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

by

E. R. Hopkins and T. B. Butcher

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Summary and Conclusions.

Studies of the effect of superphosphate and superphosphate plus urea fertiliser on pine stands over a range of sites on the Spearwood Dunes sands north of Perth were continued up to stand age 22 years. The trial was designed to compare growth under unthinned, medium and low stand densities.

Three thinning treatments, unthinned (1970 stems ha^{-1}), routine (500 s ha^{-1} age 10 years, 250 s ha^{-1} at age 18 years) and heavy (750 s ha^{-1} age 6 years, 250 s ha^{-1} age 12 years, 100 s ha^{-1} age 18 years) had the greatest effect on stand development in height, basal area and volume. Drought deaths were extreme in unthinned stands of 10 and 11 years of age but virtually absent in the heavy thinned treatment. Thinning at the first sign of drought mortalities at age 10 prevented further deaths in the routine stands. Mortalities continued in the unthinned stands throughout the trial and were associated with stand densities greater than 30 m^2 ha^{-1}.

Drought stress within stands included a record drought sequence in the 1976-1978 period and was causally associated with rainfalls less than the long term annual average. Soil moisture monitoring showed a water deficit developing at depths greater than 2 metres under the stands as a result of low rainfall and high stand density. Soil moisture deficits were less in thinned than unthinned stands and increased with location from the wetter Haddrill in the south to the drier Karakin in the north. At Karakin water deficits were present at depth throughout most of the study showing rainfall to be seriously limiting to pine growth in the area.

Height growth increased proportionally with lowered stand density during drought sequences, again revealing serious limitations to stand development due to water deficits for the area.

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. Response to fertiliser applications at any site was small with no evidence that nitrogen at the level added had any effect on growth. Average growth improvement associated with the added fertiliser ranged from 0-10 per cent at the southern locations and 10-20 per cent in the north at Karakin. There was no indication that fertiliser was more effective in stands maintained at low densities to reduce soil moisture stress during the growing season.

Foliar sampling at stand age 10 years at Karakin indicated that nitrogen levels were not limiting. Sampling at all sites at age 8 years revealed highly significant different in P, K, Zn and Mn contents with Location, site position and fertiliser treatment. P and K levels were similar at Haddrill and Karakin but high and low, respectively, at Wabling. Mn content was higher and Zn content was lower at Haddrill than at the other two locations. With site position upslope K tended to increase and Mn and Zn tended to decrease. There was no significant association with thinning treatments. Both the N+P and P treatments increased P foliar levels significantly greater than the unfertilised control and foliar Mn was significantly higher for the phosphate alone treatment.

Pine growth over the range of sites tested was remarkably uniform, considering the high drought incidence of the northern site. Up to age 22 years unthinned plots developed basal areas of 50 m^2 ha^{-1} and greater, even in the presence of the order of 23 per cent reductions in stocking due to drought deaths. Height-age curves for the plots were combined with data for the Basal Control Series at Gnangara and Yanchep to provide a single site index for the sandy sites of the Swan coastal plain north of Perth. Growth was average to good compared to the better sites on the Bassendean Dunes system at Gnangara and the Spearwood dunes system south of Perth. A combined volume equation for the species was prepared to incorporate data from the pilot plots. MAI of the unthinned stand at age 22 years was approx 10 m^3 ha^{-1}.

The single most important factor determining the growth potential of the sites is soil moisture availability. Within the rainfall system sampled soil moisture storage is inadequate to carry over a pine crop of stand density 20 m^2 ha^{-1} or more, without stress, in years following a winter of below average rainfall.

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 (Butcher 1979). 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 in 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 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.

Butcher's report concentrated on climatic and hydrological aspects of the study as the area is one of the State's most important catchments and sources of underground water. These aspects are well presented and adequately covered by the report to age 10 years. The current report documents development of the pine crop at the three locations with a concentration on subsequent mortality, thinning and fertiliser response.

Location

The soils, vegetation, climate and nature of the ground water resources of the region have been described by Butcher (1979).

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 plus 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, situated 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 Karakin (1-27), Wabling (28-54) and Haddrill (55-81) locations is shown in Table 1.

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

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 years.
   Thinned to 250 stems ha^{-1} in 1980 at age 12 years.
   Thinned to 100 stems ha^{-1} in 1987 at age 18 years.

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. and	Dbhob (diameter at breast height over bark) 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.
January 1978.	Dbhob and heights of crop trees.
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 Sampling - 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.

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

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. 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									

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 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).

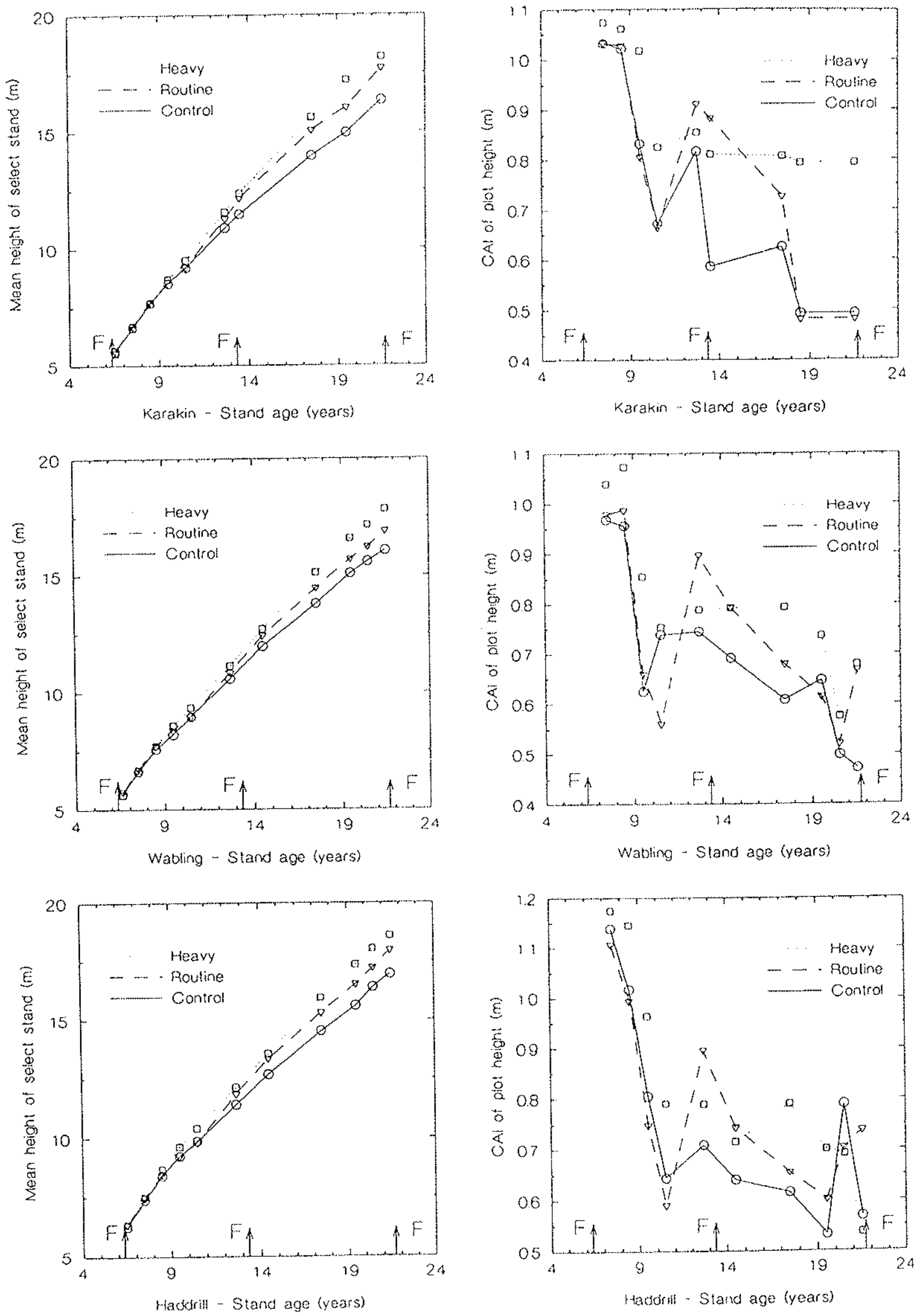

Figure 1. Mean heights and current annual increment in height of the select stand at each Location showing the impact of thinning treatments. The F and Arrow on the x axis mark fertiliser applications.

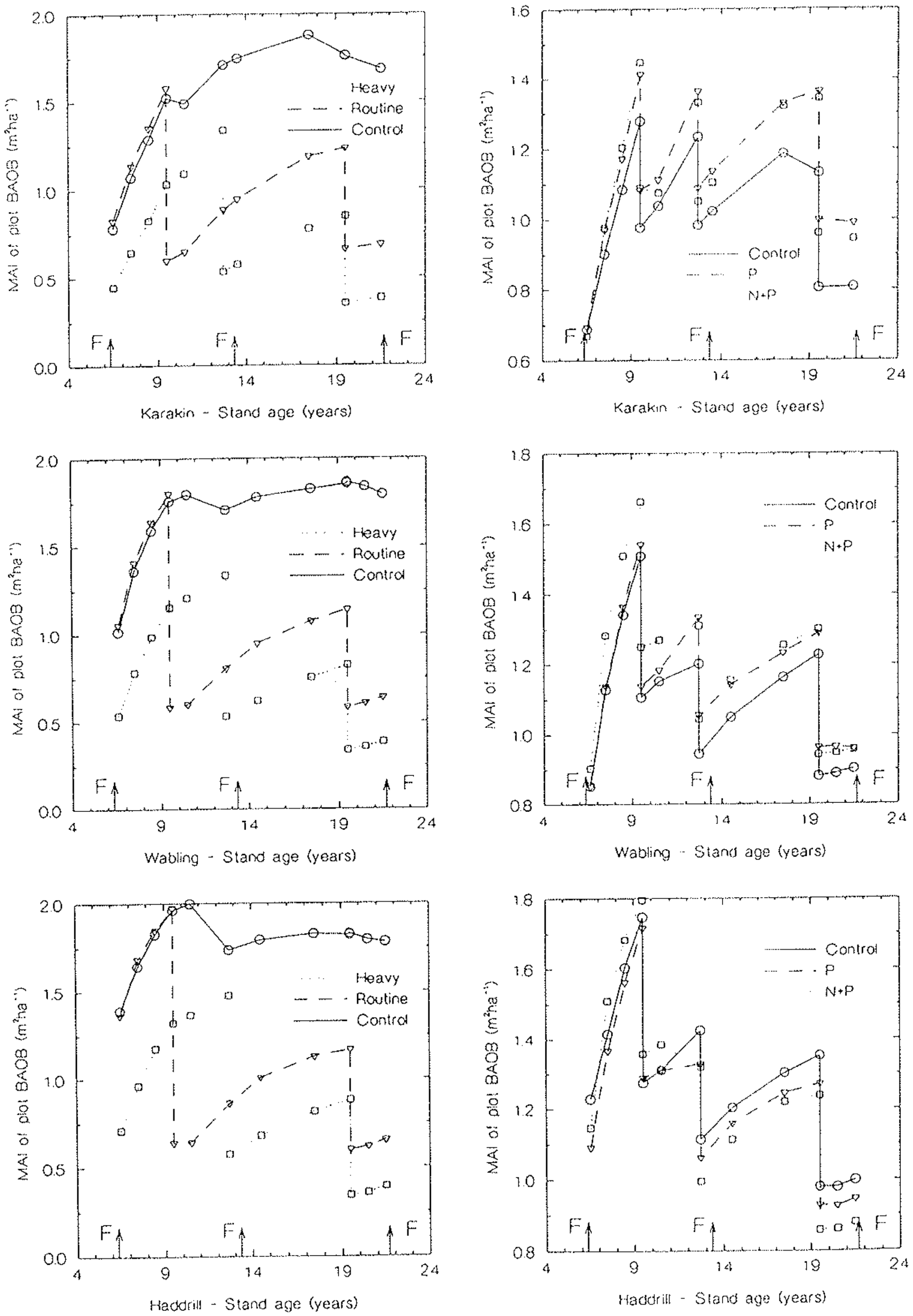

Figure 2. Plot of mean annual increment for standing basal area (m^2 ha^{-1}) at each location for thinning (left) and fertiliser (right) treatments. The F and arrow on the x axis mark fertiliser applications.

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								

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).

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

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									

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

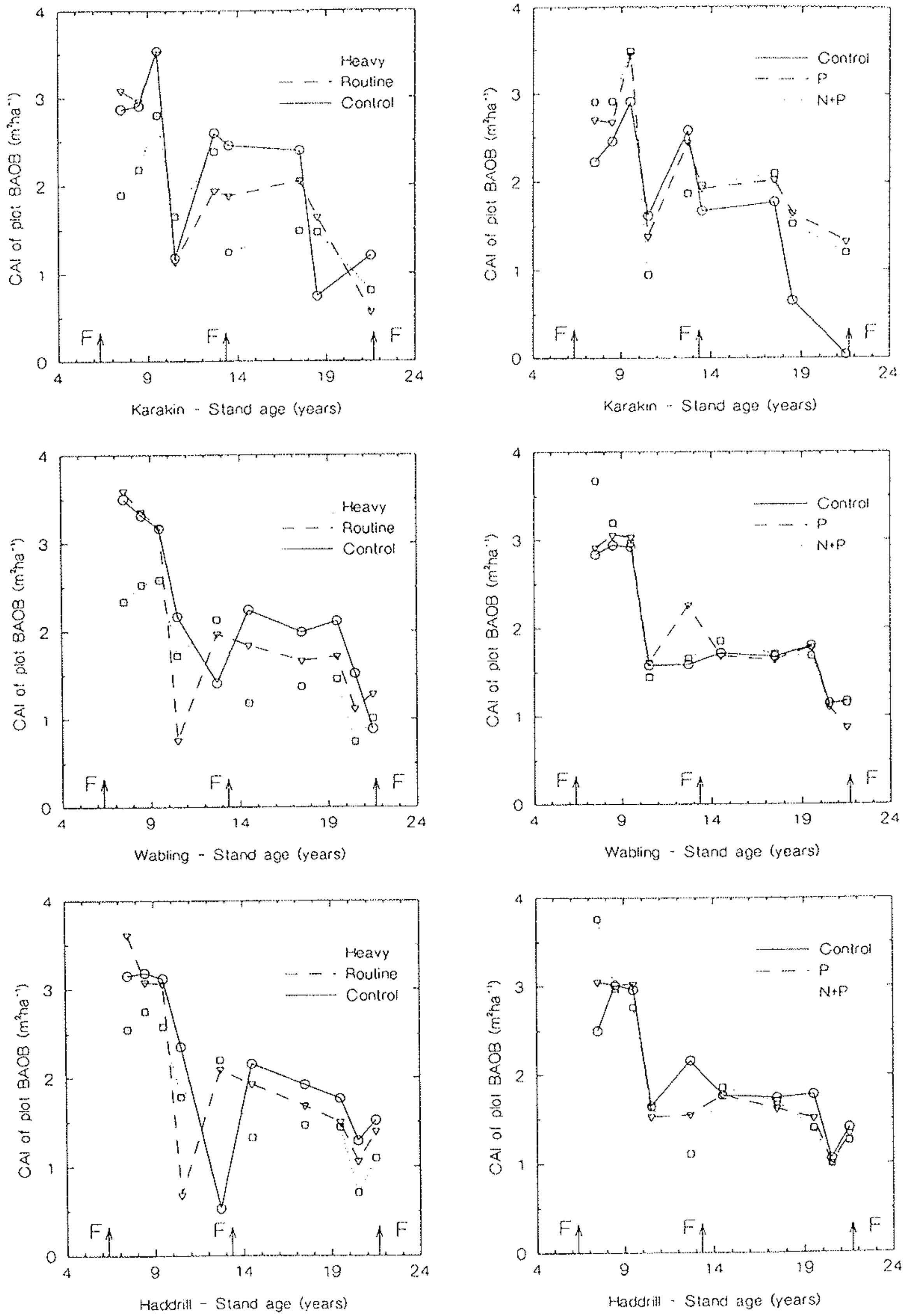

Figure 3. Plot of current annual increments for basal area (m^2 ha^{-1}) of the whole stand at each location for thinning (left) and fertiliser (right) treatments. The F and arrow on the x axis mark fertiliser applications.

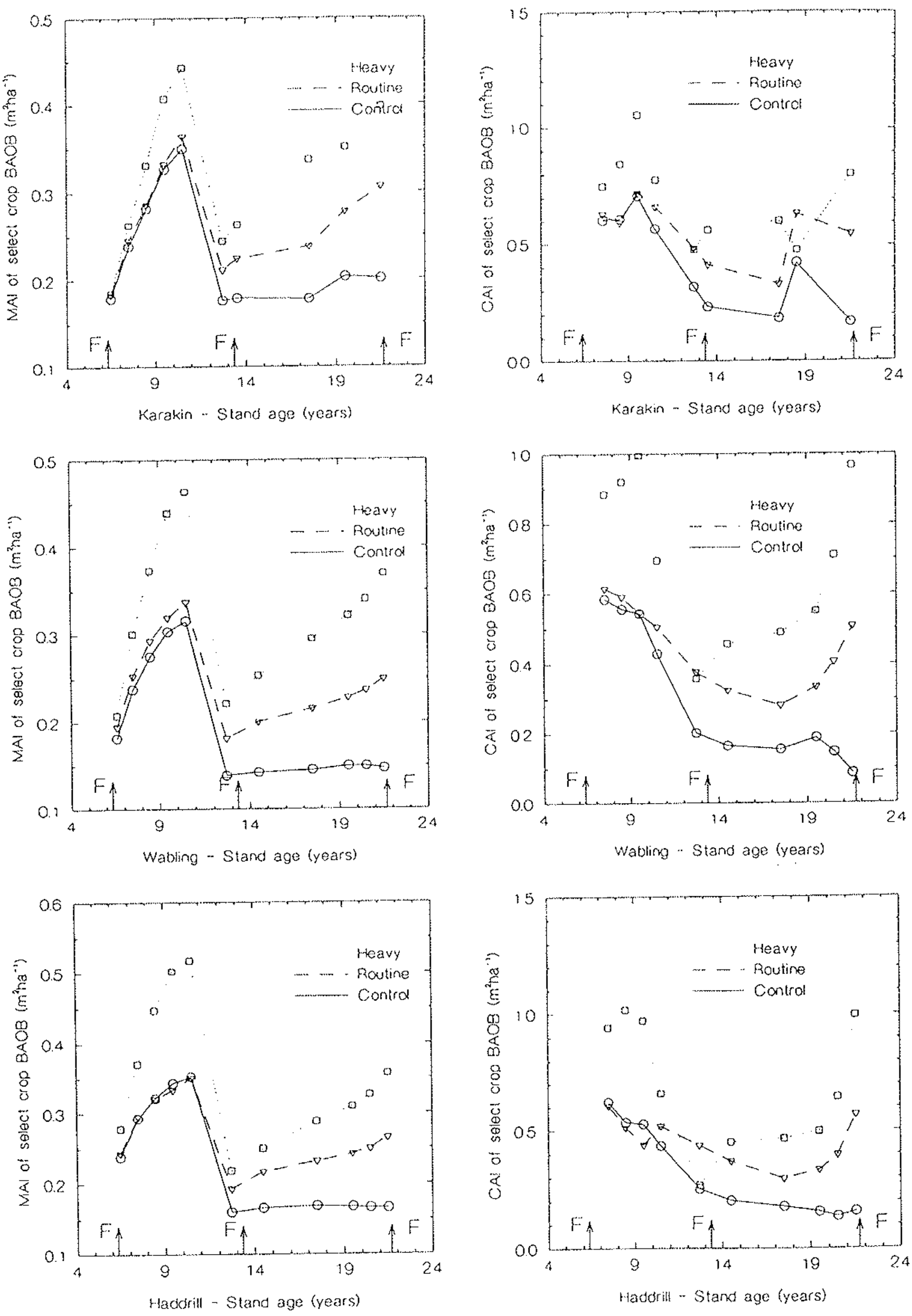

Figure 4. Plot of MAI and CAI for basal area of the select crop (m^2 ha^{-1}) for thinning treatment classes at each location. The F and arrow on the x axis mark fertiliser applications.

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).

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								

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 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

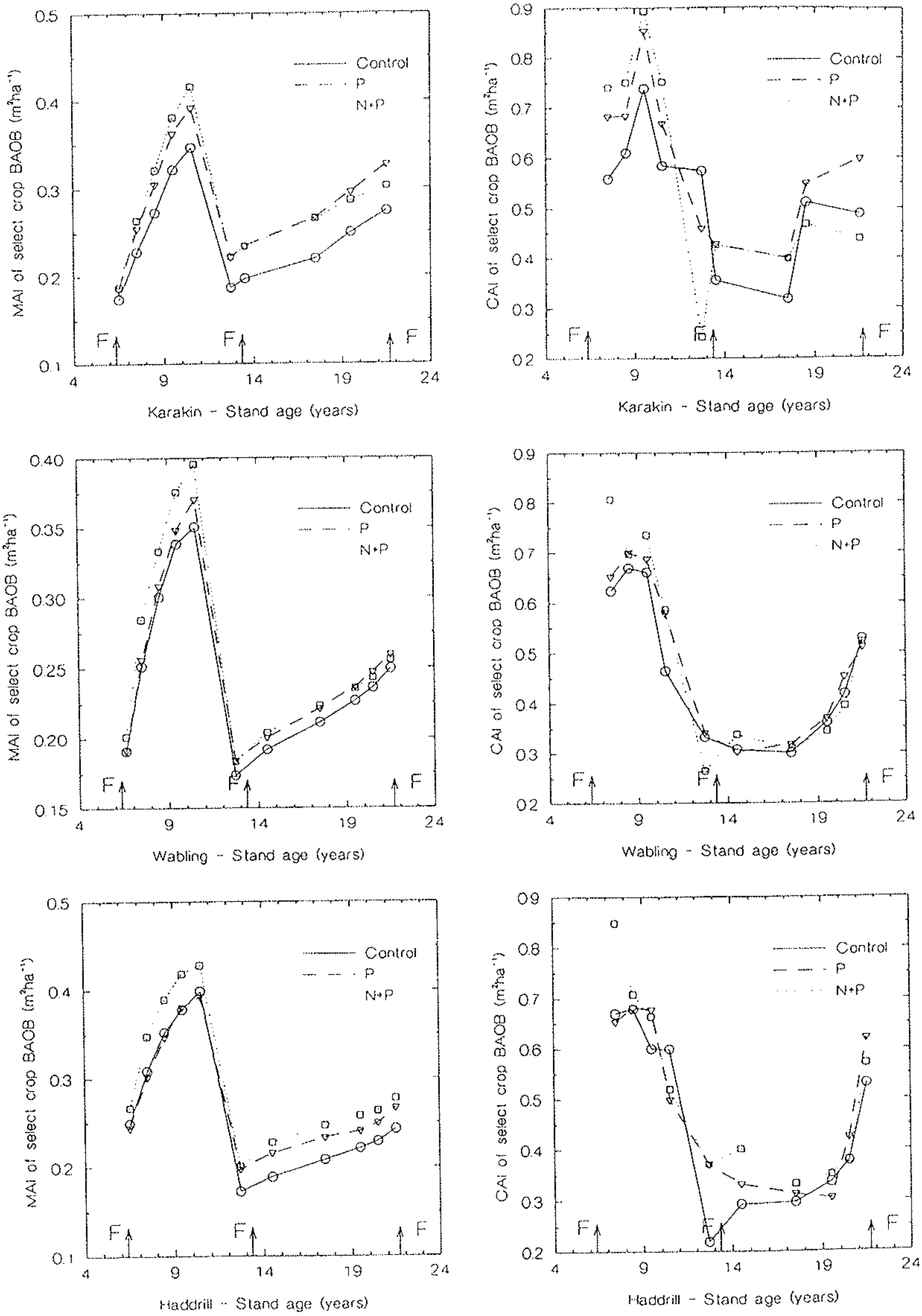

Figure 5. Plot of MAI and CAI for basal area of the select crop (m^2 ha^{-1}) for fertiliser treatment classes at each location. The F and arrow on the x axis mark fertiliser applications.

and Thinning treatments were highly significant (.001) while at Wabling and Haddrill only Thinning differences were significant for the total stand.

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

Total volumes for Locations were 118.9, 107.3 and 122.4 m^3 ha^{-1} for Karakin, Wabling and Haddrill, respectively.

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

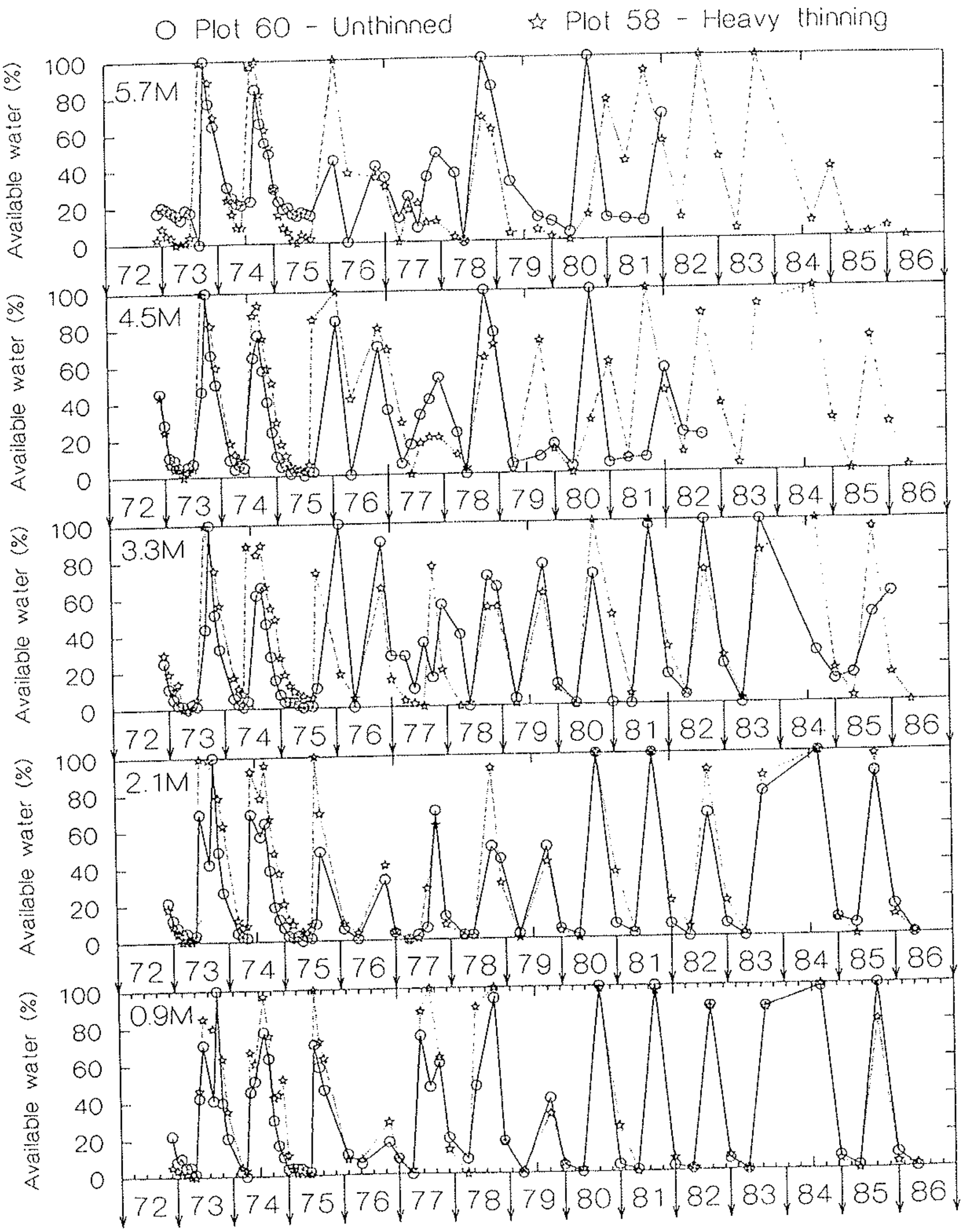

Figure 6. Comparative plots of the extent of soil water availability in thinned and unthinned stands at Haddrill location during the trial. The data is summarised by presenting the 0.9 m, 2.1 m, 3.3 m, 4.5 m and 5.7 m neutron probe traces.

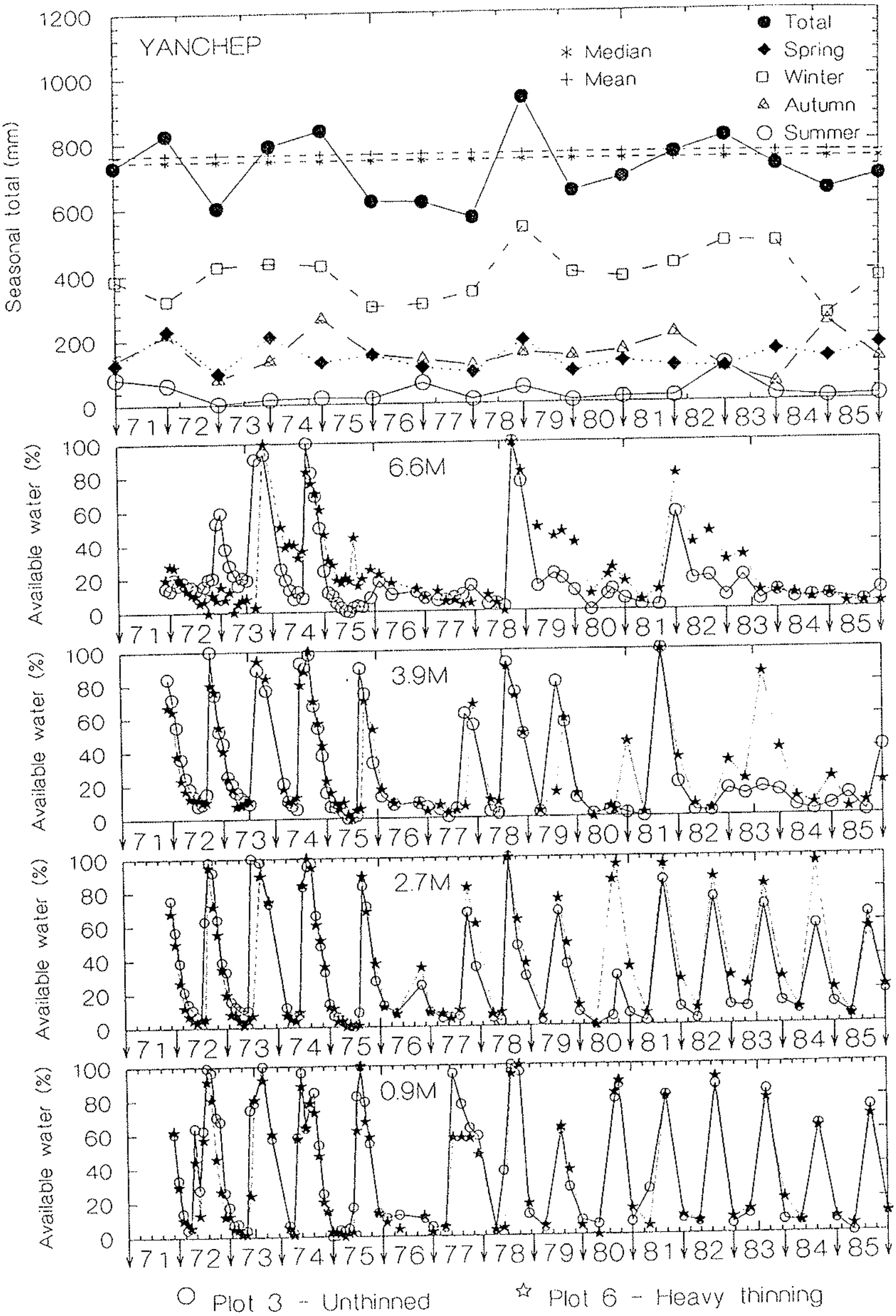

Figure 7. Comparative plots of the extent of soil water availability in thinned and unthinned stands at Karakin location during the trial. The top graph relates mean annual and seasonal rainfall at Yanchep to the trend in soil

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.

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

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 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.

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	Stems77	Height77	BA77	Stems78	Height78	BA78	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.

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.

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

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.

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

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.

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.

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				

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).

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

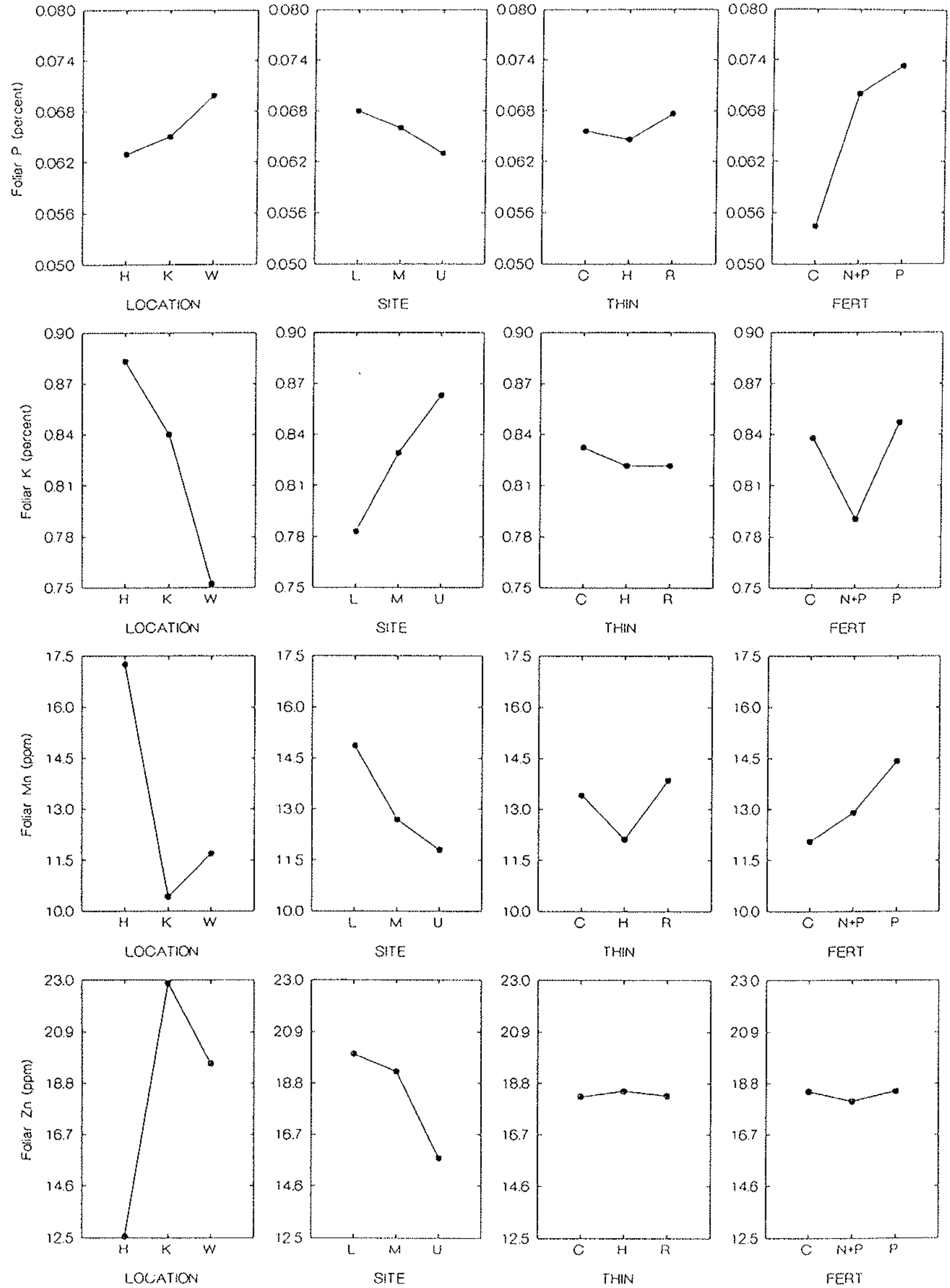

Figure 8. Trend lines of the main effects of foliar nutrient contents for locations, site positions and thinning and fertiliser classes. Foliar sampling was in March 1975 at stand age 7.6 years.

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.

It should be noted that the lowest K levels recorded are relatively high 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.

Site Index - Mean height of the final crop (100 s ha^{-1}) was regressed against stand and environmental variables (Table 15) to find main associations and prepare site age curves. Age was the strongest association (R^2=96.7) and age and site index accounted for 98 per cent of variation in height. An examination for normality and homoscedasticity showed a suitable fit to result from these two values together with the

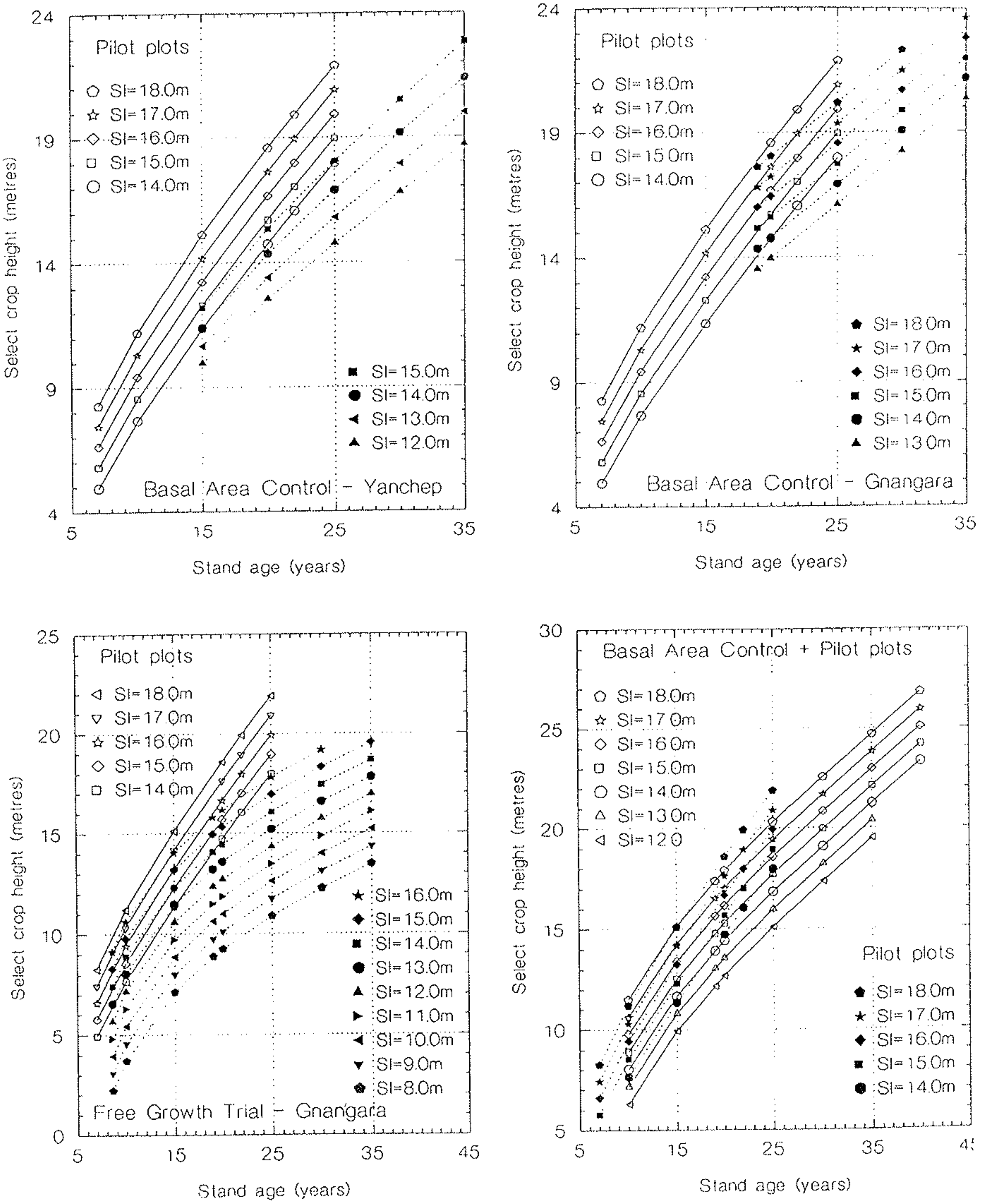

Figure 9. Comparisons of height-age curves for the Pilot plots with those obtained for the Basal Area Control Series at Gnangara and Yanchep and the Free Growth Trial at Gnangara. The bottom right plot compares the Pilot data with combined data for the Basal Area Control Series and the Pilot plots. Heights are the means for the select 100 stems ha^{-1}.

reciprocal of age. SI was the mean height at age 19.5 years, the measurement closest to the index used in the associated Basal Area Control and Free growth Trials with the species at Gnangara and Yanchep. Values at actual age 19.0 were predicted and used in regression to obtain site index curves comparable for age 19 years in all the trials with the species.

Table 15. best subsets regression for mean height (m) of the final crop of 100 s ha^{-1} with relevant independent variables.

Response is FcHeight

Vars	R^2	Adj. R^2	C-p	s	Location	Site	Thinning	Fert	Age	1/Age	Stems	BArea	SI19	SI19/Age
1	96.7	96.7	1980.8	0.7341					X					
1	91.0	91.0	6541.2	1.2030						X				
2	98.1	98.1	810.6	0.5530					X				X	
2	97.2	97.2	1554.1	0.6739			X		X					
3	98.5	98.5	467.1	0.4871					X				X	X
3	98.4	98.4	574.6	0.5087					X	X			X	
4	98.8	98.8	219.4	0.4332					X	X			X	X
4	98.7	98.7	356.1	0.4637	X				X				X	X
5	99.0	99.0	108.3	0.4065	X				X	X			X	X
5	98.9	98.9	140.1	0.4143			X		X	X			X	X
6	99.1	99.1	35.9	0.3880	X	X			X	X			X	X
6	99.0	99.0	73.4	0.3976	X		X		X	X			X	X
7	99.1	99.1	7.8	0.3804	X	X	X		X	X			X	X
7	99.1	99.1	21.1	0.3839	X	X			X	X	X		X	X
8	99.1	99.1	9.1	0.3805	X	X	X	X	X	X			X	X
8	99.1	99.1	9.1	0.3805	X	X	X		X	X	X		X	X
9	99.1	99.1	9.4	0.3803	X	X	X		X	X	X	X	X	X
9	99.1	99.1	10.5	0.3806	X	X	X	X	X	X	X		X	X
10	99.1	99.1	11.0	0.3805	X	X	X	X	X	X	X	X	X	X

The regression equation is

FcHeight = - 5.37 + 0.599 Age + 0.684 SI19 - 1.49 SI19/Age

Predictor	Coef	Stdev	t-ratio	p
Constant	-5.3736	0.3582	-15.00	0.000
Age	0.5994	0.0113	52.77	0.000
SI19	0.6842	0.0225	30.38	0.000
SI19/Age	-1.4948	0.1030	-14.52	0.000

s = 0.4871 R^2 = 98.5% R^2(adj) = 98.5% n = 729.

The range of height to which the regression applies is shown in Table 16. Comparisons with similar height age curves from other trials, indexed to age 19, are made in Figure 9. The Pilot plots were of higher site index than plots in the Basal area control study at Yanchep, similar to those for the same trial at Gnangara and equal to the best site indices in the Free Growth Trial at Gnangara.

The Pilot plot data were combined with that of the Basal Control Series to form a single height-age data set for the sandy sites planted with *Pinus pinaster* north of Perth.

Table 16. Range of mean heights (m) for the final crop of 100 stems ha^{-1} for Locations and major measurement years.

Year	Karakin		Wabling		Haddrill	
	Min	Max	Min	Max	Min	Max
1974	4.86	6.62	5.27	6.32	5.55	7.03
1975	5.94	7.64	6.20	7.46	6.67	8.14
1976	7.00	8.66	7.08	8.38	7.67	9.44
1977	7.86	9.54	7.78	9.26	8.62	10.67
1978	8.58	10.44	8.48	10.19	9.29	11.10
1980	10.45	12.42	9.97	11.70	10.75	12.70
1985	13.30	16.27	13.13	15.52	13.77	16.80
1987	14.02	17.55	14.49	17.65	15.10	18.26
1989	15.43	19.02	15.50	18.45	16.27	19.53

The regression equation is

FcHt = - 2.73 + 0.380 Age - 51.8 I/Age + 0.867 SI19

Predictor	Coef	Stdev	t-ratio	p
Constant	-2.7265	0.1836	-14.85	0.000
Age	0.380096	0.003613	105.20	0.000
I/Age	-51.8440	0.9644	-53.76	0.000
SI19	0.86735	0.01032	84.07	0.000

s = 0.6425 R^2 = 98.5% R^2(adj) = 98.5% n = 2143

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 high pine growth potential assessed for stand development north of Perth (Fig. 9).

Top height (mean height of 75 s ha^{-1}), often more convenient than final crop height (100 s ha^{-1}), can be obtained from the following regression

TopHeight = 0.419 + 0.738 FcHt + 0.228 Age

Predictor	Coef	Stdev	t-ratio	p
Constant	0.41928	0.07184	5.84	0.000
FcHt	0.73798	0.02759	26.75	0.000
Age	0.22774	0.02336	9.75	0.000

s = 0.2647 R^2 = 99.6% R^2(adj) = 99.6%

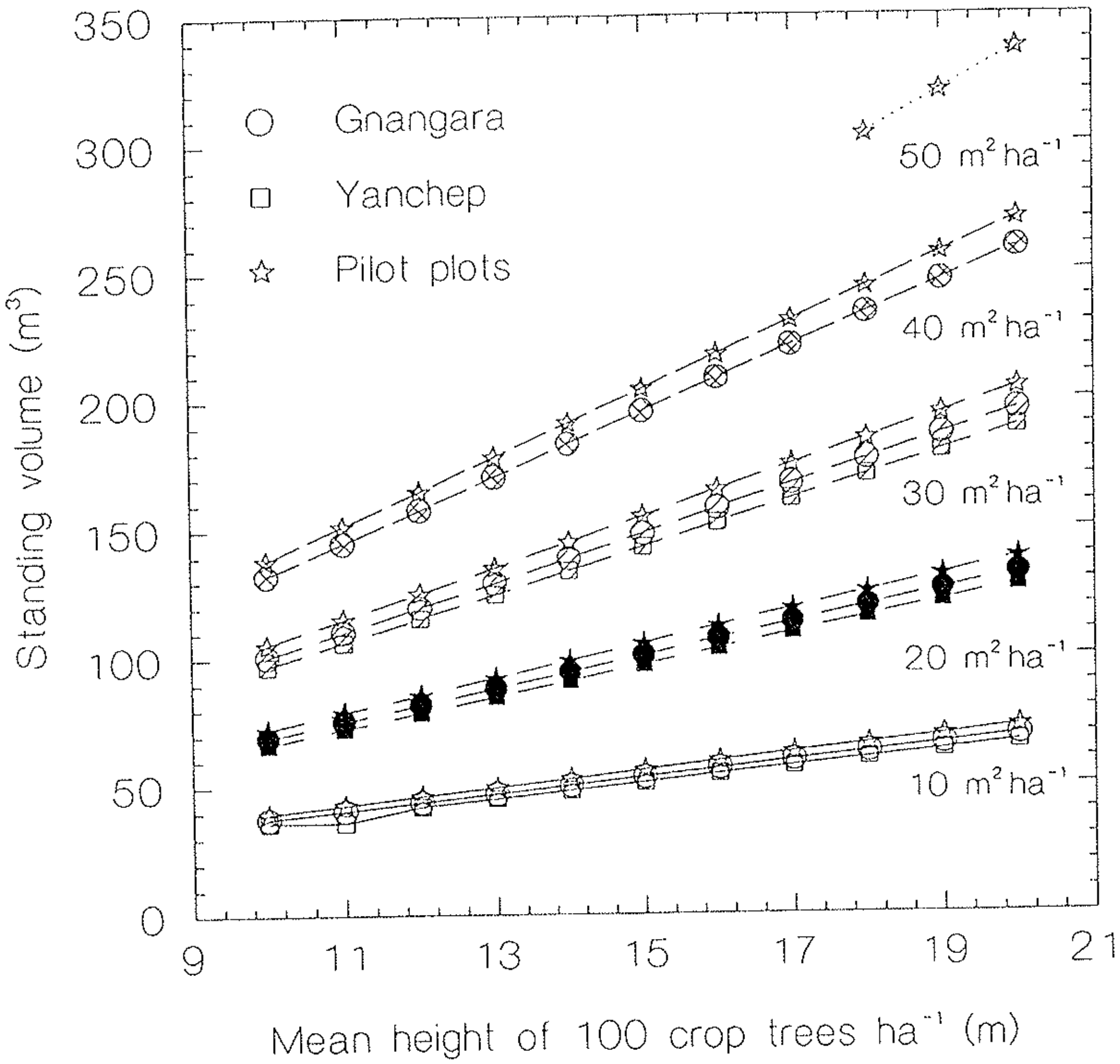

Figure 10. Variation of standing total volume underbark (m^3 ha^{-1}) with height and basal area within the Pilot plots and the Basal Area Control Series at Gnangara and Yanchep.

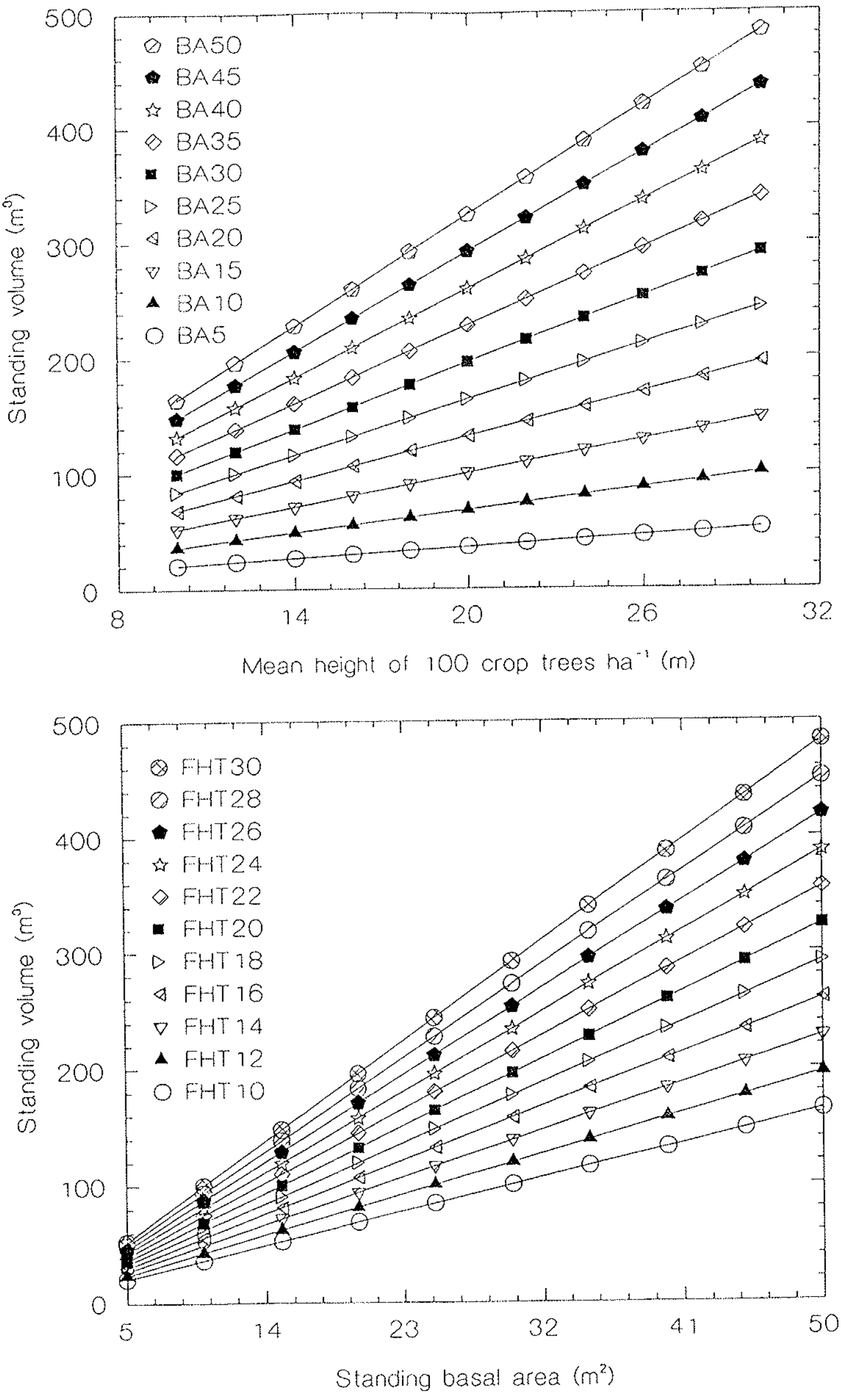

Figure 11. Association of standing volume underbark with stand height and basal area for all data on the Coastal Plain sands north of Perth

Total volume - Examination of volume data for the 1980, 1985, 1987 and 1989 measurements revealed an excellent association with the product of final crop height and total standing basal area.

The regression equation is

TVOL = 6.64 + 0.330 FcHt*TBA

Predictor	Coef	Stdev	t-ratio	p
Constant	6.6374	0.6615	10.03	0.000
FcHt*TBA	0.329777	0.001881	175.29	0.000

s = 5.375 R^2 = 99.0% R^2(adj) = 99.0% n = 324

This association was also the strongest for volume data in the associated Basal Control Trials at Gnangara and Yanchep. In Figure 10 the three associations are compared showing the Pilot data to be slightly superior in volume production over the range of relevant final crop heights and standing basal areas. The differences were within the confidence limits of prediction for the separate equations and the three data sets were combined to provide a single volume equation for pine production on all sites tested on the coastal plain sands north of Perth.

The regression equation is

TotalVol = 4.55 + 0.319 FcHt*TBA

Predictor	Coef	Stdev	t-ratio	p
Constant	4.5486	0.3201	14.21	0.000
FcHt*TBA	0.318884	0.000787	405.40	0.000

s = 6.442 R^2 = 99.0% R^2(adj) = 99.0% n = 1724

Table 17. Development of the mean annual increment in volume for the whole stand and final crop of 100 s ha^{-1} within the different thinning conditions. Volume (m^3 ha^{-1}) is the total under bark.

Age	Stand volume			Final crop volume		
	Thinning class			Thinning class		
	1	2	3	1	2	3
8.6	9.61	5.03	8.35	0.870	1.102	1.318
17.6	8.97	6.21	4.61	0.842	1.291	1.831
19.6	9.25	6.73	5.18	0.936	1.447	2.009
21.7	9.86	4.14	2.57	1.001	1.708	2.461
ALL	9.42	5.53	5.17	0.912	1.387	1.905

Associations to obtain standing total volumes under bark (m^3 ha^{-1}) for final crop (100 s ha^{-1}) heights from 10 to 30 m and basal areas from 5 to 50 m^2 ha^{-1} are set out in Figure 11.

Mean annual increments for total volumes obtained within thinning treatments for both the standing and final crops are presented in Table 17. The highest value recorded was 15.4 m^3 ha^{-1} in the unthinned stand at Haddrill in 1980. This was after volume losses by drought deaths in 1977 and 1980. Up to age 22 years the highest MAI obtained in the unthinned stands was 10.9 m^3 ha^{-1}.

Mean Annual Increment for total volume is less than on the high site index sites (15 m plus) at Gnangara which are water gaining and to a large extent drought resistant. Drought in the pilot plots has not a great impact on height development to age 19 years, but basal area and stand volume have been markedly reduced by continued drought exposure.

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