	43.5	53.3
3	P-August	16.1	20.9	27.3	34.2	41.2	49.4
4	P-Sept.	14.8	19.1	24.4	30.2	36.7	46.0
5	P-Octob.	15.9	20.0	25.7	31.7	38.1	47.3
6	NP-April	15.7	21.3	27.7	34.5	41.1	50.2
7	NP-July	15.3	20.2	26.7	33.1	40.3	49.3
8	NP-August	15.4	20.7	27.9	35.1	42.8	52.8
9	NP-Sept.	19.6	25.6	33.4	41.7	50.5	61.3
10	NP-Octob.	16.3	21.3	28.5	35.9	43.5	54.1
11	Control	16.3	20.5	25.5	30.3	35.8	44.0
		Standing select crop volumes (m^3 ha^{-1})					
1	P-April	5.7	7.2	9.0	10.8	12.8	15.5
2	P-July	7.1	8.9	11.1	13.3	15.8	19.2
3	P-August	4.9	6.4	8.2	10.1	12.0	14.8
4	P-Sept.	6.7	8.4	10.2	12.1	14.2	17.4
5	P-Octob.	6.0	7.4	9.4	11.6	13.7	16.6
6	NP-April	5.3	7.1	9.2	11.6	13.7	16.7
7	NP-July	5.4	6.7	8.7	10.5	12.7	15.4
8	NP-August	5.3	7.4	9.9	12.4	15.0	18.0
9	NP-Sept.	7.0	9.1	11.5	14.1	16.9	20.2
10	NP-Octob.	5.7	7.3	9.7	12.1	14.6	17.9
11	Control	5.8	7.1	8.6	10.1	11.7	14.3

Results

Total volume for the main trial

Contrasts- Results for mean volume for each treatment at each measurement and increment period are set out in Table 1 and Figure 1, respectively. Contrasts for standing volumes at each measurement, annual increment periods and the total period from 1981 to 1986 are summarised in Tables 2 and 3

Site differences were highly significant at all measurements. Treatment differences in standing volumes were not significant for the first two years after application but were significant in 1984, 1985 and 1986. In 1985 and 1986 the mean of fertiliser treatments was significantly different to the control (Table 2). The P treatments did not differ from the control in contrasts but the N+P treatments had significantly superior volumes from 1984 to 1986. The N+P treatments (6-10) were significantly superior to the P (1-5) treatments in contrasts from 1984 to 1986.

Table 2. Significance values for treatment (1-10) and group P(1-5) and N+P (6-10) contrasts with the control (11) and the contrast between groups for standing volume. The probabilities are for the F value to occur randomly.

Source	Year of measurement					
	1981	1982	1983	1984	1985	1986
Anova Site	.000	.000	.000	.000	.000	.000
Anova Treatment	.283	.276	.126	.043	.024	.045
P + N+P = Control	.965	.629	.283	.079	.041	.043
P = Control	.869	.891	.616	.294	.193	.197
N+P = Control	.935	.433	.123	.022	.010	.011
N+P = P	.670	.264	.071	.027	.019	.022

Table 3. Significance values for treatments (1-10) and group P(1-5) and N+P (6-10) contrasts with the control (11) and the contrast between groups. Data analysed are volume increments and probabilities are for the F value to occur randomly.

Source	Increment Period					
	81-82	82-83	83-84	84-85	85-86	81-86
	Total stand					
Anova Site	.000	.000	.000	.000	.000	.000
Anova Treatment	.134	.014	.002	.013	.408	.024
P + N+P = Control	.092	.014	.000	.006	.140	.008
P = Control	.380	.148	.007	.042	.338	.076
N+P = Control	.021	.002	.000	.001	.178	.001
N+P = P	.012	.002	.003	.017	.109	.005
	Select stand					
Anova Site	.000	.000	.000	.000	.000	.000
Anova Treatment	.208	.005	.006	.013	.634	.022
P + N+P = Control	.146	.002	.004	.004	.193	.007
P = Control	.295	.027	.036	.030	.252	.044
N+P = Control	.083	.000	.000	.001	.178	.002
N+P = P	.218	.002	.009	.023	.716	.033

Increments were more responsive than standing values and treatments were significantly different in the 1982-83 increment period, the second year after application (Table 3, Fig. 2). They were significant for all other increment periods except the 1985-86 period. The contrast of all 10 fertilised treatments against the unfertilised control was also highly significant in all but the 1981-82 and 1985-86 periods. The contrast of the P treatments (1-5) against the control was significant for the 1983-84 and 1984-85 periods while the N+P treatments (5-10) differed significantly from the control for all except the 1985-86 period for the total stand and the 1981-82 and 1985-86 periods

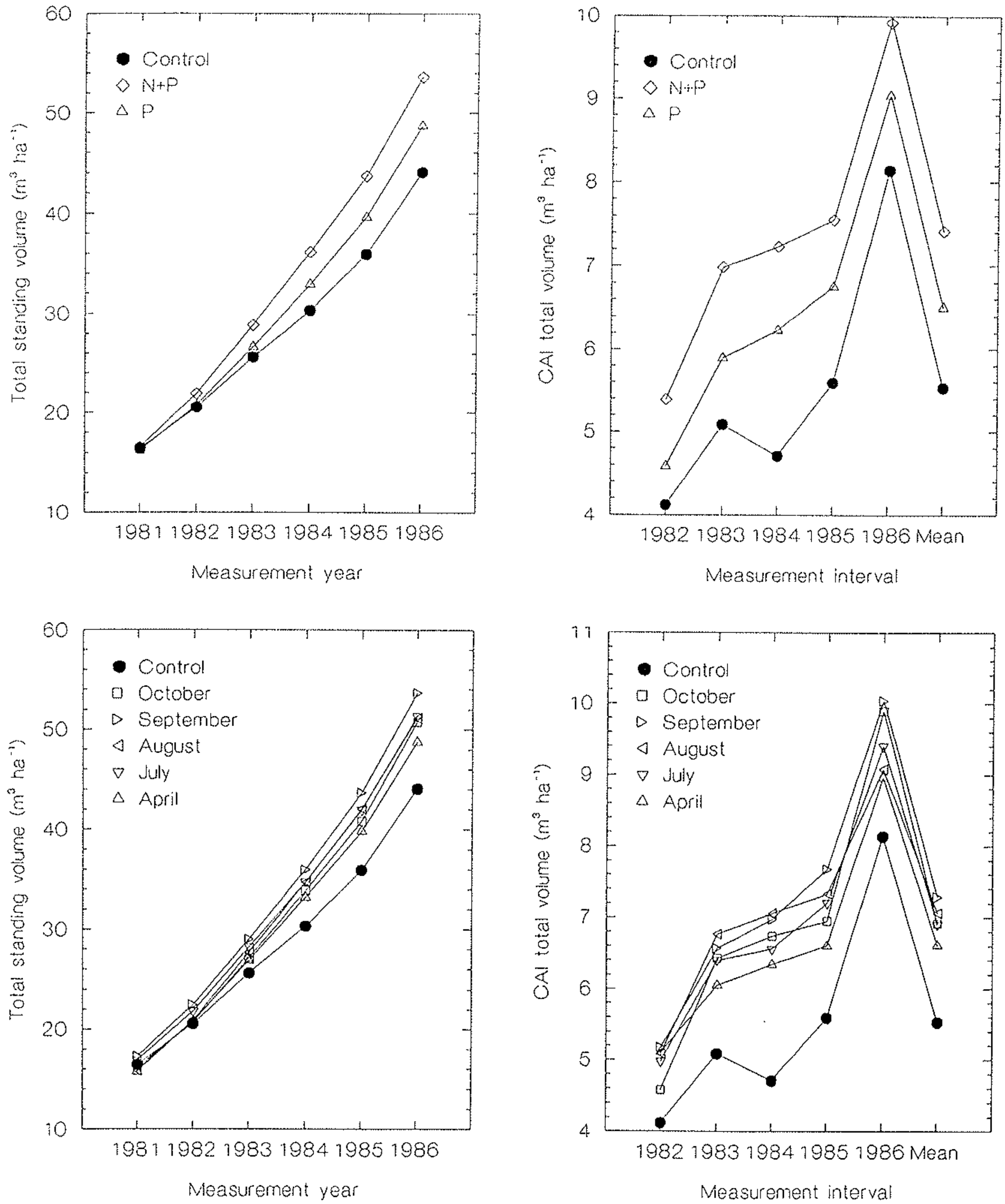

Figure 2. Trends for response to fertiliser types (upper) and month of application (lower) conpared with the control for both standing volume and current annual increment.

for the select portion of the stand (Table 3). The total stand was more responsive than the select stand.

Table 4. Factorial analysis of total standing volumes at each measurement. Results are the probabilities that the F value obtained in ANOVA would occur by chance.

		Year of Measurement					
	DF	1981	1982	1983	1984	1985	1986
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time	4	0.699	0.794	0.820	0.794	0.674	0.694
Fert.	1	0.684	0.286	0.084	0.034	0.024	0.027
Time*Fert	4	0.080	0.097	0.069	0.049	0.047	0.095
Error	27						
Total	39						

Contrast analysis also indicated that increment response from the N+P application in the total stand was significantly superior to that of the P treatment except for the 1985-86 period. For the select stand the N+P was superior to the P except for the initial increment period and the 1985-86 increment period.

Table 5. Factorial analysis of increments in stand volume. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

		Increment period					
Source	DF	81-82	82-83	83-84	84-85	85-86	81-86
		Whole stand					
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time	4	0.764	0.682	0.606	0.658	0.333	0.746
Fert	1	0.015	0.002	0.004	0.122	0.022	0.008
Time*Fert	4	0.406	0.168	0.128	0.568	0.152	0.238
Error	27						
Total	39						
		Select crop					
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time	4	0.545	0.819	0.669	0.427	0.770	0.708
Fert	1	0.242	0.003	0.012	0.027	0.729	0.041
Time*Fert	4	0.197	0.099	0.047	0.103	0.465	0.083
Error	27						
Total	39						

Table 6. Factorial analysis of standing volumes at each measurement with the non-significant application periods nested within sites. Results are the probabilities that the F value in ANOVA would be obtained by chance.

Source	DF	Year of measurement					
		1981	1982	1983	1984	1985	1986
		Whole stand					
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time(Site)	16	0.844	0.818	0.749	0.721	0.604	0.366
Fert.	1	0.739	0.365	0.135	0.068	0.050	0.035
Site*Fert	3	0.913	0.697	0.537	0.481	0.604	0.571
Error	16						
Total	39						

Table 7. Factorial analysis of increment in stand volume with the application periods nested within sites. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

Source	DF	Increment period					
		81-82	82-83	83-84	84-85	85-86	81-86
		Whole stand					
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time(Site)	16	0.495	0.206	0.393	0.109	0.041	0.131
Fert	1	0.012	0.001	0.007	0.016	0.048	0.004
Site*Fert	3	0.089	0.155	0.322	0.620	0.423	0.386
Error	16						
Total	39						
		Select crop					
Site	3	0.000	0.000	0.000	0.000	0.000	0.000
Time(Site)	16	0.650	0.860	0.556	0.088	0.490	0.548
Fert	1	0.296	0.013	0.028	0.018	0.721	0.069
Site*Fert	3	0.878	0.630	0.627	0.458	0.433	0.871
Error	16						
Total	39						

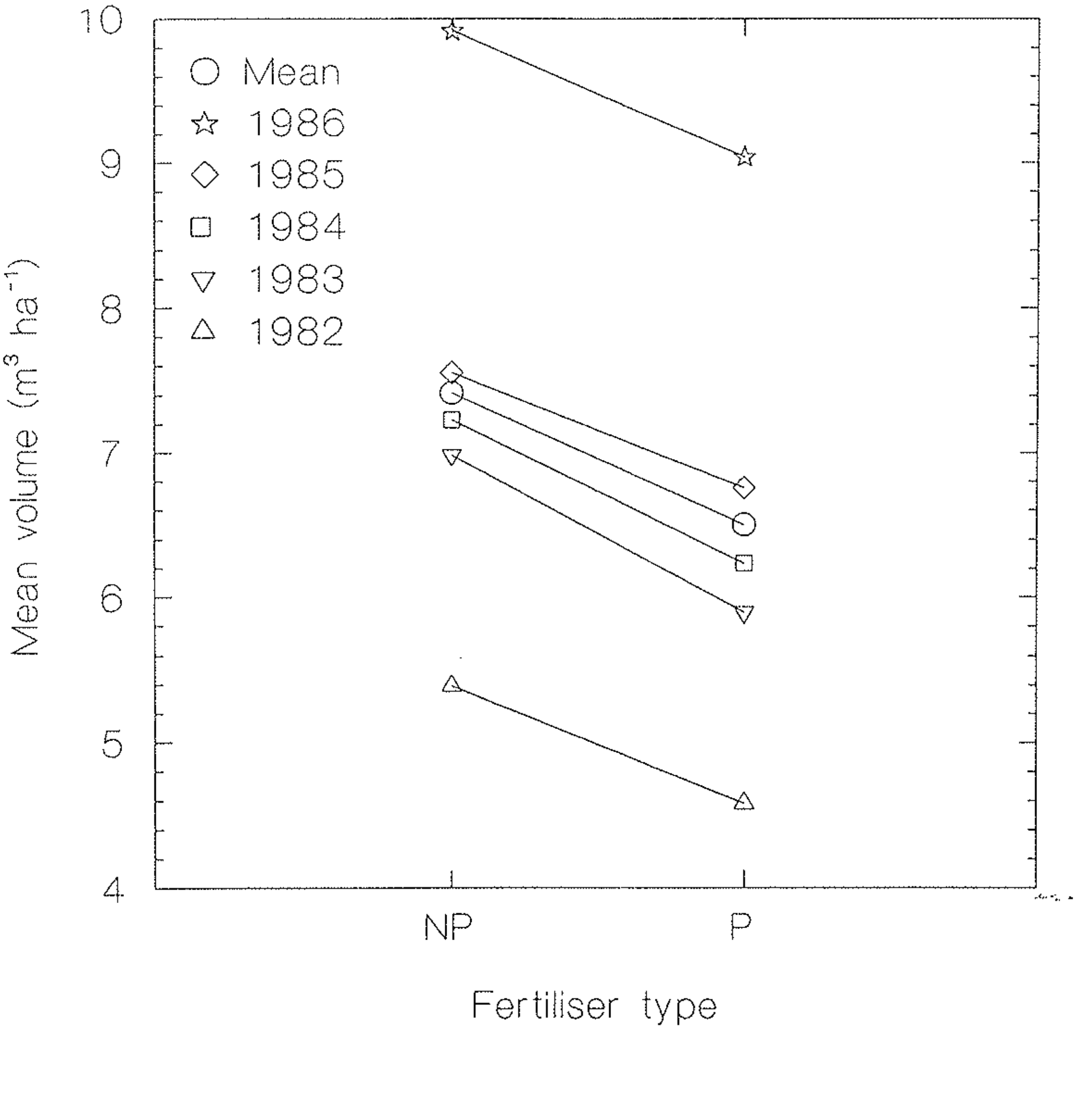

Figure 3. Response in mean volume with time to the P and N+P fertiliser applications.

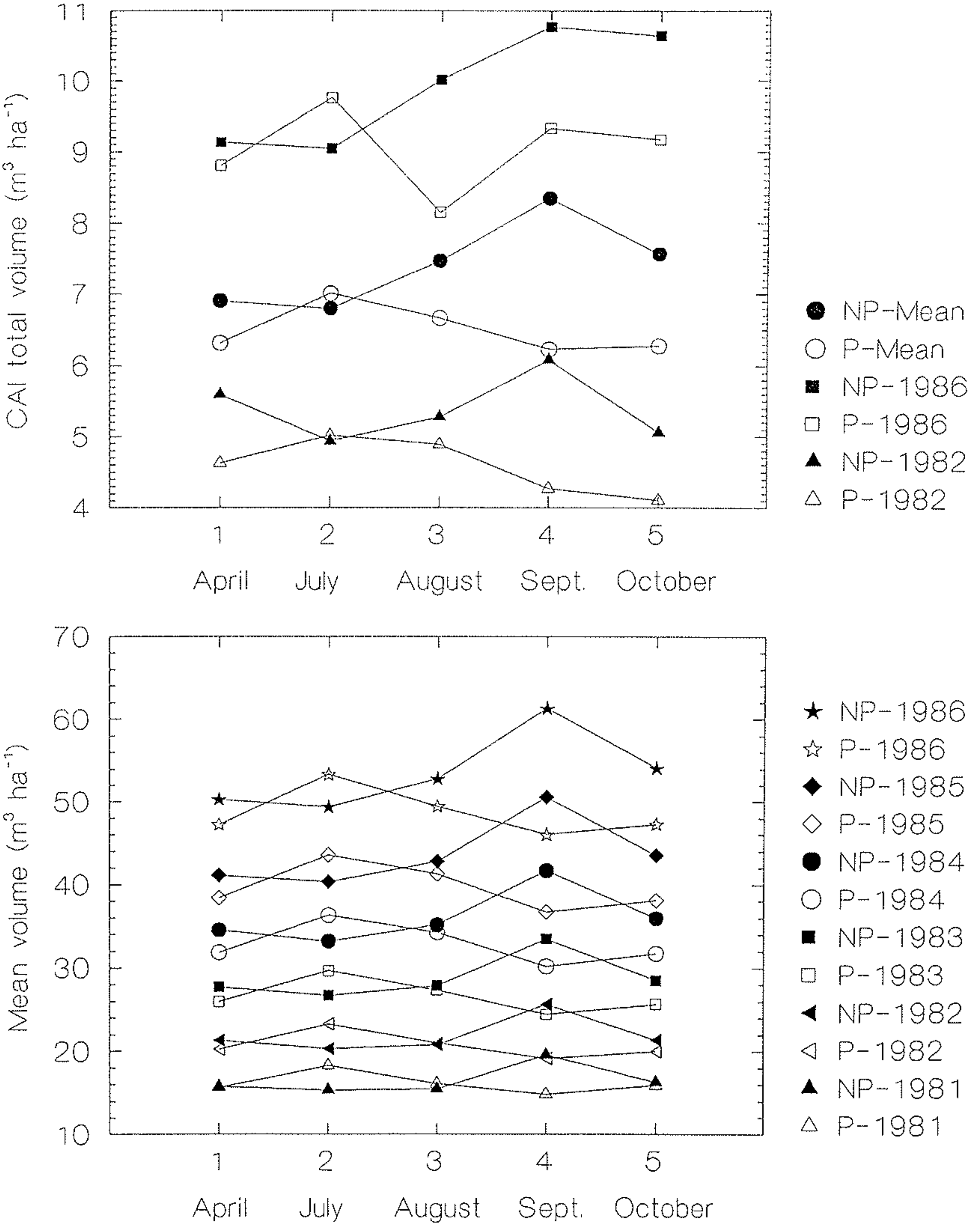

Figure 4. Trend lines for the interaction of fertiliser by month of application for current annual increment and total standing volume.

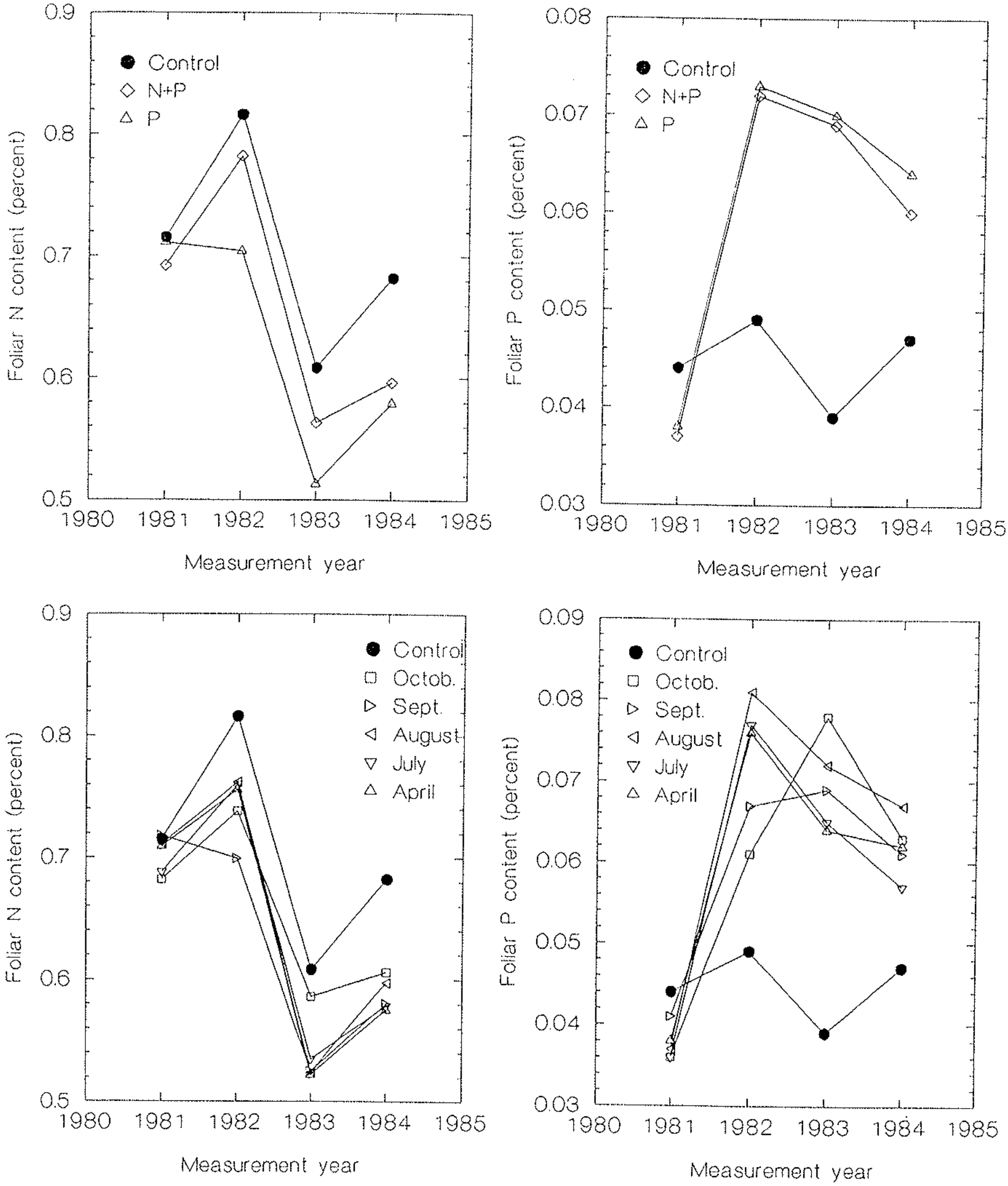

Figure 5. - Foliar levels of N (left) and P (right) for treatment fertiliser types (top) and month of application (bottom).

These results show that the N+P fertiliser significantly improved volume growth within the first 12 months after application, it was effective for four years growth and had ceased to be effective by the fifth year after application. Response to the P treatment was delayed for two years and then less effective than the N+P application (Fig. 3).

Factorial - Factorial analysis of total volumes standing at each measurement (Table 4) gave highly significant differences in volume means between the four site types. The different times of application had no influence of on volume growth. Fertiliser types had significantly different influences in the 1984, 1985 and 1986 stands and the Time x Fertiliser interaction was significant at the .05 level in 1984 and 1985. The interaction is plotted in Figure 4 (lower) to show that the N+P fertiliser tended to have a superior influence in the later monthly applications from 1983 (i.e. 2 years after application) onwards. Analysis for annual increments in stand volume (Table 5) did not detect any effect from the different months of fertiliser application. The non-significant Time x Fertiliser interactions for increments in the whole crop are plotted in Figure 4 (top). This interaction was significant (.047 level) for the 1983-84 increment interval in the select crop (Table 5) confirming the tendency for the N+P dressings in September and October to be better than the P dressings for the later applications.

To obtain some understanding of the impact of the fertilisers on the widely different sites the insignificant application times were nested in sites and subject to factorial analysis to examine the Site x Fertiliser interaction. These were not significant for either standing volume at each measurement (Table 6) or for growth increments within the whole and select crops (Table 7).

Foliar nutrient contents for the main trial.

Mean foliar compositions of N and P for treatments are contained in Table 8.

Contrasts - Results for contrasts of N and P contents for each of the four years of analysis are set out in Table 9. For phosphate content initial P and N+P and control values were equivalent but the natural phosphate levels associated with sites were different (.000 level). Both the P and N+P treatments were significantly better than the control in increasing foliar P from 1982 to 1984 and foliar phosphate contents were equivalent for the P and N+P treatments (Table 9 and Fig. 5). Foliar N contents varied significantly with site prior to treatment. The mean of the P treatments was significantly lower than the control in 1982, 1983 and 1984 and for N+P in the later two years only (Table 9 and Fig. 5). The N+P treatments tended to maintain foliar N values at the control level despite rapid growth which caused dilution of the fixed amount of N in the system. The N content of the N+P applications was significantly higher than that of the P applications in 1982 and 1983. In 1984 the effect of added N had dissipated and the foliar N contents of the two treatments did not differ.

Table 8. Mean values for foliar nutrient contents of N and P for treatments at each measurement.

Treatment		Year of Measurement 1981	1982	1983	1984
		Nitrogen (per cent)			
1	P-April	0.700	0.699	0.495	0.563
2	P-July	0.689	0.708	0.500	0.569
3	P-August	0.742	0.732	0.492	0.597
4	P-Sept.	0.735	0.678	0.526	0.577
5	P-Octob.	0.689	0.704	0.554	0.589
6	NP-April	0.719	0.813	0.549	0.588
7	NP-July	0.686	0.812	0.569	0.588
8	NP-August	0.680	0.792	0.556	0.597
9	NP-Sept.	0.702	0.721	0.524	0.583
10	NP-Octob.	0.675	0.772	0.619	0.623
11	Control	0.715	0.816	0.608	0.682
		Phosphorus (per cent)			
1	P-April	0.030	0.075	0.060	0.065
2	P-July	0.030	0.078	0.065	0.056
3	P-August	0.030	0.077	0.070	0.069
4	P-Sept.	0.040	0.073	0.076	0.066
5	P-Octob.	0.030	0.062	0.080	0.067
6	NP-April	0.040	0.078	0.068	0.059
7	NP-July	0.030	0.077	0.064	0.058
8	NP-August	0.030	0.085	0.074	0.066
9	NP-Sept.	0.040	0.061	0.062	0.056
10	NP-Octob.	0.030	0.060	0.076	0.060
11	Control	0.045	0.049	0.039	0.047

Hence the phosphate alone application increased the P foliar content within 12 months and was still significantly higher than that of the control 3 years after application. These treatments were accompanied by a decrease in the foliar N value. Application of urea with the superphosphate provided similar foliar P values to those of the phosphate alone but tended to maintain foliar N values at the level of the unfertilised control for two years after application.

Factorial analysis - Factorial analysis of foliar N levels showed no significant differences for time of application or fertiliser type (Tables 10 and 11). Foliar P associated with the October application time in 1983 was significantly higher than the values for the other months of application (Table 10, Fig. 5). The Time x Fertiliser interaction in 1982 was significant.

Table 9. Significance values for treatment (1-10) and group P (1-5), N+P (6-10) contrasts with the control(11) and between P and NP groups for foliar nutrient contents. Foliar contents are per cent of dry weight and probabilities are for the F value to occur randomly.

Source	Measurement year			
	1981	1982	1983	1984
	P Content			
Anova Site	.000	.092	.187	.010
Anova Treatment	.522	.002	.000	.112
P + N+P = Control	.052	.000	.000	.005
P = Control	.079	.000	.000	.002
N+P = Control	.109	.000	.000	.019
N+P = P	.693	.772	.708	.165
	N Content			
Anova Site	.000	.017	.000	.000
Anova Treatment	.916	.020	.000	.237
P + N+P = Control	.709	.039	.001	.003
P = Control	.915	.004	.000	.002
N+P = Control	.374	.341	.039	.008
N+P = P	.388	.001	.000	.346

Table 10. Factorial analysis of foliar contents of N and P. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

Source	DF	Year of measurement			
		1981	1982	1983	1984
		Nitrogen (per cent)			
Site	3	0.000	0.177	0.003	0.000
Time	4	0.504	0.557	0.691	0.738
Fert	1	0.112	0.122	0.616	0.829
Time*Fert	4	0.816	0.807	0.537	0.239
Error	27				
Total	39				
		Phosphorus (per cent)			
Site	3	0.000	0.075	0.000	0.003
Time	4	0.618	0.387	0.011	0.206
Fert	1	0.284	0.623	0.669	0.787
Time*Fert	4	0.972	0.024	0.072	0.229
Error	27				
Total	39				

Table 11. Factorial analysis of foliar contents of N and P with the application periods nested within sites. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

Source	DF	Year of measurement 1981	1982	1983	1984
		Nitrogen (per cent)			
Site	3	0.001	0.240	0.006	0.000
Time(Site)	16	0.677	0.776	0.699	0.705
Fert	1	0.115	0.155	0.619	0.831
Site*Fert	3	0.286	0.840	0.303	0.161
Error	16				
Total	39				
		Phosphorus (per cent)			
Site	3	0.000	0.158	0.304	0.003
Time(Site)	16	0.009	0.406	0.575	0.118
Fert	1	0.104	0.669	0.744	0.770
Site*Fert	3	0.298	0.969	0.916	0.626
Error	16				
Total	39				

Table 12. Probabilities for treatment (3, 4, 8, 9) and P group (3, 4) and N+P group (8, 9) contrasts with the control (11) and between P and NP groups. Data refers to standing volume and the five year increment for the 8 sites used in the supplementary study.

Source	Total volume			Select crop volume		
	1981	1986	81-86	1981	1986	81-86
Anova Site	.000	.000	.001	.000	.000	.000
Anova Treat	.109	.134	.045	.438	.320	.082
P + N+P = Control	.079	.143	.013	.391	.393	.042
P = Control	.020	.539	.082	.266	.853	.246
N+P = Control	.391	.042	.005	.652	.173	.012
N+P = P	.062	.075	.142	.412	.150	.074

Total volume for the supplementary study

Contrasts - The analysis of variance for treatments for the 8 sites used in the supplementary study revealed that standing volumes for all treatments (including the control) were not significantly different up to 1986 (Table 12). Significance levels for contrasts of mean volume for the P (treatments 3 and 4) and N+P treatments (8 and 9) and the control and between the fertiliser treatments for the total 8 sites are set out in

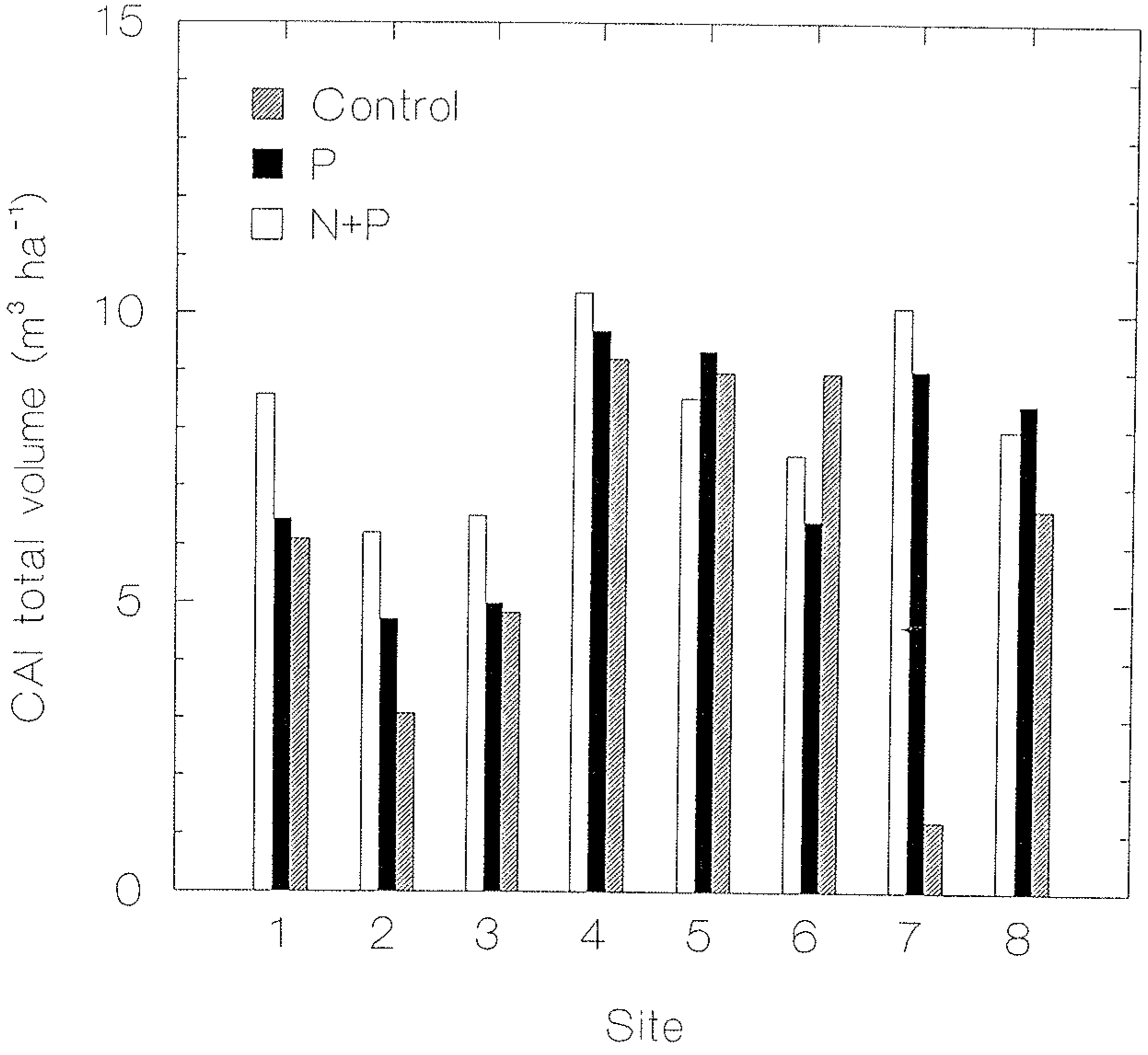

Figure 6. - Current annual increment in volume for the P, N+P and control treatments over the five years of measurement for each of the eight sites used in the supplementary study.

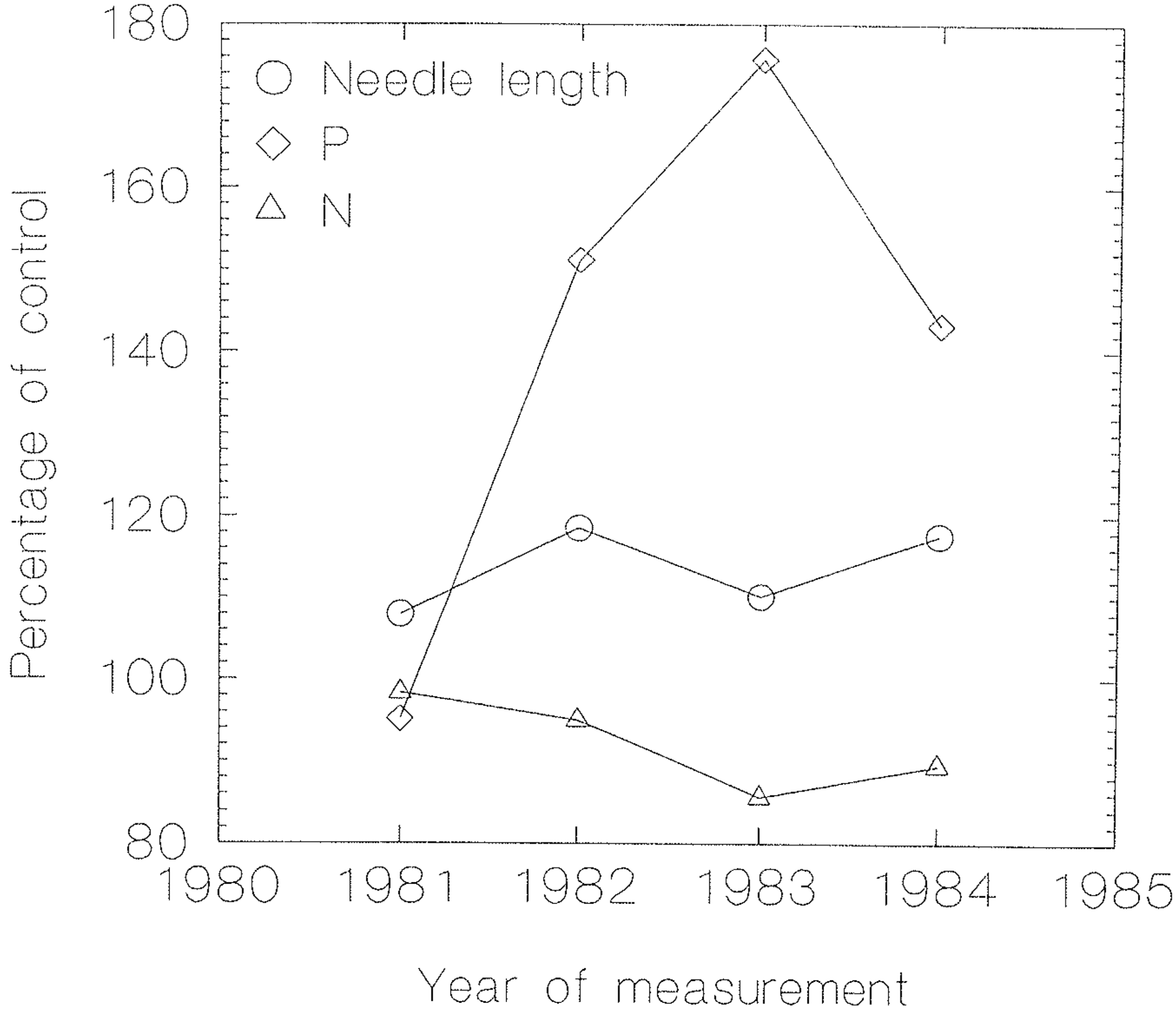

Figure 7. - Variation of needle length, foliar P and foliar N contents expressed as a percentage of the control values for the period 1981 to 1984.

Table 12. A highly significant difference for P treatment plots was present prior to applying fertiliser and covariance was required to assess the influence of fertiliser. The contrast for P against the control was not significant for the 1986 stand measurement or for increment over the period 1981-1986. The N+P treatment was significantly (.042) better than the control in the 1986 stand measurement and in the 1981-1986 increment. The select stand had a similar but less sensitive response (Table 12). Contrasts of P and N+P treatments were not significant at the .05 level. Comparisons of treatment means for current annual increment for the 1981-86 period for each of the 8 sites are shown in Figure 6)

Table 13. Probabilities for treatment (3,4,8,9) and group P(3,4), N+P (8,9) contrasts with the control(11) and between groups for nutrient content of the foliage and needle length. Data refers to the 8 sites used in the supplementary study.

Source	Year of measurement			
	1981	1982	1983	1984
	Needle length (cm)			
Anova Site	.000	.092	.000	.133
Anova Treat	.206	.000	.046	.017
P + N+P = Control	.024	.000	.006	.001
P = Control	.021	.002	.024	.001
N+P = Control	.066	.000	.005	.004
N+P = P	.525	.071	.449	.514
	Nitrogen content (per cent)			
Anova Site	.023	.175	.047	.001
Anova Treat	.712	.025	.005	.026
P + N+P = Control	.517	.088	.000	.001
P = Control	.895	.017	.000	.004
N+P = Control	.393	.496	.003	.003
N+P = P	.516	.031	.324	.835
	Phosphorus content (per cent)			
Anova Site	.000	.003	.137	.179
Anova Treat	.626	.000	.000	.000
P + N+P = Control	.430	.000	.000	.000
P = Control	.523	.000	.000	.000
N+P = Control	.422	.000	.000	.000
N+P = P	.839	.253	.061	.044

For foliar nitrogen per cent over the 8 sites the P treatment was significantly less than the control in 1982, 1983 and 1984 and the N+P treatment differed from the control in 1983 and 1984 (Table 13). Foliar phosphate levels were again much more sensitive to treatment with both the P and N+P treatments being significantly higher than the controls in 1982, 1983 and 1984 (Fig. 7). Contrasts for needle length were not useful as the mean for the P treatment plots were significantly longer than the control plots prior to fertiliser application.

Factorial - Factorial analysis of mean volumes for two monthly applications and P and N+P treatments for the 8 sites gave significant differences between the fertiliser plots in both 1981 (before application) and 1986 for the whole stand (Table 14). The 1981-86 increment and covariance established that the N+P treatment was significantly superior to the P treatment over the range of 8 sites tested for the whole stand but not for the select stand. No significant difference in effect was detected for application in either August or September and the interaction of month and fertiliser was not significant. Nesting of the monthly applications in Sites detected no significant interactions between site and fertiliser.

Table 14 Factorial analysis of data for stand volume for the 8 sites in the supplementary study. The second analysis tests the Site x Fertiliser interaction. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

Source		Whole stand			Select stand		
	DF	1981	1986	81-86	1981	1986	81-86
Site	7	0.000	0.000	0.000	0.000	0.000	0.000
Fert	1	0.046	0.015	0.026	0.449	0.167	0.081
Month	1	0.410	0.135	0.102	0.188	0.239	0.365
Month*Fert	1	0.390	0.217	0.221	0.625	0.544	0.526
Error	21						
Total	31						
Site	7	0.000	0.000	0.000	0.000	0.000	0.000
Fert	1	0.056	0.031	0.040	0.517	0.213	0.079
Site*Fert	7	0.648	0.754	0.533	0.992	0.893	0.431
Error	16						
Total	31						

Factorial analysis of foliar N and P contents (Table 15) detected little difference in levels between treatments, the P treatment having slightly lower N levels in 1982 and slightly lower P levels in 1983 and 1984. Needle length was significantly greater (.035) for the N+P treatment in 1982, the second year after application.

Discussion

Time of Application - An objective of the study was to determine if fertiliser applications at different times during the period from autumn to late spring had varied effect on stand responses. There was some evidence from standing values to indicate that urea applied later in spring could have a longer term advantage (Tables 4 and 5, Fig. 2) but this was not significant for growth data (Table 5). The study consistently demonstrated that over the range of seasons sampled, timing of application for either superphosphate or superphosphate plus urea applications had no significant effect on subsequent response. To be completely satisfied with this finding it would be necessary to repeat the trial to study variation between years. Important differences in rainfall and temperature patterns in other years may have a different effect on the outcome. There is no reason, however, to assume that the year of application, 1981, is not representative of the general climatic pattern for the area.

Table 15 Factorial analysis of data for foliar N and P and needle length in the supplementary study. Results are the probabilities that the F values obtained by ANOVA would occur by chance.

Source	DF	1981	1982	1983	1984
		Nitrogen (per cent)			
Site	7	0.053	0.161	0.150	0.010
Fert	1	0.508	0.035	0.323	0.820
Month	1	0.263	0.054	0.282	0.515
Month*Fert	1	0.922	0.447	0.408	0.738
Error	21				
Total	31				
		Phosphorus (per cent)			
Site	7	0.000	0.039	0.262	0.130
Fert	1	0.850	0.314	0.055	0.049
Month	1	0.264	0.196	0.710	0.667
Month*Fert	1	0.541	0.616	0.156	0.982
Error	21				
Total	31				
		Needle length			
Site	7	0.000	0.185	0.000	0.007
Fert	1	0.368	0.032	0.370	0.424
Month	1	0.567	0.071	0.913	0.929
Month*Fert	1	0.706	0.195	0.130	0.735
Error	21				
Total	31				

Type of Fertiliser - Both P and N+P fertilisers were compared in the trial and it was suspected that the timing for urea application could be more critical than that of superphosphate. There is little evidence in the results to suggest that this may be so.

Stand Response - The response to the N+P addition was significantly greater than that of P alone in the initial comparison of Sites 1-4 (Fig. 6) with the 5 applications of fertiliser types. Both fertiliser types were still improving increment in the fifth year after application (Tables 3 and 5).

For the 8 sites compared, contrast analysis (Table 12) showed N+P to be highly significantly better than the control and P not significantly better than the control. It did not separate P from N+P. A balanced analysis of the P and N+P treatments for the 8 sites, although showing significant difference between the treatment groups prior to fertiliser addition, separated a significant (.026 level) difference in the 1981-86 increment which allows for covariance of the 1981 differences. Of the 8 sites tested (Fig. 6, Table 16), several (Sites 4, 5 and 6) had little or no response to fertiliser, several responded better or as well to superphosphate alone (Sites 5 and 8) while the remainder showed significantly superior growth with the addition of urea with the super. Analysis of the data for Fertiliser, Site and Fertiliser x Site interaction could not detect a significant interaction for the data set (Table 14), as could be suggested by the differences in responses to treatment noted for the 8 sites above. Superiority of the N+P effect is obvious within the analyses.

In other trials in the area it was doubtful if the superiority of the N+P additions, when obtained, was sufficient to warrant the extra cost for nitrogen additions over superphosphate alone. The impact of previous additions had generally dissipated within five years of application and from the decreased effect in 1985-86 (Fig. 3) it is not expected that a continuation of the current study would have recorded further treatment effects on increment.

The current trial is, however, outstanding in achieving a significant nitrogen effect with as little as 150 kg ha^{-1} urea (70 kg ha^{-1} N) plus a base dressing of 500 kg ha^{-1} superphosphate. Previous trials, YS35, YS36, WP 8/72 and WP 20/76 in particular, did not produce a significant N response with fertiliser applications up to 70 kg ha^{-1} N plus base phosphate fertiliser. Trial WP 21/76 tested a wide range of urea applications and required at least 350 kg ha^{-1} urea (161 kg ha^{-1} N) plus a base phosphate fertiliser to improve growth significantly over the base dressing alone. In Trial WP 29/71 a similar improvement of 38 per cent over the control was obtained on a good site with 1 t super plus 500 kg ha^{-1} ammonium sulphate (105 kg ha^{-1} N), but it was not possible to separate the effects of N and P..

Previous studies have also shown a reduced response to fertilisers on the yellow, less leached sands of the Spearwood Dunes series than on the grey sands of the Bassendean Dunes series (WP 54/66, WP 48/66, WP 8/72). Sites with yellow sands in Figure 6 and Table 17 are 3, 4 and 8. Site 4, an 8 year old stand with a PAI for the control of 9.2 m^3 ha^{-1} for the period, was the most vigorous of all tested. Here, the N+P treatment produced 5 per cent more growth than the control. Site 8 response was slightly better for the P treatment and improvement was 28 per cent better than the control. The poorest Karrakatta sand on Site 3 was the third poorest stand tested and it had an N+P response of 34 per cent and no useful response to P alone. Hence on the Karrakatta sites fertiliser was of no value on the best Site 4, N addition was unnecessary for a 30 per cent improvement on Site 8 but essential for a similar improvement on Site 3. The best fertiliser responses overall were obtained on the 8 and 17 year old stands on the Bassendean sands, Site 7, Site 2 and Site 1 producing 834, 202 and 141 per cent the growth of the control over the trial period, respectively. The current trial thus supports previous evidence for lower fertiliser response on the yellow sands.

Sites 7, 2 and 1 are on grey sands and from their growth rate (PAI = 1.2, 3.1 and 6.1 m^3 ha^{-1}, respectively) are the poorest sites sampled. For these N was only essential for improvement on Site 1.

The supplementary plots were included in the trial to provide a broader picture of stand response to subsequent fertiliser application and to investigate possible Site x Fertiliser interactions. Interactions were not detected within the trial although a wide range of stand response to the treatments applied was detected. Sites 5 and 6 which were part of the 1964 planting at Gnangara, as was Site 1, did not respond to fertiliser (Fig. 6, Table 16,) while Site 7 which is in the same area of planting as Site 2 provided a massive response (Fig. 6, Table 16).

Table 16. Volume increments for treatments and site and stand details for the supplementary study.

Site	Vol.81-86(m^3 ha^{-1})			Ratio of	Stand description			
No.	P	N+P	Cont	Control	Age	Soil	Foliar % N	Foliar % P
1	6.42	8.58	6.08	141	17	Bassendean	.701	.059
2	4.71	6.20	3.07	202	8	Bassendean	.644	.026
3	4.98	6.48	4.83	134	14	Karrakatta	.647	.041
4	9.69	10.35	9.21	112	8	Karrakatta	.817	.036
5	9.34	5.53	8.97	95	17	Bassendean	.674	.060
6	6.40	7.54	8.96	84	17	Bassendean	.763	.057
7	9.01	10.10	1.21	834	8	Karrakatta	.661	.015
8	8.43	7.98	6.61	121	7	Bassendean	.610	.026

For the study period of 1981-86 the P and N+P treatments improved growth over the control by an average of 117.6 and 134.2 per cent, respectively, for the four original sites compared. For the 8 sites which included the supplementaries (Fig. 6, Table 16) average improvement over the control was 120.5 and 134.4 per cent, respectively, for the P and N+P treatments.

Differences between P and N+P applications were not significant for pair-wise comparisons at each site for either the original 4 site study or the 8 site study, but it is suggested that detailed testing on sites 1, 2 and 3 could establish the N+P response as significantly better than the P alone. This is conjecture, however, as more detailed investigations on specific sites mentioned above have not produced a significant N effect with an N addition as low as the 150 kg ha^{-1} urea used in the present study. Without further confirmation of effective N responses, it is considered that nitrogen fertilisers supplying less than 160 kg N ha^{-1} with a base dressing of superphosphate have little value over the base dressing alone for general application to stands on either the Bassendean or the Spearwood Dunes sands.

Foliar analysis - Foliar analysis accompanied diameter and height measurement for trial assessment providing an alternative method to assess the response of fertiliser additions to developing stands. A significant response in foliar P was recorded in samples taken in 1981, 12 months after fertiliser application and persisted into 1983 and 1984 (Table 6, Fig. 5).

This response was supported by data from the supplementary plots in which the foliar P increase following fertiliser addition was again pronounced (Fig. 7). Foliar analysis effectively related the P status of the stands to wood yield on sites on the Bassendean sands. Deficient stands had foliar P contents of .02 to .05 per cent (Fig. 5, Table 16) which was reasonably constant between years. Volume response to fertilisers in stands with control P levels of .057 and higher were small or nil while response in the two stands with control foliar P levels of .026 per cent were considerable (Table 16). Maximum volume response to fertiliser addition, obtained on Site 7, was associated with the lowest control foliar P values of .016 per cent (Table 16). The maximum foliar P content for a healthy plant was in the order of .07 to .08 per cent (Fig. 5). Improved growth over the control was still being achieved with P contents of .06 per cent. The consistency of the phosphate data and its association with growth responses provide foliar assessment for P content as a useful diagnostic technique to manage fertiliser application for these plantations .

On the Karrakatta sands low foliar P contents were associated with only modest volume gains following fertiliser addition (Table 16). The degree of response at Yanchep is better associated with relatively low foliar N levels (0.610 per cent and 0.647 percent for sites 8 and 3) than foliar P values..

Foliar data for N in Figure 5 reveal that both P and N+P fertiliser applications depressed foliar levels below that of the control. The depression was least with the N+P application (Table 9) and is associated with dilution of a limited amount of N with increased needle growth. Per cent foliar N for the superphosphate alone additions was, however, significantly less than that of the control for all measurements except in the first year after application. These low N values and accompanying high levels of foliar P define a relative deficiency in the NP balance in comparison with the control situation. Foliar N content varied considerably between years (Fig. 5) and it could be difficult to set a useful level at which an imbalance could be expected. Without a control to set a standard of comparison each year the utility of foliar N values for the diagnosis of nutrient deficiency in stands may be limited.

Foliar sampling can therefore detect a deficiency in P for optimum growth on the Bassendean sands and, by comparing foliar N values with those of a suitable control, may indicate a need for additional nitrogenous fertiliser to promote the maximum growth response.

WP 3/63 - Provenance variation in seedlings of *Pinus pinaster* in pot trials.

Summary and Conclusions

Plants of *Pinus pinaster* raised from provenances from Portugal, France, Italy and Corsica were compared for seedling differences within a pot trial in a glasshouse. Comparisons were made within a factorial design which included five plant groups, high and low nutrition treatments and, for one harvest, high and low watering treatments. *Pinus radiata* was included in the trial to allow comparison of variation of attributes measured both between species and within species. Three harvests were made over a period of nineteen months comparing attributes at different stages of seedling development.

Attributes measured at each harvest were root and shoot dry weight, root/shoot ratio and N, P, K concentration of root and shoot tissue. Needle length was measured for Harvests 2 and 3 and proportion of resting (dormant) buds for Harvest 2. For Harvest 3 the number of damaged shoots was assessed for each treatment.

Significant differences occurred between provenances in height growth, dry weight production, concentration of potassium, vigour of terminal buds and extent of shoot mortality. No useful distinctions were obtained for comparisons of means for root/shoot ratio, phosphate concentration, nitrogen concentration and needle length.

Pinus radiata produced superior growth under high nutrient levels but was exceeded by some *P. pinaster* provenances at low nutrient levels. The Portuguese provenance was the most comparable, in growth, to the *P. radiata*.

Attribute means for provenances indicated that variation was continuous within the species with the Leiria R and Leiria 2 and Corsican and Landes pairs being most similar.

Response to potassium nutrition was most pronounced between provenance groups and differences obtained may be of value in future environmental comparisons or of significance to fertiliser testing.

The trial was designed to complement long term field studies and is supported by those results.

Introduction

This study was a pilot trial with some provenances of *Pinus pinaster*, established in the field program, compared in pots under glasshouse conditions. At the time of planning the trial in 1964 no specific data was available for comparative seedling performance under a range of nutrition and drought conditions. Treatments with seedlings of *Pinus radiata* Don. were also incorporated in the pot trial to provide a standard for comparison. Its inclusion allowed evaluation of the extent of differences between species and within *P. pinaster*.

At some stage in the seed store or nursery, the Luccan batch was replaced with a more vigorous provenance. This has since been identified, with maturity, as of Portuguese origin and is referred in this trial as Leiria 2. Part of the reason for this trial was to obtain an early comparison of the unusual, supposed, Luccan provenance which appeared to be like a Portuguese provenance in the nursery.

Location

The trial was conducted in the Wanneroo glass house to confirm provenance similarities observed in field trial WP 3/63 in Clover Block, Gnangara plantation. Seed batches in the trial were obtained as representatives of *Pinus pinaster* in Portugal (Leiria), Italy (Lucca), Corsica and France (Landes).

Procedure

The experiment was commenced with one year old seedlings raised in the nursery and surplus to requirements for a long term field trial (3/65).

Preparation - All seed was sown in August 1963 at the Wanneroo nursery with identical treatment for all provenances. Selection of seedlings from the nursery beds aimed to ensure that differences in nursery fertility and plant type would not influence comparisons between provenances and species.

For each plant group (Genotype) six plants, uniform in size, were transplanted in May 1964 into cans 22.9 cm deep and 17.8 cm diameter. A standard potting mix of three parts coarse sand and one part loam was weighed to provide equal weights of mix in each can. Forty such pots were prepared for each of the five seedling groups used.

Design - Following an establishment period of three months the pots were thinned to the four most uniform plants. Average plant height per pot was determined and the pots were allocated to ten uniformity blocks with four pots of each seed origin per block. Uniformity was based on a height ranking with the tallest plants of each genotype in Block I grading to the smallest in Block 10.

Within each block the four pots of common origin were randomly allocated as A, B, C and D to receive the following treatments.

A - Fertilised, high watering (F, HW)
B - Not fertilised, high watering (NF, HW)
C - Fertilised, low watering (F, LW)
D - Not fertilised, low watering (NF, LW)

Nutrition - The two fertilizer levels were maintained by adding 0.5 litres of liquid fertilizer (23% nitrogen, 4% phosphorus, 10% potassium) to treatments A and C at least once a month during the trial. During summer months of rapid growth and daily watering, fertiliser was added twice a month. Treatments B and D received no added fertiliser during the trial.

Watering - The droughting treatment was only applied to the four blocks used for the second harvest. Pots not involved in this comparison were watered regularly with free bottom drainage.

On 17 February 1965, all pots involved in the four blocks (80 pots) for Harvest 2 were watered thoroughly and allowed to drain overnight. At 8.00 am the following morning the drainage holes in each pot were sealed and the pots weighed on an automatic balance. Each day at 8.00 am the pots were weighed and water added to the high watering treatments (A and B) to return them to the initial drained weight (field capacity). Treatments C and D were permitted to dry to the condition of permanent wilting of contained plants, before re-watering. The point of permanent wilting was assessed as a compromise between visual symptoms of wilt in the shoot and levelling off of daily pot weight (water) loss. Both diagnostic techniques appeared to be equally effective in assessing the permanent wilting point. Only one wilting cycle was imposed and harvesting followed directly after all pots had been re-watered.

Throughout the droughting trial the fertilised, regularly watered treatments were used as an atmometer with the daily water loss providing a measure of the evaporative potential of the environment.

Measurement

Height growth.- Heights of the plants in each pot were measured throughout the trial. Measurement frequency varied from weekly, during periods of active growth, to monthly, during dormant periods.

Harvesting.- The trial was potted and placed in the glasshouse in May 1964 and treatments applied in August 1964. Harvests were made for dry weight analyses in November 1964, March 1965 and January 1966. Two blocks, randomly selected, were involved in the first harvest and four in each of the second and third harvests.

Harvesting consisted of cutting the shoots at soil level and grouping the shoots and washed roots from each pot. Shoot and root weights were obtained after drying at 70^{o}c. Dry residues of both roots and shoots were analysed for nitrogen (N), phosphorus (P) and potassium (K) concentrations.
Maximum needle length and shoot condition (health, dormancy) were recorded for each plant during harvesting.

Results

A. Harvest 1

Plants were 15 months of age at harvest with 3 months exposure to fertiliser treatments.

Height Growth - Seedling heights were measured at approximately fortnightly intervals. During this measurement the condition of the buds and plants was recorded to observe any obvious differences between provenance performance. Some shoot deaths were noted in January 1965 and the number increased as the trial progressed. This mortality and the necessity to thin pots from four plants to two in May 1965, complicated height comparisons for the entire trial period. Consistent and reliable height measurements were available, however, for the period July 1964 to April 1965.

Results (Figure 1) showed the Leiria R and Leiria 2 provenances to be superior in height growth to the Corsican and Landes groups; both for fertilised and non fertilised conditions. The Leiria growth was almost identical to that of *P. radiata* over the period.

Table 1. Results from Harvest 1 for tissue dry weight and root/shoot ratio. Significance of the analysis of variance is included.

	Shoot Dry Wt.			Root Dry Wt. (g)			Root/Shoot Ratio*		
Source	Fertiliser		Geno-type	Fertiliser		Geno-type	Fertiliser		Geno-type
	F	NF		F	NF		F	NF	
Leiria2	13.4	10.2	11.8	7.8	8.8	8.3	.59	.85	.72
Corsica	10.8	10.3	10.5	6.4	7.3	6.9	.59	.73	.67
Landes	12.5	9.5	11.0	5.7	7.1	6.4	.47	.75	.61
LeiriaR	11.9	13.0	12.5	7.3	8.2	7.8	.62	.63	.62
Radiata	22.3	16.6	19.5	11.1	11.7	11.4	.49	.70	.60
Mean	14.2	11.9		7.7	8.6		.55	.73	
				Significance of the Variance Ratio					
Blocks		.001			.001			113	
Genotype		.001			.001			074	
Fertiliser		001			030			.001	
GxF		.012			987			045	
GxBlock1		.011			.018			.065	
FxBlock		.869			.726			.893	

* Data was transformed to angle arcsins for analysis.

Plant Dry Weight - Treatment effects were highly significant (.001 level) for both shoot and root data (Table 1). The genotype by fertiliser (GxF) interaction for shoot tissue was also significant resulting from either an uncharacteristic, higher non fertilised value for the Leiria R genotype or a lower than expected value with fertiliser (Fig. 2). Removal of the Leiria R data from the set gave similar results for main effects but no interaction was significant. Major differences in genotypes present were due to the greater dry weight of the *P. radiata* either with or without fertiliser.

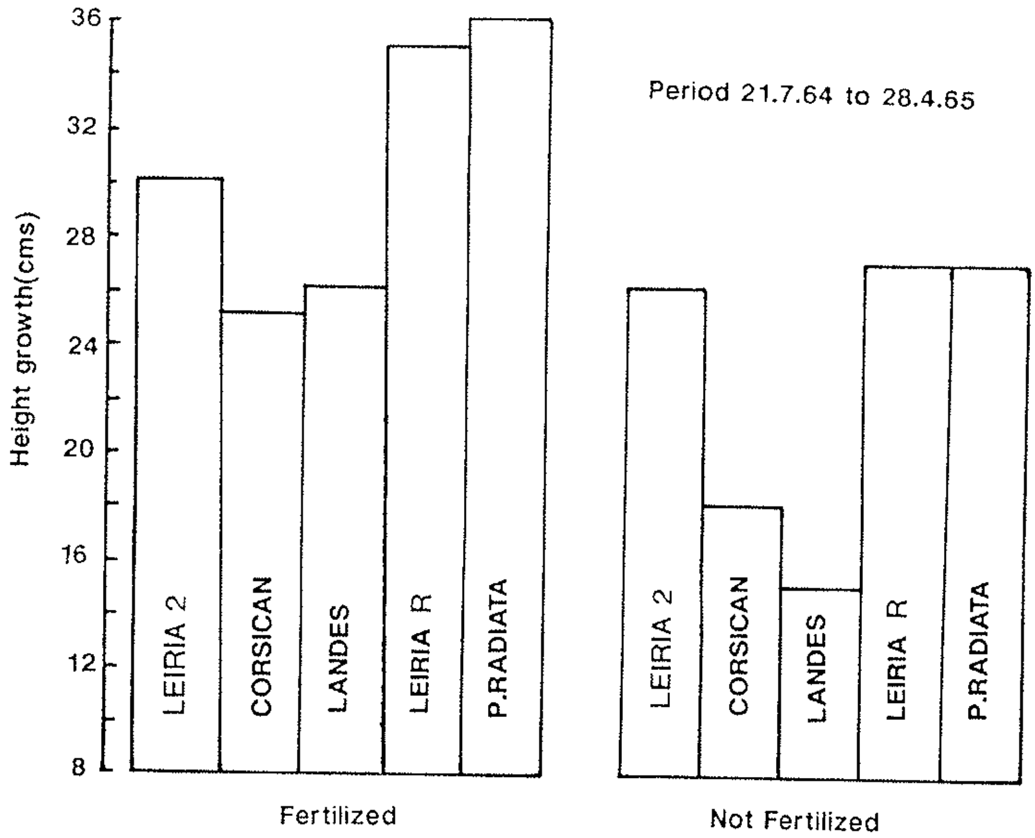

Figure 1.

Mean height growth for seedlings in the pot trial.

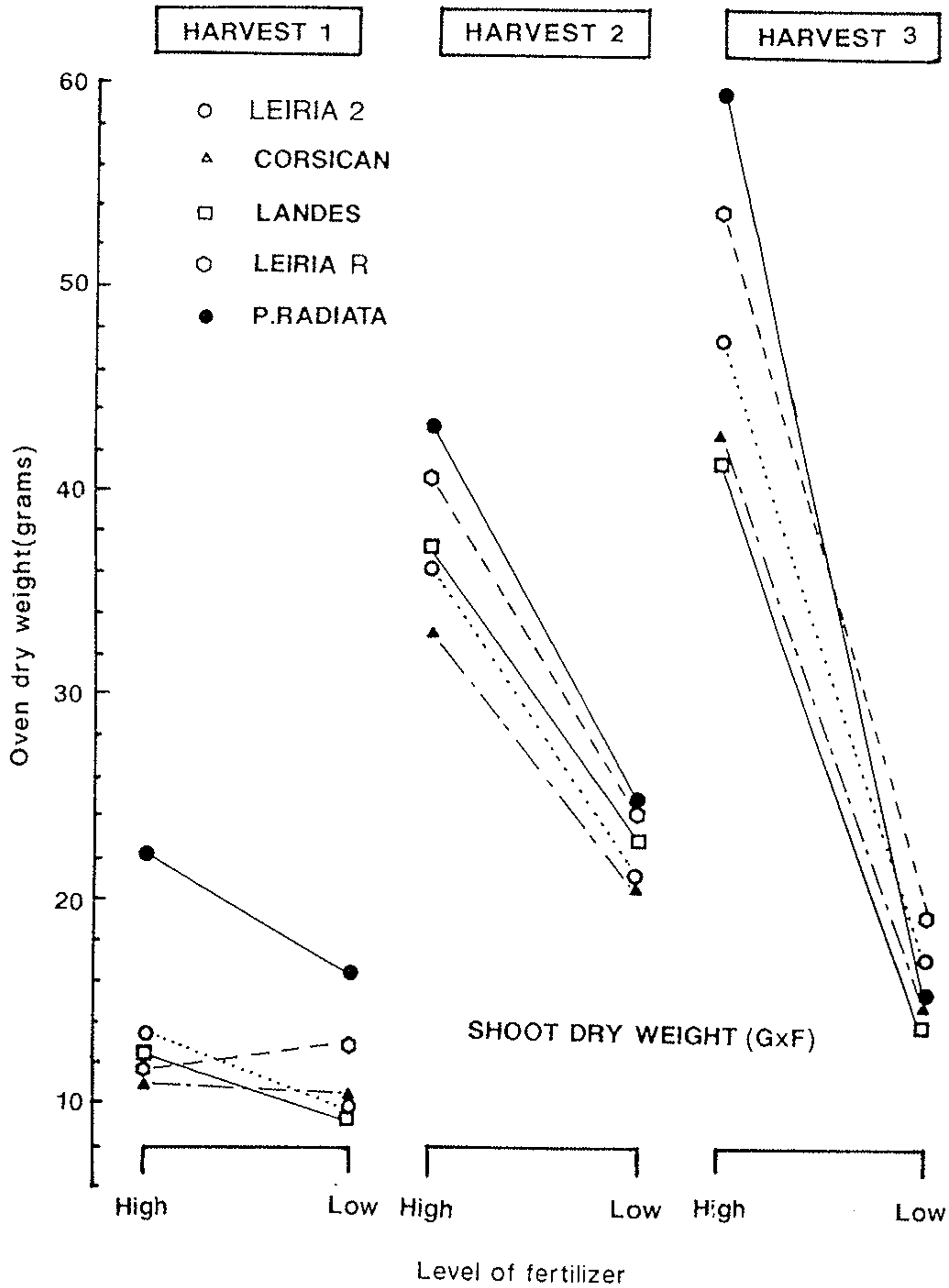

Figure 2.

Shoot dry weights in the seedling trial.

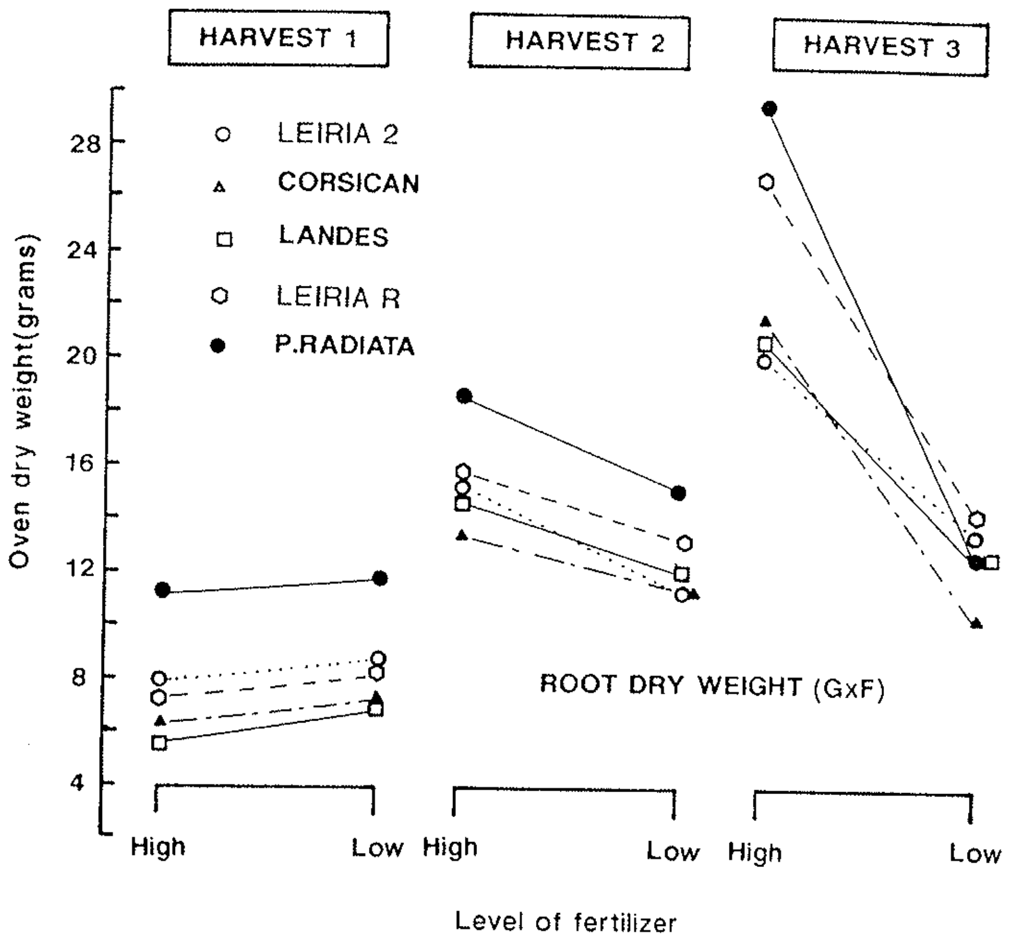

Figure 3.

Root dry weights in the seedling trial.

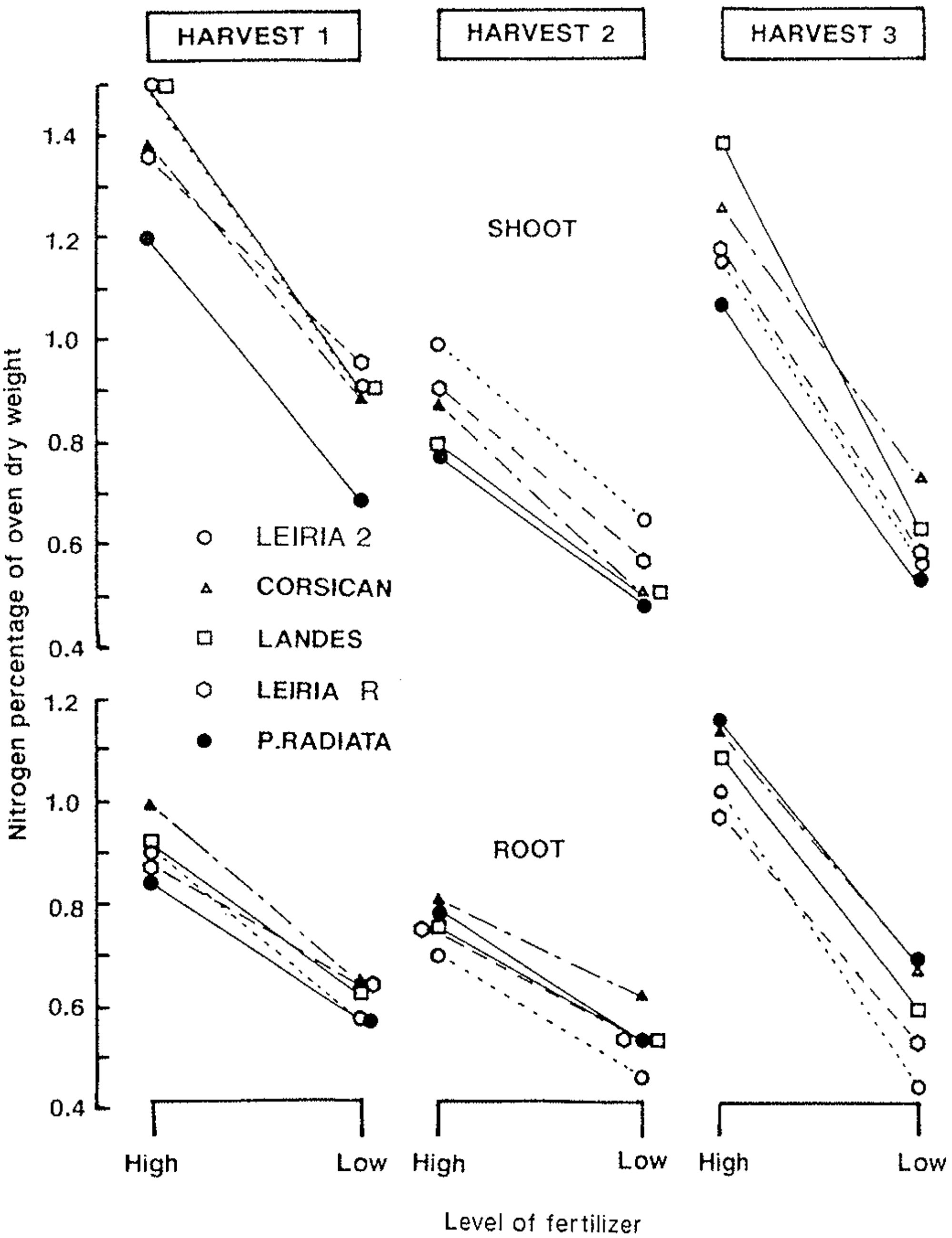

Figure 4.

Percentage of nitrogen in shoot and root dry weights, at each harvest.

Fertiliser addition significantly increased root dry weight over the three month treatment period. Genotype differences also related to the significantly higher dry weight production of *P. radiata* (Fig. 3).

Root/Shoot Ratio - Root/shoot ratios were significantly influenced by fertiliser additions but did not differ between genotypes (Table 1). Root production was relatively greater in the absence of fertiliser.

Nitrogen Concentration - Fertiliser additions resulted in greater N absorption in both shoots and roots (Table 2). For the shoot mean values, *P. radiata* was significantly lower than the pinaster genotypes. There was no significant difference between genotypes for root N concentration.

Nitrogen concentrations of root tissue were less than those in the shoots in all cases (Fig. 4).

Table 2. Results from Harvest 1 for tissue nutrient contents.

Source	Nitrogen (% Dry Wt.)		Phosphorus (% Dry Wt.)		Potassium (% Dry Wt.)	
	Shoot	Root	Shoot	Root	Shoot	Root
			Genotype Means			
Leiria2	1.207	.734	.060	.079	.930	.487
Corsica	1.132	.829	.065	.096	1.067	.585
Landes	1.209	.771	.099	.075	1.164	.560
LeiriaR	1.156	.761	.074	.104	.913	.503
Radiata	.939	.709	.085	.063	.902	.426
			Fertiliser Means			
F	1.389	.907	.073	.078	1.031	.541
NF	.863	.614	.081	.088	.959	.484
			Significance of F			
Blocks	.020	391	.769	.143	.188	.016
Genotype	.001	.421	.007	.002	.001	.001
Fertiliser	.001	.001	.235	.097	.020	.003
GxF	.412	904	.179	.746	.601	.907
GxBlock	.224	.219	.840	.518	.362	.540
FxBlock	.519	.945	.374	.819	.671	.343

Phosphorus Concentration - Fertiliser additions had no significant influence on P concentration of roots and shoots (Table 2). Genotype differences were significant. In the shoots, Landes had the highest P concentration which was similar to that of *P. radiata* and significantly higher than the P levels of the other pinaster genotypes. These latter did not differ significantly.

Leiria R had the highest concentration of phosphorus in the roots and this was significantly higher than that of other genotypes except Corsican.

Mean phosphorus concentrations were similar in roots and shoots (Fig. 5).

Potassium Concentration - Potassium concentration varied with both fertiliser addition and genotype (Table 2). Landes had the highest potassium concentration in the shoot with Corsican the next in order. The other genotypes did not differ and had significantly lower K concentrations than the Corsican genotype. For root tissue the Landes and Corsican again had significantly higher K concentrations than Leiria R and Leiria 2. *P. radiata* had significantly lower K concentrations than the pinaster genotypes (Fig. 6).

Table 3. Results for tissue dry weights in Harvest 2.

Source	Shoot Dry Wt. (g)					Root Dry Wt. (g)				
	Fertiliser		Watering		Genotype	Fertiliser		Watering		Genotype
	F	NF	HW	LW		F	NF	HW	LW	
Leiria2	36.2	21.4	29.7	27.9	28.8	15.2	11.5	13.3	13.3	13.3
Corsica	33.0	20.6	28.1	25.4	26.8	13.5	11.6	12.8	12.4	12.6
Landes	37.3	23.1	31.5	28.9	30.2	14.8	12.0	13.6	13.1	13.4
LeiriaR	40.7	24.3	34.2	30.9	32.6	15.8	13.2	15.1	13.9	14.5
Radiata	43.2	25.0	38.3	29.9	34.0	18.6	15.1	18.2	15.5	16.8
Mean	38.1	22.9	32.3	28.6		15.6	12.7	14.6	13.6	
Water	41.6	23.1				16.6	12.7			
Drought	34.6	22.6				14.6	12.7			
	Significance of F									
Blocks	.0021					.074				
Genotype	.001					.001				
Fertiliser	.001					.001				
Watering	.010					.043				
GxF	.364					.767				
GxW	.192					.399				
FxW	.001*					.034*				

Fertiliser addition resulted in considerable (.001 level) increases in tissue K concentrations with values for shoots approximately double those for roots.

B. Harvest 2

Plants were 19 months of age with 7 months exposure to treatment at Harvest 2. This stage of the trial included treatments in

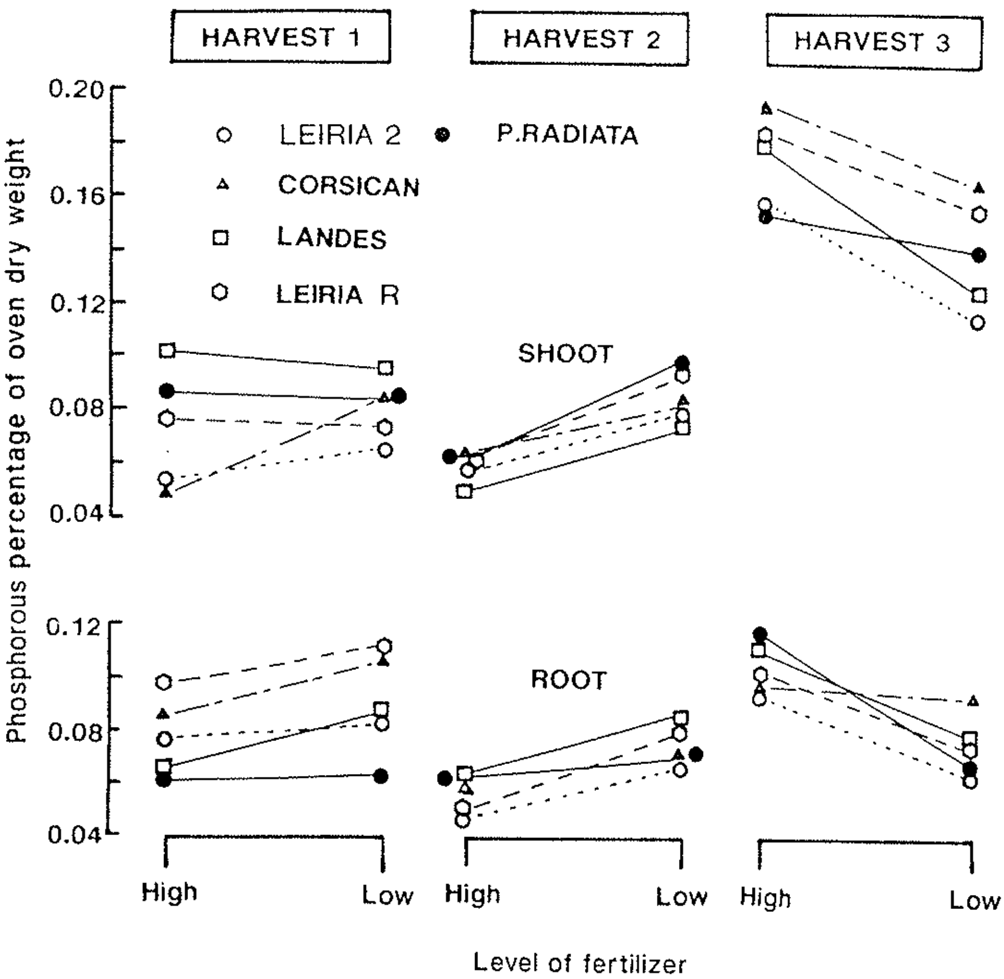

Figure 5.

Percentage of phosphorus in shoot and root dry weights, at each harvest.

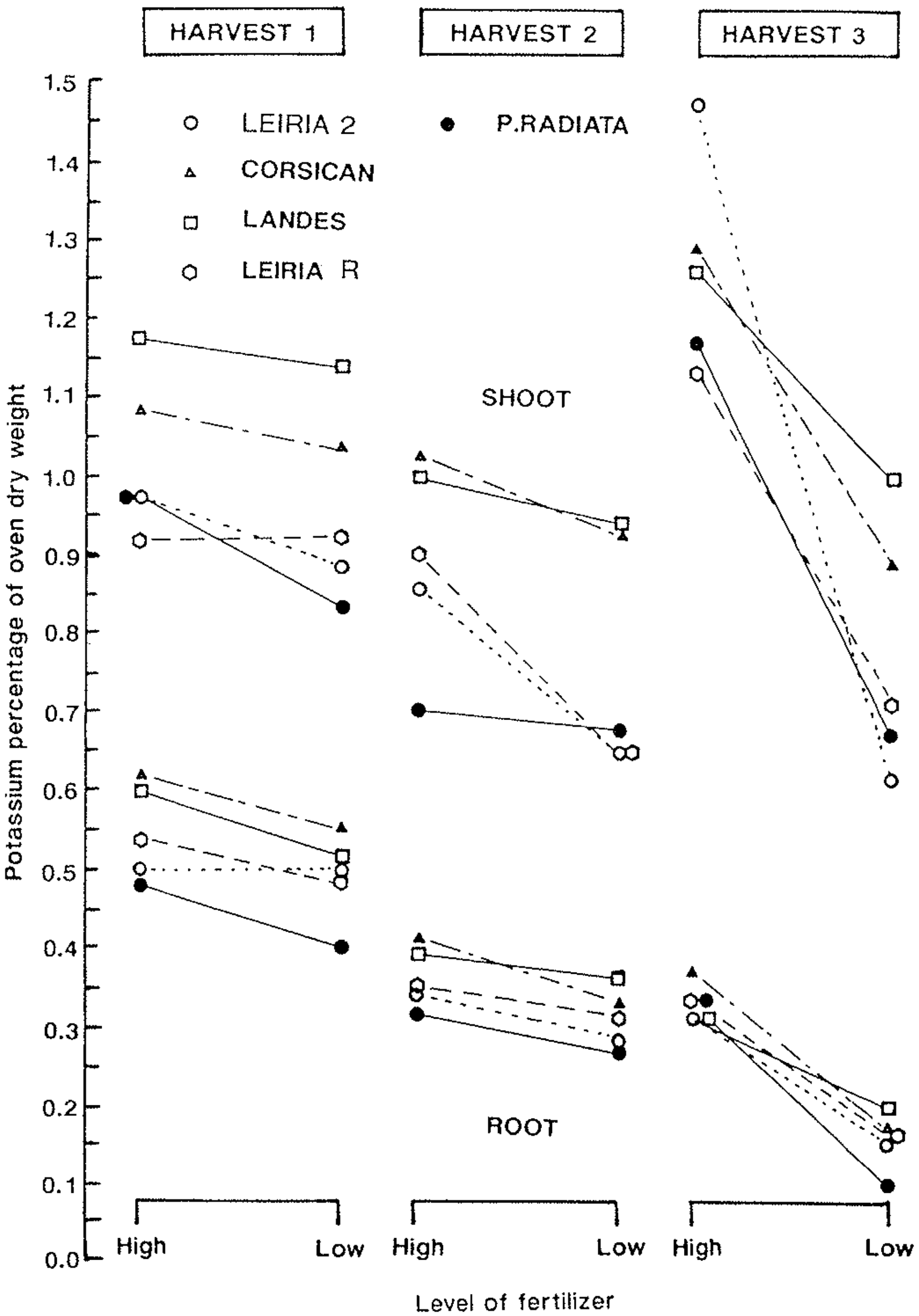

Figure 6.

Variation in potassium levels with provenance. Results are shown for roots and the shoots at each of three harvests.

which plants were droughted to the permanent wilting level prior to re-watering.

Plant Dry Weight - Fertiliser, genotype, watering and the fertiliser by watering interaction were significant for both root and shoot analyses (Table 3).

* Not significant when analysed for pinaster plant groups only.

The fertiliser by watering interaction (Fig. 7) resulted from a depressing effect of drought on dry weight production of fertilised plants but not of non fertilised plants. This interaction was significant only at the .034 level for root tissue and was removed, together with the significant watering effect, when the analysis was conducted for the pinaster genotypes only. In Figure 8 it can be seen in the non significant genotype by watering interaction that major depressions in dry weight, due to drought, are associated with the *P. radiata* genotype.

Analysis of root dry weights for the pinaster genotypes only, found no significance in differences between means for Leiria R, Leiria 2 and Landes genotypes and between Landes, Corsican and Leiria 2 genotypes (Table 3).

Root/Shoot Ratio - Analysis of root/shoot data (Table 4) provided results similar to those of Harvest 1, with only the fertiliser effect proving to be significant. The values in these older plants were lower than those in the first harvest indicating relatively greater shoot growth during this second stage of seedling growth in the 1964-65 summer.

Needle Length - Genotype and fertilisation had a significant effect on needle length. Droughting did not influence needle length (Table 4).

Needle length increased with the addition of fertiliser and the Corsican and Landes genotypes had significantly larger needles than the other genotypes. Differences between Leiria R and Leiria 2 were not significant. *P. radiata* had the shortest needles.

Resting (Dormant) Buds - The number of dormant buds per treatment at time of harvest was expressed as a percentage of the total possible. Percentages were transformed to angle arcsins for analysis.

All buds in *P. radiata* were actively growing.

Significantly more dormant buds were found in the absence of fertiliser (Table 4) and no effect of droughting was measurable. The Landes and Corsican genotypes contained significantly more buds in the dormant condition than Leiria R and Leiria 2.

Nitrogen Concentration - For shoot tissue N concentration genotype, fertiliser and watering each had a significant influence (Table 5). The genotype by watering interaction was also significant in the analysis for root N.

Table 4. Results from Harvest 2 for root/shoot ratio, needle length and proportion of dormant buds.

Source	R/S Ratio			Needle Length(cm)			%Resting Buds		
	Fertiliser		Geno-type	Fertiliser		Geno-type	Fertiliser		Geno-type
	F	NF		F	NF		F	NF	
Leiria2	.42	.54	.46	11.4	9.4	10.4	41	44	42
Corsica	.41	.56	.47	13.9	12.0	13.0	78	91	84
Landes	.40	.52	.44	13.6	12.4	13.0	72	91	81
LeiriaR	.39	.54	.45	11.7	10.4	11.0	31	59	45
Radiata	.43	.60	.49	11.2	8.8	10.0	0	0	0
Mean	.41	.55		12.3	10.6		45	58	
Watered		.45			11.6			50	
Drought		.48			11.3			53	
				Significance of F					
Blocks		.141			.354			.973	
Genotype		.074			.001			.001	
Fertiliser		.001			.001			.014	
Watering		.138			.272			.635	
GxF		.587			.596			.456	
GxW		.477			.836			.171	
FxW		.922			1.000			.117	

In the root genotype by watering interaction, N tended to increase with drought effects with the exception of the Leiria 2 genotype (Fig. 9). This anomaly cannot be explained and probably represents experimental error.

Leiria 2 had the significantly highest N concentration for shoot data, and the lowest N concentration, by some considerable margin, in root tissue (Fig. 3).

For the shoot the N concentrations of Leiria 2 and Leiria 2 were not significantly different. Both were significantly higher than the other genotypes. For roots Leiria R N was significantly less than that of Landes. All other genotypes did not differ.

Droughting resulted in increased N concentration in both roots and shoots.

Phosphorus Concentration - Fertiliser and genotype had significant influences on shoot and root P. Watering had no effect (Table 5).

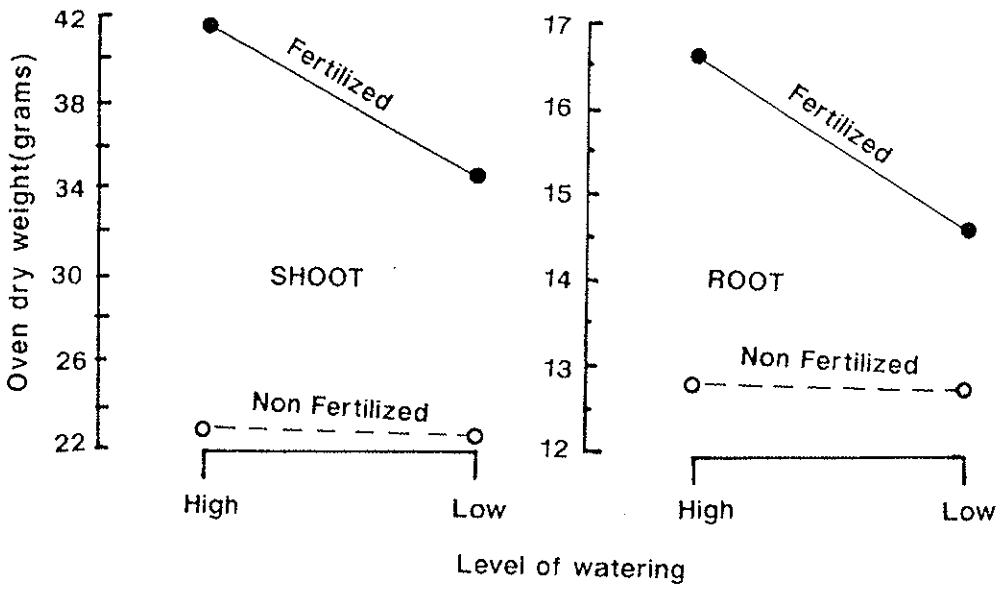

Figure 7

The nutrition by watering interaction in harvest 2.

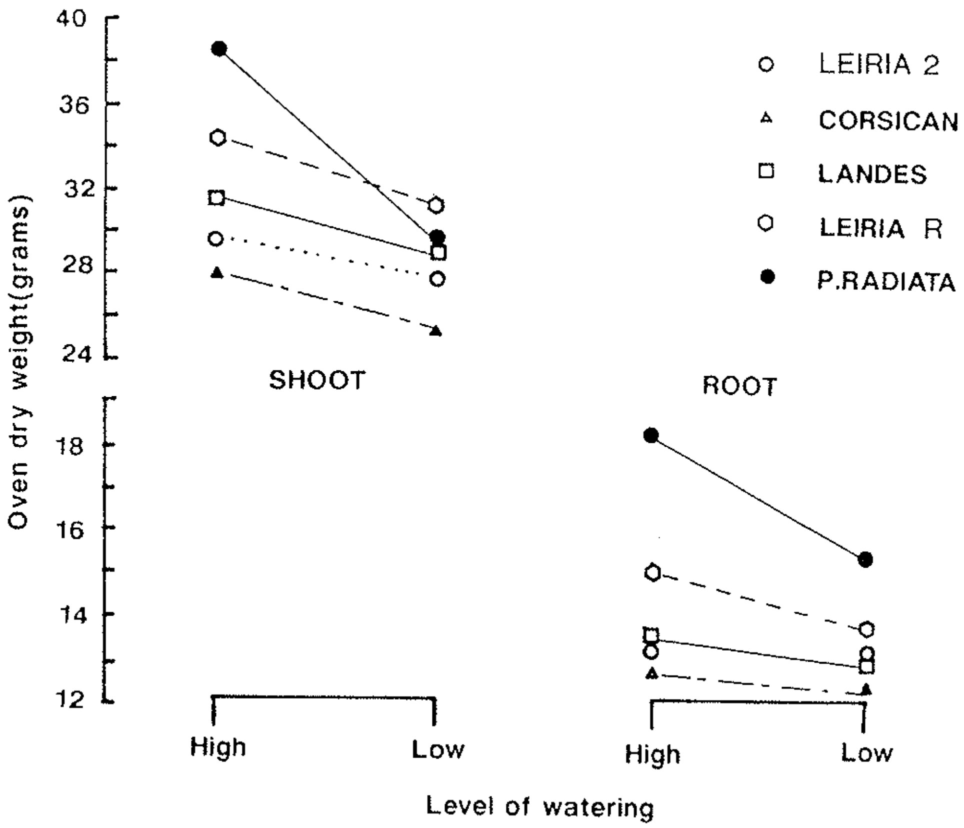

Figure 8.

The plant by watering interaction in harvest 2.

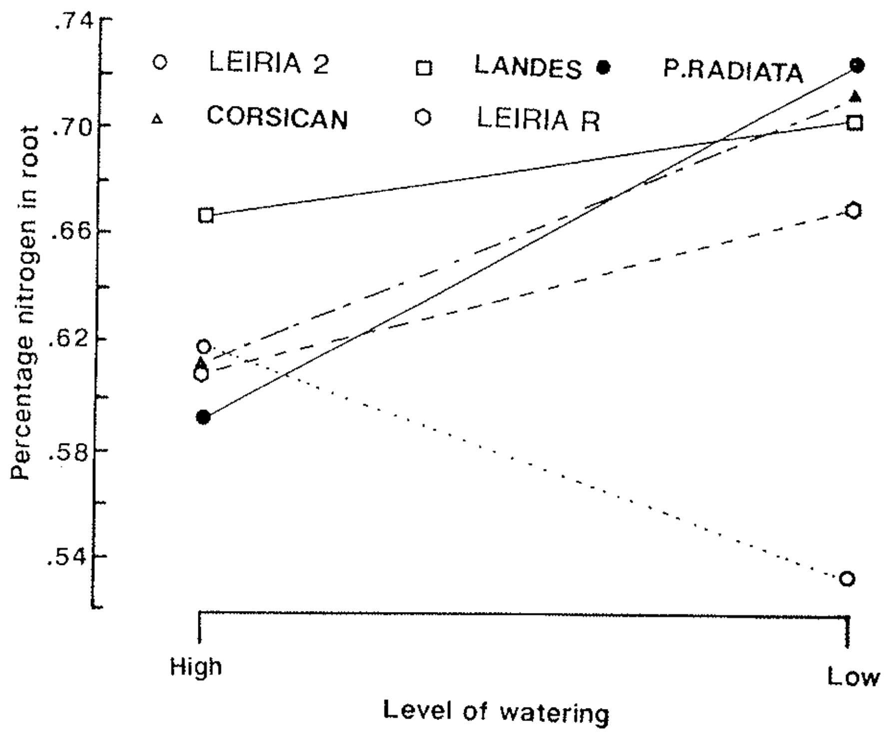

Figure 9.

Interaction between plant and watering for nitrogen content.

Table 5. Results from Harvest 2 for tissue nutrient contents. Values are expressed as percentage of tissue dry weight.

Source	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
			Genotype Means			
Leiria2	.813	.577	.068	.057	.751	.312
Corsica	.682	.661	.075	.066	.974	.370
Landes	.653	.685	.062	.076	.969	.375
LeiriaR	.748	.641	.076	.064	.770	.333
Radiata	.622	.659	.078	.066	.690	.294
			Fertiliser Means			
F	.866	.756	.058	.056	.894	.362
NF	.539	.535	.085	.075	.768	.312
			Watering Means			
HW	.671	.620	.071	.067	.824	.344
LW	.735	.671	.072	.065	.838	.330
			Significance of F			
Blocks	.002	.279	.001	.004	.155	.001
Genotype	.001	.021	.009	.009	.001	.001
Fertiliser	.001	.001	.001	.001	.001	.001
Watering	.003	.016	.661	.588	.327	.129
GxF	.812	.204	.347	.270	.001	.514
GxW	.198	.017	.300	.349	.706	.532
FxW	.046	.204	.778	.149	.656	.874

In the absence of fertilisers P concentration was significantly higher than with fertiliser additions and of the same level in both roots and shoots (Fig. 5). Shoot P in the Landes genotype was significantly less *P. radiata*. Other genotypes did not differ significantly in shoot P.

For root P, Landes was significantly higher than Leiria R and Leiria 2. The remaining genotypes did not differ significantly from either of these extreme values.

Potassium Concentration - Potassium concentrations in root and shoot tissue varied significantly with genotype and fertiliser main effects but not for watering (Table 5). The genotype by fertiliser interaction was significant for the shoot data and largely associated with exceptionally low values for *P. radiata* shoot K when fertilised (Fig. 6). The interaction remained (.05 level) when *P. radiata* was excluded from the analysis and would appear to result from relatively low values for Leiria R and Leiria 2, without fertiliser.

In root tissue, K concentrations for Corsica, Leiria R and Landes were highest and significantly different. to *P. radiata* but not to Leiria 2. Fertiliser addition increased the level of K in both shoot and root tissue.

Table 6. Results from Harvest 3 for tissue dry weight and root/shoot ratios.

Source	Shoot Dry Wt.(g) Fertiliser F	Shoot Dry Wt.(g) Fertiliser NF	Shoot Dry Wt.(g) Genotype	Root Dry Wt.(g) Fertiliser F	Root Dry Wt.(g) Fertiliser NF	Root Dry Wt.(g) Genotype	R/S Ratio Fertiliser F	R/S Ratio Fertiliser NF	R/S Ratio Genotype
Leiria2	47.6	17.3	32.4	20.1	13.6	16.8	.42	.79	.52
Corsica	42.9	15.1	29.0	21.6	10.4	16.0	.50	.69	.55
Landes	41.4	14.1	27.7	20.8	12.1	16.5	.50	.86	.59
LeiriaR	53.8	19.5	36.6	26.8	14.5	20.6	.50	.74	.56
Radiata	59.5	15.4	37.4	29.7	12.8	21.2	.50	.83	.58
Mean	48.9	16.3		23.8	12.7		.49	.78	

Significance of F	Shoot Dry Wt.(g)	Root Dry Wt.(g)	R/S Ratio
Blocks	.026	.008	.415
Genotype	.001	.001	.462
Fertiliser	.001	.001	.001
GxF	.026*	.004*	.507

* Not significant in analysis of pinaster genotypes only.

As for Harvest 1, K concentrations in shoots were at least double those in the roots. Values were slightly lower than those recorded in Harvest 1.

C. HARVEST 3

Plants were 29 months old with 17 months exposure to fertiliser addition at time of Harvest 3. After Harvest 2, two plants were thinned from each pot by culling at ground level and shoot weights in Harvest 3 represent extended growth of two plants per pot only. Root dry weights still contained the remnants of the culled plants.

Plant Dry Weight - Significance was established for genotype, fertiliser and their interaction in both root and shoot data for dry weight (Table 6).

The significant interaction was removed in each case by excluding *P. radiata* from the analyses. It is believed that significance of the interaction was associated with relatively poor growth of this genotype in the absence of fertiliser (Figs. 2 and 3).

For the pinaster genotypes, Leiria R was significantly higher than Corsican and Landes but did not differ from Leiria 2 in shoot dry weight. It was significantly higher than the other three genotypes in root dry weight.

Fertiliser addition trebled shoot weight and doubled root weight.

Root/Shoot Ratio - As for the previous harvests only fertilisation had a significant effect on root/shoot ratio; shoots growing relatively better than the roots with fertiliser (Table 6).

Table 7. Results from Harvest 3 for needle length and shoot mortality per treatment.

Source	Needle Length (cm)			Shoot Mortality %		
	Fertiliser		Genotype	Fertiliser		Genotype
	F	NF		F	NF	
Leiria2	15.4	12.1	13.8	0.0	0.0	0.0
Corsica	14.5	12.9	13.7	6.2	6.2	6.2
Landes	13.9	12.1	13.0	25.0	37.5	31.2
LeiriaR	15.5	11.3	13.5	6.2	0.0	3.1
Radiata	12.8	9.6	11.3	50.0	43.7	46.9
Mean	14.5	11.6		17.5	17.5	
			Significance of F			
Blocks		.046			.698	
Genotype		.001			.001	
Fertiliser		.001			.546	
GxF		.041			.681	
GxBlock		.922			.953	
FxBlock		.047			.159	

Needle Length - Needles had developed more of a mature appearance by Harvest 3 at which stage there was no significant difference in lengths between the pinaster genotypes (Table 7). The needles of *P. radiata* were significantly shorter than those of the pinaster genotypes.

Fertilisation increased needle length.

Shoot Mortality - Percentages for shoot deaths at Harvest 3 were transformed to angle arcsin for analysis of variance.

Fertiliser addition had no effect on shoot health but genotype differences were significant at the .001 level (Table 7).

Greater mortality occurred in the *P. radiata* and Landes genotypes. The other pinaster genotypes had significantly less shoot damage and did not differ significantly between themselves.

Nitrogen Concentration - Significant differences in N concentration resulted from genotype and fertiliser in both root and shoot tissue (Table 8). The highest N concentrations in shoots were in the Landes and Corsican genotypes which were significantly higher than *P. radiata* but not Leiria 2 and Leiria R (Fig. 4).

Table 8. Results from Harvest 3 for tissue nutrient contents. Values are expressed as a percentage of tissue dry weight.

Source	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
			Genotype Means			
Leiria2	.859	.781	.136	.078	1.044	.226
Corsica	.993	.904	.180	.095	1.085	.270
Landes	1.019	.838	.151	.094	1.131	.257
LeiriaR	.875	.746	.168	.087	.918	.248
Radiata	.750	.919	.146	.091	.918	.222
			Fertiliser Means			
F	1.187	1.076	.173	.104	1.261	.331
NF	.607	.599	.140	.074	.778	.156
			Significance of the Variance Ratio			
Blocks	.931	.609	.014	.119	.003	.040
Genotype	.001	.002	.019	.113	.130	.465
Fertiliser	.001	.001	.001	.001	.001	.001
GxF	.181	.779	.664	.041*	.072	.291
GxBlock	.153	.749	.191	.750	.906	.551
FxBlock	.056	.916	.002	.402	.289	.637

* Not significant when analysed for pinaster plant groups only.

In root tissue the highest N concentrations were in *P. radiata*, Corsican and Landes. Leiria R had significantly lower concentrations than *P. radiata* and Leiria 2 had significantly lower N concentrations than Corsican and *P. radiata*.

Root and shoot N levels were comparable and almost doubled with fertilising.

Phosphorus Concentration - Treatment effects for shoot P concentration were significant (Table 8). Corsican values were significantly higher than Leiria 2 but not the other genotypes. For root tissue a significant genotype by fertiliser interaction was removed when *P. radiata* was excluded from the analysis (Fig. 5).

Phosphorus levels were significantly higher in the fertilised treatments.

Potassium Concentration - In both shoot and root tissue only the effect of fertiliser had an impact on K level (Table 8).

Potassium levels were three to four times higher in shoot tissue than in root tissue and higher in fertilised than in non fertilised plants.

Discussion

Trial Design. - The trial was designed to compare some juvenile attributes (growth rate, response to fertiliser and drought, needle length, root/shoot ratio, bud activity) of major *P. pinaster* provenances, that were not readily amenable to testing under field conditions.

The object was to evaluate similarities and differences between the pinaster genotypes over the early growing stage. The levels of fertiliser and droughting were imposed to allow comparison over an extreme range of conditions which influence the species in the field. Species response to fertiliser and drought per se was considered of secondary importance and hence these treatments were of simple, reliable application.

On a similar basis, *P. radiata* was incorporated in the trial as a control. It is a species well known to most workers in Mediterranean climates, it has a wealth of research literature directed to it and provides a scale on which to judge any variation between provenances. In all of these aspects the trial was successful in that significant effects for genotype, nutrition and droughting were obtained.

Three harvests were employed to sample variation associated with stages of seedling development. The stability of tissues and morphology during this early stage of rapid development and the sensibility of endeavouring to assign fixed, distinguishing features (i.e. height growth, needle length, fertiliser response) to provenances at this early developmental stage was questionable. Again, the staged harvesting procedure was successful in defining seedling variability. No attempt was made to analyse differences between harvests with statistical procedures.

Destremau *et al.* (1982) have recorded that for the Landes race, the young pine passes through several stages of development. Up to two years it possesses juvenile characteristics of rapid growth, short, fine needles, carmine coloured shoots, a significant number of 3 needled fascicles, smooth bark and a tendency to multinodal growth. From 2-6 years the pine enters a pre-puberty stage with longer, more supple needles, it loses the early, carmine colour of the spring shoot, regenerates less vigorously from cuttings or shoot damage and commences a better seasonal rhythm of growth in reaction to favourable conditions of the environment. After 6 years it commences to fruit but it is not until 18 years that full cone production is reached. At this age the needles are dense, long, plump, stiff and pointed. The current trial comparing plants from 15 to 29 months, samples the transition from juvenile to pre-puberty.

Detailed anatomical analysis of tissues was not incorporated, partly through the work involved but mainly due to the unsatisfactory yield associated with this avenue of investigation in the past (Fieschi 1932, Marsh 1939, Perry 1949). Developments of more useful genotype differentiating procedures by monoterpene (Bernard-Dagan *et al.* 1971) or isozyme analysis were beyond the scope of knowledge and facilities available at that time.

Species Comparisons. - Comparative performance of dry weight production for plant groups (Figs. 2 and 3) clearly established the superiority of *P. radiata* to *P. pinaster* under conditions of high nutrition in the trial. This would be expected from a knowledge of performance of the two species under field conditions. Within the low nutrition treatment, however, an initial dry weight advantage expressed by *P. radiata* in Harvest 1 decreased at Harvest 2 and in Harvest 3 the *P. pinaster* provenances for Leiria exceeded *P. radiata*. Again, this may be expected from experience of the performance of the two species on infertile soils in Western Australia.

It is important that, at Harvest 3 when the low nutrient treatment was most pronounced, the genotype by fertiliser interaction was significant (.026 level) and attributable entirely to the *P. radiata* reaction. Removal of *P. radiata* data from the trial and re-analysis showed no significant interaction between genotype and fertiliser for the *P. pinaster* groups.

Other major differences measured between the two species were in the proportion of terminal buds in a dormant (resting) condition at Harvest 2 and the extent of shoot mortality at Harvest 3. Within the trial conditions these are considered to be intrinsic species differences representative of performance in the field.

Within the scope of this trial it is not possible to definitely state the cause of shoot mortality. Tip deaths were independent of soil fertility level and probably resulted from a combination of extreme insolation and restricted root moisture due to size of pots. Results revealed that under environmental stress significant differences between plant health are associated with different provenance sources in *P. pinaster*. A general superiority of this species over *P. radiata* was indicated for the conditions tested. Further, the provenances of maximum dry weight production (Leiria R and Leiria 2) were also amongst the most resistant to the disorder.

Little interpretation is offered for results obtained for chemical analysis of roots and shoots. Shoot nitrogen concentrations for *P. radiata* were consistently less than those of *P. pinaster* under both high and low nutrition treatments.

No clear pattern emerged between species for phosphorus concentrations. Shoot and root values of potassium for *P. radiata* tended to be the lowest of all plant groups and most similar to those of Leiria provenances.

Provenance Comparisons. - Improved provenance comparisons were provided by removing the *P. radiata* data from analysis for root dry weight in Harvest 2 and shoot and root dry weight in Harvest 3.

Results from height development (Fig. 1) and shoot and root dry weight (Figs. 2 and 3) showed the Leiria R to be consistently greater in growth than the other three provenances. This superiority was present in all treatments in Harvest 2 (Table 3) and shown to be significant in Harvest 3 (Table 6). The greatest genotype similarity was between Leiria R and Leiria 2 and Corsican and Landes provenances, respectively.

It will be seen from the tables of results for each harvest and Figures 2 and 3 that, apart from the Leiria, the genotypes were reasonably similar over the variable conditions and period of the trial. Results for plant nitrogen (Fig. 4) contained no consistent pattern for provenances but tended to support the above trend for similarity between the pairs of provenances. Plant phosphorus concentrations (Fig. 5) were variable and not considered to be specific in provenance comparisons under conditions of the trial.

Results for potassium concentration (Fig. 6) showed clear differences between the provenances. The Leiria R and Leiria 2 plant groups were clearly the most similar in tissue potassium concentration. In Harvest 1 the Leiria R and Leiria 2 means did not differ significantly and were significantly different to the Corsican and Landes means which were similar (Table 2). The trend was consistent at each harvest (Tables 5 and 8) and suggests that provenance reactions to potassium in the environment are consistently different. These reactions may serve as a useful diagnostic tool under some circumstances and possibly are indicative of a variable response to applied potassium in the field. The similarity of K values for *P. radiata* and Leiria, could reflect dilution of a fixed amount of K, in the most rapidly growing plants.

Terminal bud development (Table 4) and shoot mortality (Table 7) indicate a continuous variation amongst provenances. Again the Leiria R and Leiria 2 and Corsican and Landes provenance pairs showed the greatest similarity. Although this trend was demonstrated in needle length comparisons in Harvest 2 (Table 4), results from Harvest 3 revealed (Table 7) that this attribute is not consistently suitable for comparing provenances in the seedling stage (Destremau *et al.* 1982).

Nutrient Concentration. - Response of the separate pinaster genotypes to fertiliser was reasonably uniform and there is no sound reason to expect that fertiliser application is more relevant to one provenance than for the others. The variable potassium concentrations in the Leiria provenances may indicate that further field trials with potassium fertilisers with this provenance are warranted. Previous limited results for K fertilisers with the species in Western Australia (Hopkins 1960) most probably only relate to the Landes provenance which was most common in the earlier plantings. The data for *P. radiata* showed that responses to levels of fertiliser may vary between species.

The trial was designed simply to identify major differences in nitrogen, phosphorus and potassium concentrations of provenance groups and not to study physiological differences. With this in mind, the soil mix and the liquid fertiliser were ones that had been used for several years at Wanneroo for forcing *P. pinaster* stocks for grafting and in the after-care of grafts. There are no indications that they were not completely effective and safe. Plant phosphate concentrations may have differed at higher levels of added phosphorus (added fertiliser contained 23% nitrogen, 4% phosphorus and 10% potassium). This is not expected, however, as levels over the three harvests show a considerable range and expected adequacy of supply.

There was no significant relationship between the leading shoot disorder and level of nutrition and this supports the suggestion that the fertiliser program was adequate for healthy growth throughout the study. Low nutrient levels were significantly associated with an increase in the extent of shoot dormancy in Harvest 2.

Table 9. Water loss by treatments to permanent wilting (PW) and atmometer(control) loss to treatment permanent wilting.

Genotype	Fertiliser	Pot Loss to PW (ml)		Atmometer Loss (ml)	
		Treatment Mean	Genotype Mean	Treatment Mean	Genotype Mean
Leiria R	F	1109	1059	1611	1231
	NF	1101		852	
Leiria 2	F	1011	1067	1766	1337
	NF	1123		909	
Corsican	F	1103	1096	1666	2082
	NF	1088		2498	
Landes	F	1056	1091	1647	1678
	NF	1126		1712	
Radiata	F	946	984	476	529
	NF	1023		584	
Mean (ml)	F	1045		1432	
	NF	1074		1311	
Significance		NS		.01	

Droughting. - The single drought cycle to permanent wilting (PW) of the plants was monitored by daily measurements of pot water loss and the appearance of the plants each morning. Droughting commenced on February 18th 1965 and was terminated on March 18th, a period of 28 days. Over this period the average loss of the watered (HW) fertilised treatments in Block 2 (atmometer loss) was 210 ml per day. The first plant reached permanent wilting on the 13th day of droughting.

Pinus radiata and the fast growing Leiria genotypes reached permanent wilting earlier than the Corsican and Landes plants. This is shown in Table 9 by the atmometer loss associated with permanent wilting of each treatment. The interaction and fertiliser effects were not significant but the time for *P. radiata* to permanent wilting is significantly less than the *P. pinaster*. *P. radiata* has larger plants and more drought susceptible shoots (Hopkins 1971b). There was no significant effect due to fertiliser and hence time elapsed to wilting is a function of tissue characteristics and not a simple function of plant size.

Leiria R and Leiria 2 wilted with significantly less atmometer exposure than the Corsican genotype (Hopkins 1971b). The amount of water transpired by each plant to permanent wilting was the same for all species (Table 9). As the pots contained equal soil weights and volumes and were watered to a constant pot capacity prior to commencing the droughting, it is reasonable to assume that the soil moisture potential at permanent wilting was similar in all cases.

Harvesting was not carried out until all plants had wilted and been re-watered, hence those that reached permanent wilting earliest (*P. radiata*, Leiria) had longer to recover from re-watering. There is no evidence from the genotype by watering interaction for dry weight (Fig. 8) that these differences had any influence on the pinaster results. The *P. radiata* results were most influenced by droughting (Fig. 9). This influence could also contribute to the significant fertiliser by watering interaction (Fig. 8) which did not apply to root dry weights when *P. radiata* was removed from the analysis.

The drought treatment was effective and again shows similarity between the Leiria R and Leiria 2 provenances in the time taken to reach permanent wilting. The Corsican genotype was the slowest to reach permanent wilting.

Drought resistance of *P. pinaster* provenances has been further compared by Hopkins (1971b) and supports the current performance to permanent wilting.

Root/Shoot Ratios. - Roots were grown within confined containers and root/shoot ratios obtained cannot be confidently related to field conditions. In the trial there was no evidence of different ratios for genotypes. In all harvests a highly significant effect of fertiliser indicated that root growth was relatively greater under low nutrient conditions for all genotypes.

The single droughting sequence had no discernible influence on root/shoot ratios.

Provenance Origin. - Experience with Italian seed of *P. pinaster* (and that reputably from Lucca) in the past produced a slow growing, relatively short, flat topped pine. The current batch thought to be of Luccan origin (Leiria 2) behaved in the nursery and in field trials in a manner similar to that of Portuguese seed. A further batch of Italian seed included in the field trial has confirmed previous expectations for this provenance. The suggestion was that the Luccan seed batch could have been unexpectedly replaced by a Portuguese batch.

Sweet and Thulin (1963) identified a distinct fast growing, long needled provenance of *Pinus pinaster* from the Genova-La Spezia region of Italy in field trials in New Zealand. Such a provenance differing from the usual Italian tree was also suggested by Duff (1928) in his earlier studies of the species. The Valfreddana location could perhaps, have been within this group.

In the field trial associated with the present plant sources it has not been possible to separate the Leiria R and Leiria 2 groups on height, diameter and volume growth, after 21 years in the field. Pollen production, cone production and stem straightness were also significantly similar but significantly different (with volume) from the other provenances; including a further Italian provenance, in the trial (Hopkins and Butcher 1993). These similarities and the often close matches in the seedling study verifies that Leiria 2 provenance was derived from a Portuguese source.

The actual Luccan seed batch was included in a strip comparison trial in a following year. At age 22 years it has identical performances in flowering time, growth and form to the other Italian provenance (Hopkins and Butcher 1993).

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Captions for Figures

Figure 1. Mean height growth for seedlings in the pot trial. Data are separated to compare fertilised and non fertilised growth.

Figure 2. Shoot dry weights obtained at each harvest for plant groups. Values for high and low fertiliser are separated.

Figure 3. Root dry weights for each harvest in the trial. Means for fertilised and non fertilised treatments are separated.

Figure 4. Percentage of nitrogen in shoot and root dry weights at each harvest. Provenances and fertiliser levels are separated.

Figure 5. Percentage of phosphorus in shoot and root dry weights at each harvest. Provenances and fertiliser levels are separated.

Figure 6. Percentage of potassium in shoot and root dry weights at each harvest. Provenances and fertiliser levels are separated.

Figure 7. The nutrition by watering interaction obtained in Harvest 2.

Figure 8. The plant by watering interaction obtained in Harvest 2. Differences between means are not significant.

Figure 9. Interaction between plant and watering treatments for nitrogen content of roots.