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BASAL AREA THINNING STUDIES IN PINUS PINASTER AIT. IN WESTERN AUSTRALIA.

by

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BASAL AREA THINNING STUDIES

Summary and Conclusions

The main plantation areas considered for *Pinus pinaster* production in Western Australia are Gnangara and Yanchep. Trials were designed to assess the effects of a range of stand densities and fertiliser treatments on stand growth over major sites at these centres. The Gnangara trial was established in 19 year old stands in 1965 and covered fixed stand density treatments of 37, 25, 16, 11 and 7 m^2 ha^{-1} in 5 site uniformity blocks. Treatments duplicated within blocks provided for two fertiliser levels within each density treatment. At Yanchep the trial was established in 1966 in 14 year old pine plantation. The design was similar to that at Gnangara except that the 37 m^2 density treatment was omitted to provide 40 plots as compared to the 50 at Gnangara. Density classes were maintained by regular thinning until 1970. Fertiliser treatments were applied in 1971 and 1979. Measurement was annually up to 1985 for Gnangara (stand age 38.5 years) and 1986 for Yanchep (stand age 33.7 years). As the stand stocking was continually being adjusted by thinning to maintain density classes, a select crop of the 100 best final crop stems ha^{-1} was marked to provide comparisons of the dominant stands for treatments. These generally remained constant in stocking but some select stems were removed to maintain the 7 m^2 ha^{-1} treatment in the later part of the trial.

The trials sampled severe drought conditions which incurred mortalities within the 37 and 25 m^2 treatments at Gnangara and the 25 m^2 treatment at Yanchep.

The major impact of the density treatments was to modify volume and diameter assortments. Average diameter increased significantly in the lower densities improving quality considerations for saw log production. The impact of reduced stand density on diameter of the fixed number of stems in the select crop was pronounced and at the end of the trials the mean for 7 m^2 treatment was 1.4 times greater than for the 25 m^2 density treatment.

Basal area and volume increment significantly decreased with decreasing stand density treatments for the whole stand but increased for the fixed number of select crop trees. Production during the trial period in the 7, 11, 16, and 25 m^2 treatments was 49, 60, 78 and 83 per cent respectively of the 37 m^2 treatment for the whole stand and 206, 214, 187, and 118 per cent respectively, of the 37 m^2 treatment for the select crop trees at Gnangara. At Yanchep the 7, 11 and 16 m^2 treatments produced 57, 75 and 93 per cent of the volume of the 25 m^2 treatment, respectively for the whole stand and 175, 181 and 158 per cent for the select stand. Similarity of results of the two trials is demonstrated by the fact that the relevant proportions of the 25 m^2 treatment for the whole stand at Gnangara were also 58, 72 and 93 per cent. The improved volumes and increased mean diameter of the select

crop with decreasing stand density needs to be placed in a perspective with total volume production. The select crop of 100 s ha^{-1} constituted 79, 67, 45, 26 and 19 per cent respectively, of the volume growth of the 7, 11, 16, 25 and 37 m^2 stands.

Height growth in the select crop at Yanchep was significantly better in the lower density treatments during drought periods. The treatment differences were associated with greater water availability to the select crop through lower stand transpiration with lower stand densities. The effect was not noticeable at Gnangara where most stands had access to ground water supplies. This however, did not prevent tree mortality and variable cambial activity with stand density to be associated with drought stress at Gnangara.

From early data at Yanchep it had been proposed that on drought prone sites without access to soil water tables the soil water available is depleted rapidly and early in the season by a dense stand or more slowly and later in the season by a heavily thinned stand. As a result the same amount of wood is produced on a heavily thinned site as on a dense stand, during droughts. The limited indications of this situation over the course of the trial were also associated with a reduction in volume increment in the heavily thinned site. Generally during drought the highest stand density reduced in CAI to that of a reduced lower density class but the higher densities still produced more volume than the lowest stand densities tested. There is little doubt that volume increment is lost with reductions in stand density over the range 7 m^2 - 37 m^2 investigated, even under the rather severe drought conditions experienced by the trials. No indications were found for a site by density interaction in either trial. Treatment effects are also considered to be independent of site.

Height age curves for the poorest site at Gnangara were slightly better than for the best site sampled at Yanchep. Height age data for both trials were combined to provide site index curves for the age range 14.5 to 38.5 years. These were combined with data sets from adjacent trials to provide height-age curves for stand ages 7 to 39 years and site indices (19 years of age) from 12 to 21 metres.

Fertiliser treatments applied at Gnangara were 46 kg P for F1 and 90 kg ha^{-1} P + 53 kg ha^{-1} N for F2 at stand age 25 years and 46 kg ha^{-1} P for F1 and 84 kg ha^{-1} P + 88 kg ha^{-1} N for F2 at age 34 years. At Yanchep F1 was a non-fertilised control and F2 was 46 kg ha^{-1} P + 53 kg ha^{-1} N at age 19 years and 38 kg ha^{-1} P + 88 kg ha^{-1} N at age 27 years. Response in basal area and volume increment was detected in the year of application and the effect on current increment was significant for up to 4 years after application. Response at Gnangara was greatest with a 17 per cent increase in volume production for the high application, during the period of the trial. Density by fertiliser interactions were not significant and there was no detectable interaction with site. Responses for the select stand were similar to that of the total stand. At Yanchep volume increase with fertilising during the trial was only 6 per cent of the control. There was no indication of a density by fertiliser interaction and the select crop responded in a manner similar to that of the total stand. Response with site varied. Little response occurred on the best 2 sites, up to 15 per cent improvement was measured on sites 3 and 4 and a 7 per cent improvement resulted on site 5.

Foliar analysis in 1971, prior to fertiliser application, detected a highly significant effect for site, P levels decreasing progressively from the best site 1 to the poorest site 5. A significant K effect for stand density was also found prior to fertiliser application, K levels decreasing progressively with increasing stand density. Foliar analysis for samples 1.8 years after fertilising at age 19 years detected the application mainly for applied P. All sites had a similar P level supporting the need to improve low P values on the poorer sites. Fertiliser addition also resulted in significant increases in foliar Mg, Mn and Zn, Mn increasing with increasing stand density and decreasing significantly with decreasing site class. Mg decreased significantly with increasing stand density and could be a dilution effect. Foliar Zn increased significantly in the fertilised plots. Sampling in 1976, 4.7 years after fertiliser addition, found no significant differences in the above foliar nutrient levels for treatments but detected low N values in fertilised plots.

At Gnangara CAI curves for the densest treatments for the whole stand fell below the MAI curves at age 25 years on both the best and poorest sites. The least dense treatments crossed at age 31-32 years on all sites. For the select crop of 100 s ha^{-1} the CAI remained above the MAI for the whole trial over the whole range of stand densities, except briefly during drought periods, when CAI in the higher densities temporarily dropped below MAI. At Yanchep the curves for the whole stand crossed considerably earlier, at age 23 years for the range of densities and sites tested. The select crop curves did not cross at Yanchep except for those of the highest density during drought periods. It is suggested that satisfactory volume increment could be maintained on stand densities of 16 to 25 m^2 for longer than 40 years at either site, but particularly at Gnangara with regular fertiliser additions. An examination of the log assortments for different top diameter limits obtained during the trials also indicates that the 16 to 25 m^2 densities offer a good compromise between high total volume and quality volume production.

Soil moisture availability over the range of stand densities was monitored by neutron probes in both trials. At Gnangara the presence of a friable coffee rock within the soil profile generally restricted access holes to a depth of approximately 2 m. At Yanchep most access holes were to a depth of 6.3 m. Although 2 random holes were located in each plot monitored, analysis showed a single hole adequately portrayed the moisture status of the profile with the tendency for soil moisture deficits to increase with increasing stand density.

Annual rainfalls below the mean were usually associated with water deficits within the profile. Continued below average rainfall during the period 1975-1980 was associated with a carry over deficit in soil water availability throughout the profile from year to year. This period experienced the worst drought in the history of the area and some mortalities occurred in stands with stand densities of 25 m^2 ha^{-1} and above. Increment in basal area and volume decreased during periods of below average rainfall and soil moisture deficit. Height increment of the heavily thinned stands was significantly better than that of the high stand densities at Yanchep during drought periods.

Introduction.

In 1965 and 1966 a Basal Area Control Thinning Series was established to sample *Pinus pinaster* stands at Gnangara and Yanchep plantations. These trials were supplementary to a partly replicated Late Thinning Series, established in 18 year old pine at Gnangara in 1957, and a Free Growth Trial established in 1958 to cover a wide range of site classes in 5 year old pine at Gnangara. The former had demonstrated a need for a heavy reduction in stem numbers and stand density to provide for economic returns in the developing stands of the species. The latter revealed that a remarkable response in stem diameter was possible from early thinning in the closely planted stands.

The Late Thinning Trial demonstrated that the rate of exhaustion of available soil moisture in the surface 2 metres depth of profile was associated with the degree of stocking in stands. The heavily thinned stands had more available water through the spring, summer and autumn months and recharged more rapidly with rain. This longer period of availability was correlated with an extended period of cambial growth on the remaining dominant trees. Trial design in the Late Thinning Trial was inadequate to quantify these effects of stand density on hydrology or to separate the increment effect of fertiliser addition to the stands.

Design of the Basal Area Series provided for fixed stand densities, fertiliser treatments and the incorporation of soil moisture monitoring to further develop the studies commenced in the Late Thinning Series.

Essentially the concept of basal area control arises from the work of Moller (1954) which suggested that stand basal area can be reduced to approximately 50 per cent of the maximum for the site without significant losses in increment. The lower limit of basal area, below which significant loss in increment will result, is referred to as the critical basal area. Hence, between the critical basal area limit and the maximum basal area limit for the site, stands may theoretically be managed to produce similar increment but with wide variation in value return depending on the number of trees retained as the growing stock.

The present series aimed to determine a critical basal area limit for *Pinus pinaster* over the range of site qualities and throughout the life of a rotation. This was to be achieved by locating series of plots in stands of acceptable age and stocking and thinning to fixed basal areas embracing the critical range, i.e. from virtually unthinned to a thinning expected to be too heavy for the site. Each plot was measured at yearly intervals and re-thinned regularly to maintain the fixed basal area initially decided. Comparison of annual increments should then outline the most effective basal areas for volume production at the age of measurement.

Just how well the concept of a critical basal area would hold with the range of sites, stand ages and the species concerned was a matter for conjecture. Whatever the theoretical outcome however, the growth curves obtained from the plots and the various conditions of merchantability of the residual stands should allow key stand densities to be determined for all ages. Combined with results from the Free Growth Series, in which stand density was variable and treatments were based on a series of fixed stocking levels, data for most management strategies should be forthcoming.

Previous Results

The aims for the basal area series of trials may be summarised as :-

1. To determine the increment from a range of fixed basal areas which embrace the maximum and minimum requirements for optimum growth on different sites and with increasing stand age.

2. To examine the concept of critical basal area for *Pinus pinaster* under local conditions.

3. To separate the effects of thinning and fertiliser application on stand increment.

4. To determine the association between available soil moisture and stand density for the sands and climate concerned.

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 on dominants in the lowest density class to those in the highest density class. Significant differences in seasonal growth between years were largely related to rainfall variability and 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 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. At Yanchep, cessation of girth increment 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 that on the Yanchep sites, which are known to be drought prone, there is only so much water available at the beginning of the growing season, and 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.

The situation on the Gnangara sites was considered to be somewhat different. Here they found that the gradient of diameter increment still 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 metres. On the drier (poorer) sites the differences in volume production were much smaller.

Butcher and Havel (1976) also evaluated the interaction between stand density, moisture availability and response to fertiliser application in the Yanchep experiment. The response of the heavily stocked stands in terms of girth increment of the final crop trees (the best 100 per hectare (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.

Butcher (1977) studied the hydrological relations of the stands in the Yanchep trial in detail, incorporating throughfall and stemflow studies with the soil water availability measurement on certain plots. He concluded that the major factor determining *Pinus pinaster* growth on the drought prone, weakly leached coastal plain sands, which have 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 throughfall 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.

Hatch and Mitchell (1971) published mean values for foliar N, P, K, Ca, Mg, Mn, and Zn from samples of the plots at Yanchep for stand ages 15, 16 and 19 years. They found that foliar levels were largely unaffected by thinning treatment and only potassium showed a significant increase as a result of the treatment. As thinning caused a marked improvement in crown volume of the dominant crop which was compared, the total nutrients contained in the crowns of the thinned trees were greater than the amounts present in the dominant crowns of the unthinned plots. Whole tree samples were to be collected from the plots to measure the total nutrient uptake after the thinning treatment. For all elements examined there were significant differences between sampling years. They concluded that the similarity of the nutrient levels in the thinned and unthinned stands at ages 17 and 19 years of age suggest that the pool of available nutrients is adequate to maintain satisfactory growth over a wide range of stand densities.

The Current Report - Maintenance of the annual basal area reduction ceased in 1980 and regular measurement terminated in 1986. This provides a measurement record to stand age 38.5 at Gnangara, with 19.5 years of treatment effect and a record to stand age 33.7 at Yanchep with a similar period of treatment effect.

The objective of the present report is to document the study, check the early assumptions and make available measurements for stand modelling to aid the management of the species. The measurement record of the Basal Area Control Series, with associated measurements from the fixed stocking Free Growth trial are ideal for the development of management models for the species. Detailed soil moisture monitoring offers the opportunity to extend such models to all sites within Western Australia to which the species may be practically related.

SITE CONDITIONS

Location

The Gnangara Trial (WP 20/65) - The initial 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 were planted at 1.8 x 1.8 m square spacing in 1946 with seed imported from Portugal. They then represented the largest available area of plantation, of reasonable age, covering the range of sites and conditions typical of more recent planting. The 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). The stands were low pruned in 1958, pruned higher with a saw with a 2.5 m handle in 1959 and taken up further with a 3.7 m handle in 1964.

The Yanchep Trial (WP 54/66) - The Yanchep trial was established in Section A, compartments 1, 3 and 4 of the "

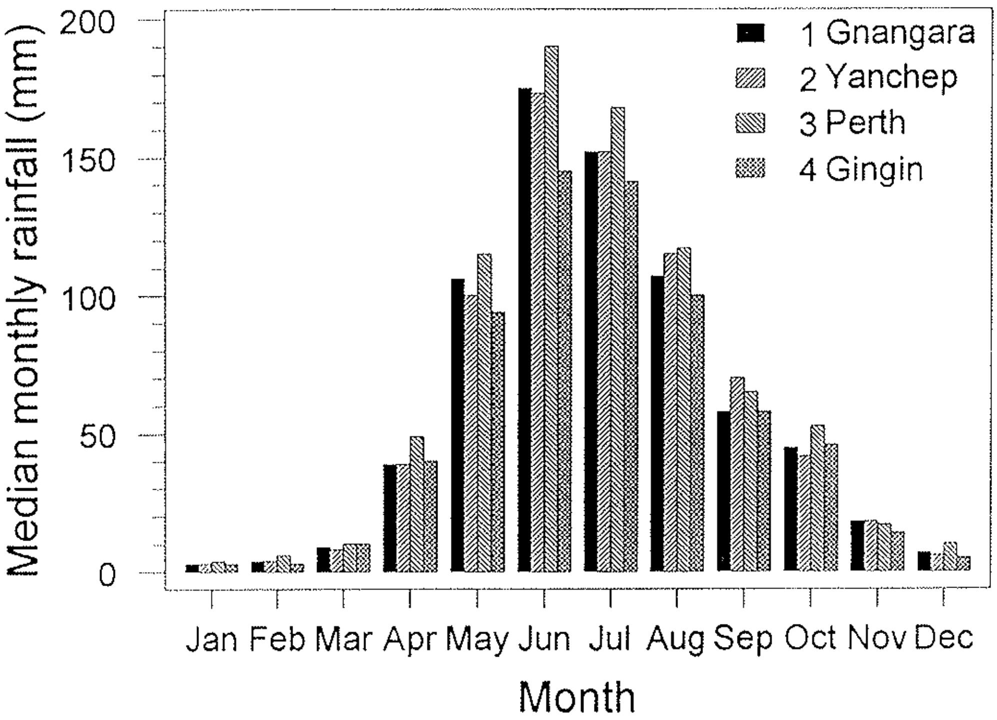


Figure 1. Bar diagrams showing the monthly rainfall variability for collection stations in the study area.

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 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.

Climate

The coastal plain area north of Perth experiences a temperate, Mediterranean climate with warm, dry summers and mild, wet winters (WAWA 1986).

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) has collated results of rainfall sampling on sites in the area of interest for plantation development. His estimate of average annual rainfall for the general plantation area was 772 mm. Variation was considerable in the year to year totals 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, has been calculated as being 41 years out of a 100 at Yanchep, but only 16 out of 100 for Perth (Havel 1968).

TABLE 1

Climate averages relevant to the study area (WAWA 1986). Rainfall and evaporation are in mm, temperature in °c and relative humidity in percentage units.

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

Temperature - Temperatures for the study area are moderate (Table 1), with the highest mean monthly recorded in January and February (34°C) and the lowest mean monthly minimum recorded in August (7°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 evapo-transpiration and the remainder is potentially available for redistribution and subsequent plant use during the period when evapo-transpiration exceeds rainfall.

Landforms and Soils

Details of landforms, soils and associated vegetation for the plantation areas are provided by Havel (1968) 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 furthermost inland and oldest is the Bassendean Dune System which is developed from 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 overlying limestone of this system.

Gnangara Sands - The Bassendean Dunes have low relief and the minor variations in topography are reflected by differences in depth to the water table. The plantations sampled by the trial are principally located on the level or gently sloping terrain of the Gavin type. Relief is generally less than 5 m. The soil is free draining quartz sand with a dark grey surface, a grey subsurface, and a dark brown, sometimes cemented subsoil; there may be iron concretions. The Joel unit is associate with the Gavin sands as small, separate, depressed areas which may be swampy during winter but do not have free water on the surface for extended periods. These soils are quartz sands with a high organic content at the surface, a grey subsurface, and a dark brown, often cemented sub-soil at 1-2 m. The water table is usually within 2 m of the surface.

Yanchep Soils - The "Hundred Acre Block" samples mainly the Karakatta Sands which comprise low hilly to gently undulating terrain with relatively deep, well drained yellow sands over limestone.

TRIAL ESTABLISHMENT

Introduction - The initial trial was located at Gnangara where the 1952 planting provided a relatively large area of unthinned pine over a range of sites relevant to the plantation program. The second trial sampled a younger pine stand on the large areas of soils with a limestone influence in the more drought prone sites to the north.

The Gnangara Trial (WP 20/65)

Selection - Within the stands rectangular plots of 40 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 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 x 20 m plots, selected within each 40 x 20 m temporary plot, provided 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.

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	BT	Hght	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			

The plots were ranked on the basis of mean height of the 10 predominant trees and the height range in which a reasonably uniform series of plots was available was considered. Fifty plots ranked from the tallest to the smallest mean height were allocated consecutively 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 (Appendix 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 i.e. 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 were assigned randomly to one of two fertiliser schedules.

Soil Moisture Monitoring - in 1968 two neutron probe access holes were randomly located in each of the plots in the first, third and fifth site uniformity groups (Appendix 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 average stand density over time, plots exceeding the specified treatment density due to growth were thinned to a value 5 per cent less than the treatment specification. Thinning was at approximately 2 yearly intervals (Table 2).

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.

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

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

Agras is a mixed NP fertiliser with 17.5% Nitrogen and 7.6% total Phosphorus.

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 pot, the samples pooled for each plot and analysed for per cent N, P and K and Zn and Mn content in ppm.

The Yanchep Trial (WP 54/66)

Selection - The trial was established using the procedure described for Gnangara. The younger stand, limited area and more drought prone sites set the maximum treatment density at 25 m^2 ha^{-1} and a total plot number of forty plots. Five site uniformity classes were therefore used to contain four density classes and two fertiliser levels (Appendix 1).

Treatments - Four density and 2 fertiliser treatments were randomly allocated to each of the 5 selected site uniformity groups (Appendix 1). The F1 treatments for three site groups were also fitted with access tubes for soil moisture monitoring.

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.

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

F1 - Nil fertiliser.
F2 - 500 kg ha^{-1} super, copper, zinc + 250 kg ha^{-1} Ammonium sulphate.

A second application was applied in August 1979:-

F1 - Nil fertiliser
F2 - 500 kg ha^{-1} Agras No 1 (NP).

TABLE 3

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 (Tables 2 and 3). Full measurement 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 Crop trees (100 ha^{-1}) were subject to height measurement (Tables 2 and 3).

Measurements were recorded on 80 column computer sheets under the following classifications.

1. Tree number - Stems in each plot were numbered.

2. Volume Class - recorded as a single digit code.
   1 = Normal - Successive mill log lengths can be obtained without waste.
   2 = Malformed - Contains a defect other than forking which requires wasting sections when logged.
   3 = Forked - Stem forked above 1.3m height.

3. Silvicultural Class - A single digit classification
   1 = dominant
   2 = co-dominant
   3 = sub-dominant
   4 = suppressed.

4. Status - Each tree was recorded for the measurement under a single digit status code.
   0 = The four best formed, vigorous and well spaced trees warranting retention for the whole rotation as a Select Crop Tree. These were pruned to 7.5 m height and together with Status 1 are often referred to as "Selects".
   1 = Final crop stems normally high pruned to 5 m stem height and including status 0 represent 250 crop stems ha^{-1}.
   2 = Other than final crop select stems.
   3 = Removed by a previous thinning.
   4 = Dead stems.
   5 = Trees of Status 0 to be removed in the next thinning.
   6 = Other final crop trees to be removed in the next thinning.
   7 = Other stand trees to be removed in the next thinning.

Data Analysis - The 90 plots in the series were measured at near annual intervals. Basal areas, diameters, heights and stem volumes were required for both the whole plot and the Select Crop trees to allow regular adjustment of stand density. To follow increment trends it was essential to analyse the data as a 5x2 (Gnangara) or 4x2 (Yanchep) factorial experimental within 5 randomised blocks. Means for site, density and fertiliser and interactions between density and fertiliser were obtained.

TABLE 4.

Mean number of stems for density and site classes in the Gnangara trial. Data is separated for the total stand and the 100 stems ha^{-1} initially selected for a Select crop.

Total stand

Age (Years)	Density class ($m^2\ ha^{-1}$)					Site class				
	7	11	16	25	37	1	2	3	4	5
19.0	252	412	705	1140	1707	717	782	852	845	1020
20.6	252	412	702	1140	1707	717	780	852	845	1020
21.8	252	412	702	1140	1707	717	780	852	845	1020
23.8	202	317	550	892	1405	560	625	675	695	812
25.5	117	212	395	697	1172	435	477	515	542	625
26.5	97	175	332	610	1055	382	412	442	472	560
27.5	97	175	332	610	1055	382	412	442	472	560
29.5	72	137	270	522	927	327	347	375	395	485
30.5	62	110	220	440	812	272	292	312	345	422
31.5	62	110	220	440	812	272	292	312	345	422
32.5	62	110	220	435	800	272	292	302	340	420
33.6	47	82	165	357	675	227	232	252	277	337
34.5	47	82	165	357	675	227	232	252	277	337
35.5	47	82	165	357	675	227	232	252	277	337
36.5	47	82	165	357	675	227	232	252	277	337
37.5	47	82	165	357	675	227	232	252	277	337
38.5	47	82	165	357	675	227	232	252	277	337

Select crop

Age (Years)	Density class ($m^2\ ha^{-1}$)					Site class				
	7	11	16	25	37	1	2	3	4	5
19.0	100	100	100	100	100	100	100	100	100	100
20.6	100	100	100	100	100	100	100	100	100	100
21.8	100	100	100	100	100	100	100	100	100	100
23.8	100	100	100	100	100	100	100	100	100	100
25.5	100	100	100	100	100	100	100	100	100	100
26.5	90	100	100	100	100	100	97	100	97	95
27.5	90	100	100	100	100	100	97	100	97	95
29.5	72	100	100	100	100	95	92	95	95	95
30.5	62	97	100	100	100	90	92	87	95	95
31.5	62	97	100	100	100	90	92	87	95	95
32.5	62	97	100	100	100	90	92	87	95	95
33.6	47	80	100	100	100	85	82	82	87	90
34.5	47	80	100	100	100	85	82	82	87	90
35.5	47	80	100	100	100	85	82	82	87	90
36.5	47	80	100	100	100	85	82	82	87	90
37.5	47	80	100	100	100	85	82	82	87	90
38.5	47	80	100	100	100	85	82	82	87	90

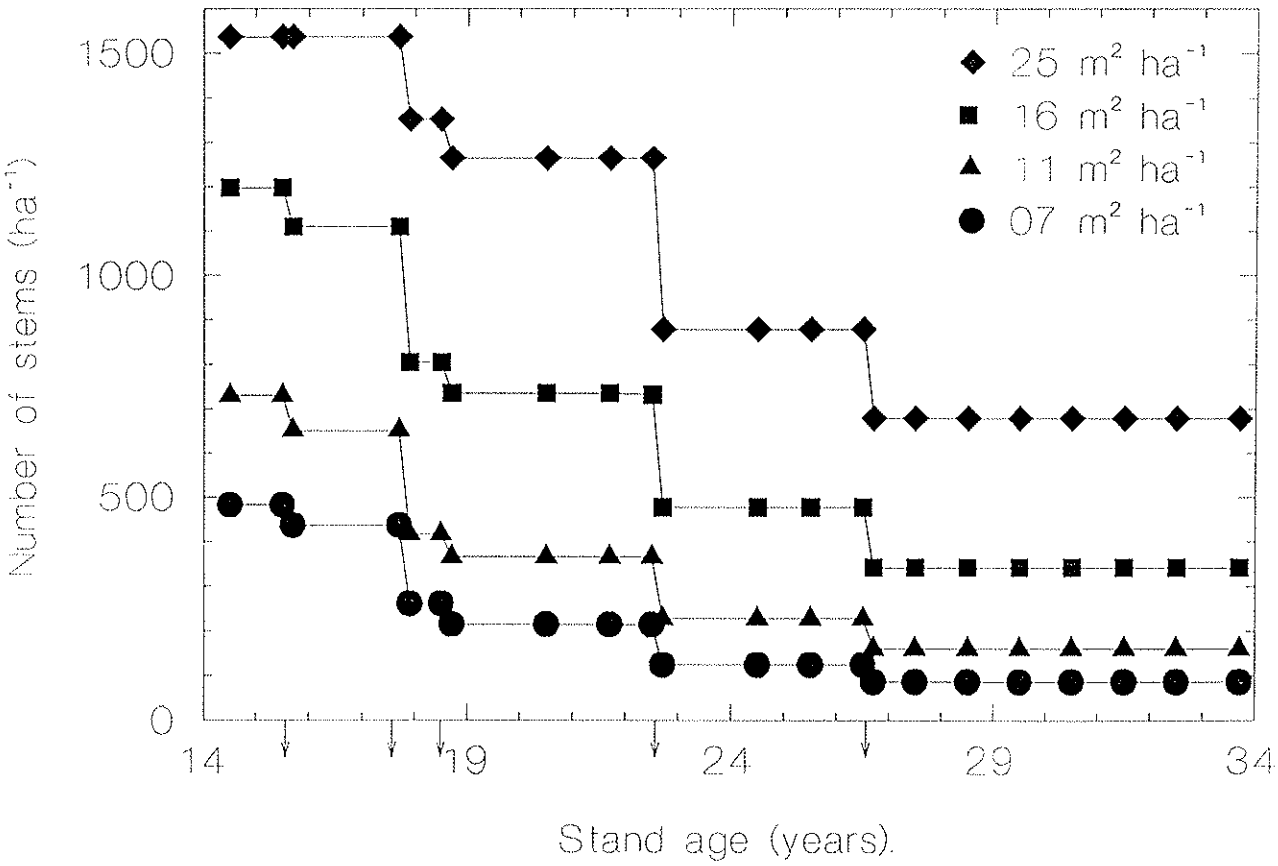


Figure 2. Variation in stem numbers in the whole stand with density and age in the Yanchep trial. The arrows on the horizontal axis depict a thinning event.

In 1982 a detailed study was made of measurement data to produce algorithms to obtain diameter under bark in the absence of bark thickness measurement and under bark volumes to determined stem heights or top diameter cutting limits. The latter simulate tree volume to the required stem height or diameter by integrating segmented polynomials (Max and Burkhardt 1976). These and various other modules required to determine predominant height, stem mortality and to thin the stand where trees had been coded for future thinning were combined into a "Pine Analysis Program" (N. R. Sumner 1982[1]). The program provides results of full volume measurements on pine thinning or increment plots. It summarises on a plot basis diameter, basal area, stem numbers, tree heights and tree volumes. The program will also calculate volumes of individual trees if required. Output is a two page printed summary for each plot (Appendix 2) and an ASCI file containing all relevant mean values to allow statistical analysis for all plots for each measurement. The program was originally written in Pascal for Cyber and Concurrent mini-computers and now has been compiled to run on desktop computers using the DOS operating system.

The program allowed measurement data to be processed and analysed conveniently.

STAND DEVELOPMENT

Stem Numbers

Introduction - Stocking was not a feature in control of the study but the number of stems was useful in checking records after thinning adjustment (Fig. 2) to ensure all relevant measurements were recorded. In both trials a few trees died.

Stand Density - Stocking in the 37 m^2 ha^{-1} treatment of the Gnangara trial ranged from 1700 s ha^{-1} to 675 s ha^{-1} over the study period (Table 4). For the lowest stand densities it ranged from 413 (11 m^2 ha^{-1}) and 253 (7 m^2 ha^{-1}) at age 19 years to 80 and 48 s ha^{-1} respectively, at age 38 years.

For the Select Crop of 100 s ha^{-1} the basal area exceeded the 7 m^2 ha^{-1} class limit by age 25.5 years and progressive reduction of stems was required to maintain the treatment values. At Yanchep all density treatments contained 100 s ha^{-1} selects except the 7 m^2 ha^{-1} treatment which was reduced to 85 s ha^{-1} following the thinning at age 24 years (Fig. 2).

Site Class - Total stem numbers for the mean stand for all density classes, varied by 30 per cent from the poorest (338 s ha^{-1}) site class to the best (Table 4).

Mortalities. - Tree deaths recorded in the Gnangara trial were restricted to the two highest stand density classes (Table 5). At Yanchep 25 deaths ha^{-1} occurred in each of two of the 25 m^2

1Unpublished report.

ha^{-1} treatment plots at stand age 26.5 years. Both plots were in the site class 4. The major mortality at both centres was associated with the drought in 1978.

TABLE 5

Number of tree deaths per hectare recorded during the Gnangara trial. Data is presented as total deaths for different years within each stand density treatment and total deaths for each site class for each density treatment.

Density Class	Age in years 25.5	27.5	31.5	32.5	All	Site class 1	2	3	4	5	All
7	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
25	0	0	101	50	152	51	0	25	76	0	152
37	25	25	102	25	178	0	0	102	0	76	178
All	25	25	203	76	330	51	0	127	76	76	330

Table 6

Diameter over bark at breast height for the Gnangara trial over the measurement and thinning period. The data, prior to thinning adjustment, are summarised within stand density and site classes and expressed for both the total stand (All) and the select crop (SC) trees.

Date	1965		1970		1974		1979		1984	
Stand	All	SC	All	SC	All	SC	All	SC	All	SC
Treat	Mean diameter (cm)									
7	19.0	19.8	26.7	27.6	34.5	35.3	45.1	46.0	55.0	55.0
11	18.6	19.7	24.9	25.9	31.2	31.7	39.3	39.9	47.8	47.9
16	17.6	18.9	22.1	23.7	26.7	28.2	33.5	34.6	40.8	41.8
25	16.9	18.9	20.2	22.5	23.6	25.6	28.1	29.6	32.6	34.5
37	16.7	19.8	19.1	22.9	21.6	25.5	24.7	28.6	27.9	32.4
Block	Mean diameter (cm)									
1	19.2	20.6	24.7	26.3	29.6	31.2	36.4	37.6	42.9	44.4
2	18.4	20.0	23.4	25.5	28.6	31.0	35.9	38.2	43.6	45.5
3	17.8	19.3	22.8	24.5	27.8	29.4	35.4	36.8	42.5	43.6
4	17.6	18.9	22.0	23.5	27.0	28.0	32.9	34.1	39.3	40.6
5	15.9	18.3	20.2	22.9	24.6	26.9	30.1	32.0	35.8	37.5
Age	19.0 year		23.8 year		27.5 year		32.5 year		37.5 year	

Stand Diameter.

Stand Density - Differences in stem diameter between treatment classes for both the total stand and the Select Crop trees were marked (Table 6, Fig. 3). The mean diameter for the stand at age 38 years at Gnangara was 27.9 cm for the 37 m^2 ha^{-1} treatment compared to 55.0 cm for the 7 m^2 ha^{-1} treatment. At the same time in the 37 m^2 ha^{-1} treatment the diameter of the Select Crop was 16 per cent greater than the average for the total stand. Mean diameter of the Select Crop in the 7 m^2 ha^{-1} stand density was 97 per cent greater than the mean stand value for the densest treatment.

Site Class - Site class strongly influenced diameter development (Table 6) resulting in 18 per cent greater diameter in the mean Select Crop tree, over the range of sites, at age 38 years.

Regressions for Plot Data - Regression of stand diameter against BAob and mean Select Crop height (SCHt) for the Yanchep plot data provided the relationship

$$DOB(cm) = -\ 4.62 - 0.373\ BAob(m^2\ ha^{-1}) + 2.11\ SCHt(m)$$

$R^2 = 92.2$, s = 2.1 cm, n = 720.

For the Gnangara data the relationship was

$$DOB(cm) = -\ 15.6 - 0.541\ BAob(m^2\ ha^{-1}) + 2.75\ SCHt(m)$$

$R^2 = 88.3$, s =3.5 cm, n = 650.

Combining the data marginally improved the fit for the Gnangara size classes but was poorer for the Yanchep trees. Values used in the regression for diameter in the heaviest thinned plots (7 m^2 ha^{-1}) at the inception of the trials have no previous benefit from the thinning and hence are lower than values estimated from regression which reflect accelerated diameter growth, with reduced competition, as the stands develop.

Regressions for mean diameter of the Select Crop (SCDOB) were

$$SCDOB(cm) = -\ 2.93 - 0.288\ BAob(m^2\ ha^{-1}) + 2.01\ SCHt(m)$$

with $R^2 = 91.9$, s = 1.9 for Yanchep and

$$SCDOB(cm) = -\ 18.7 - 0.425\ BAob(m^2\ ha^{-1}) + 2.86\ SCHt(m)$$

with $R^2 = 87.3$, s = 3.5 for Gnangara.

Basal Area Over Bark

Stand Density - Basal area values for the whole stand in Table 7 are prior to thinning adjustment and hence exceed the prescribed level. At each thinning the basal area was adjusted to approximately 5 per cent below the prescribed value to compensate for growth prior to the next thinning.

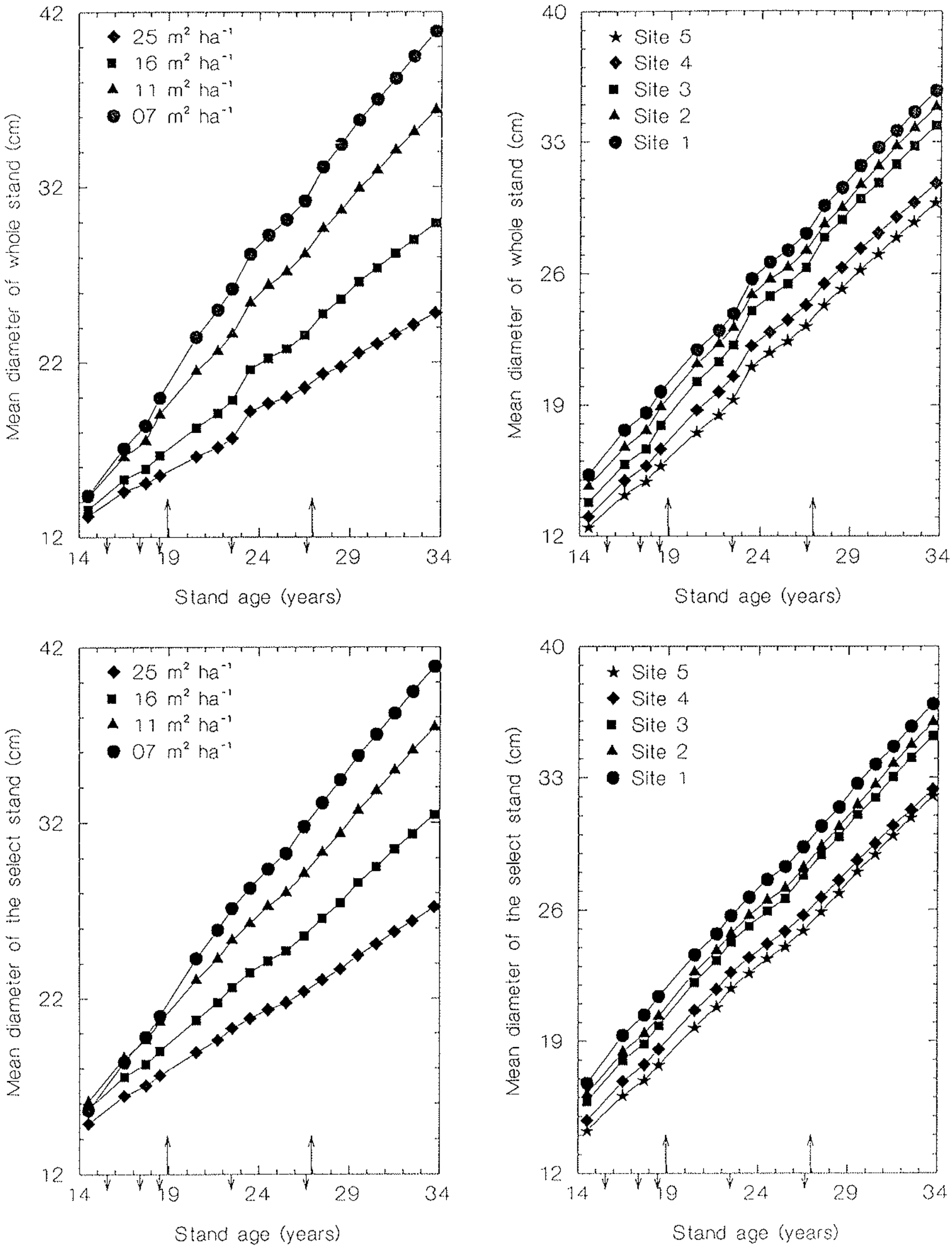


Figure 3. Variation in diameter with density treatment and site class of the whole and select stands at Yanchep. Upright arrows on the horizontal axis depict fertiliser events and downward arrows depict thinning events.

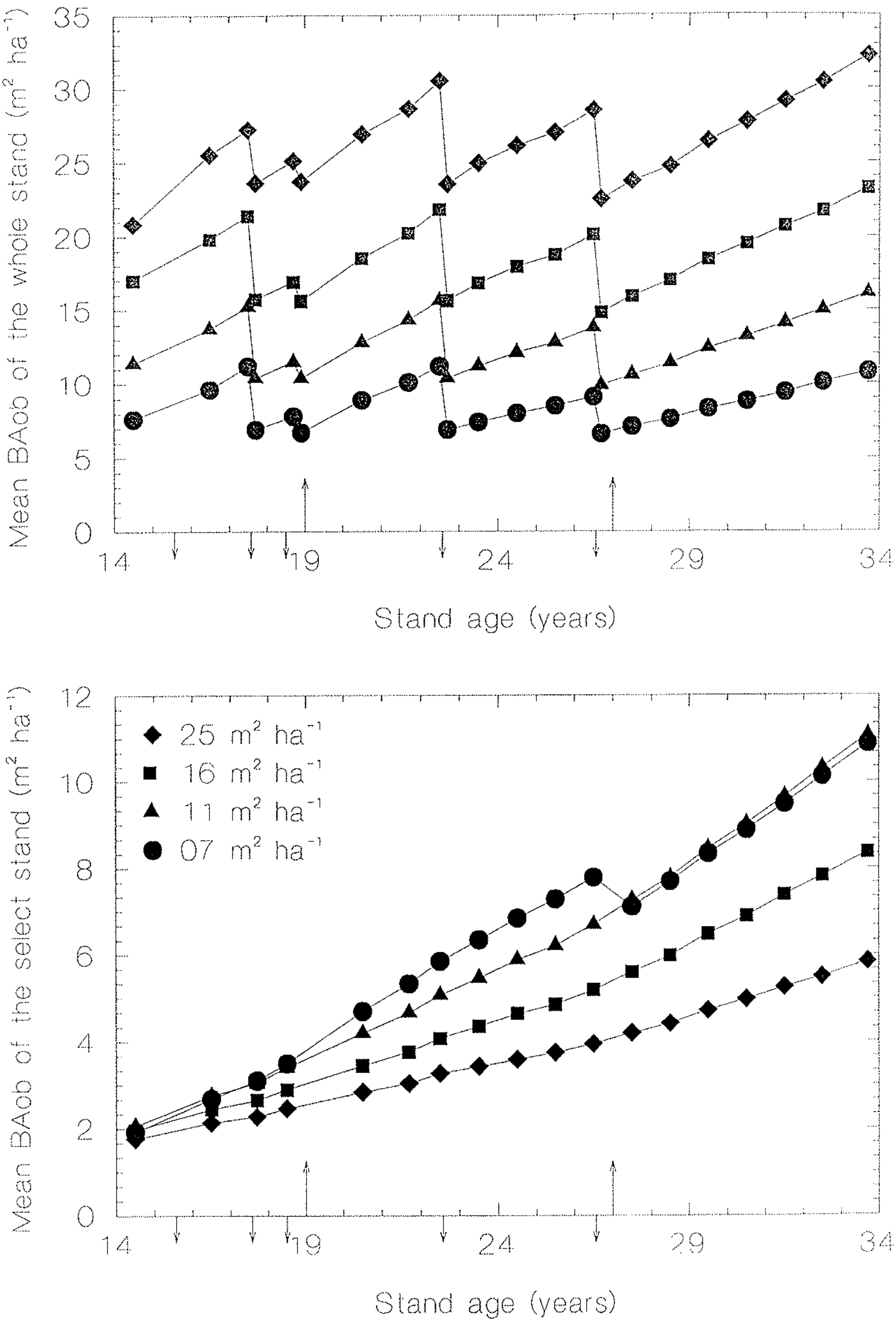


Figure 4. Basal area development of the whole stand and select stand within density classes at Yanchep. The small downwards pointing arrows on the horizontal axis show major thinning events and the upward pointing arrows show fertiliser events.

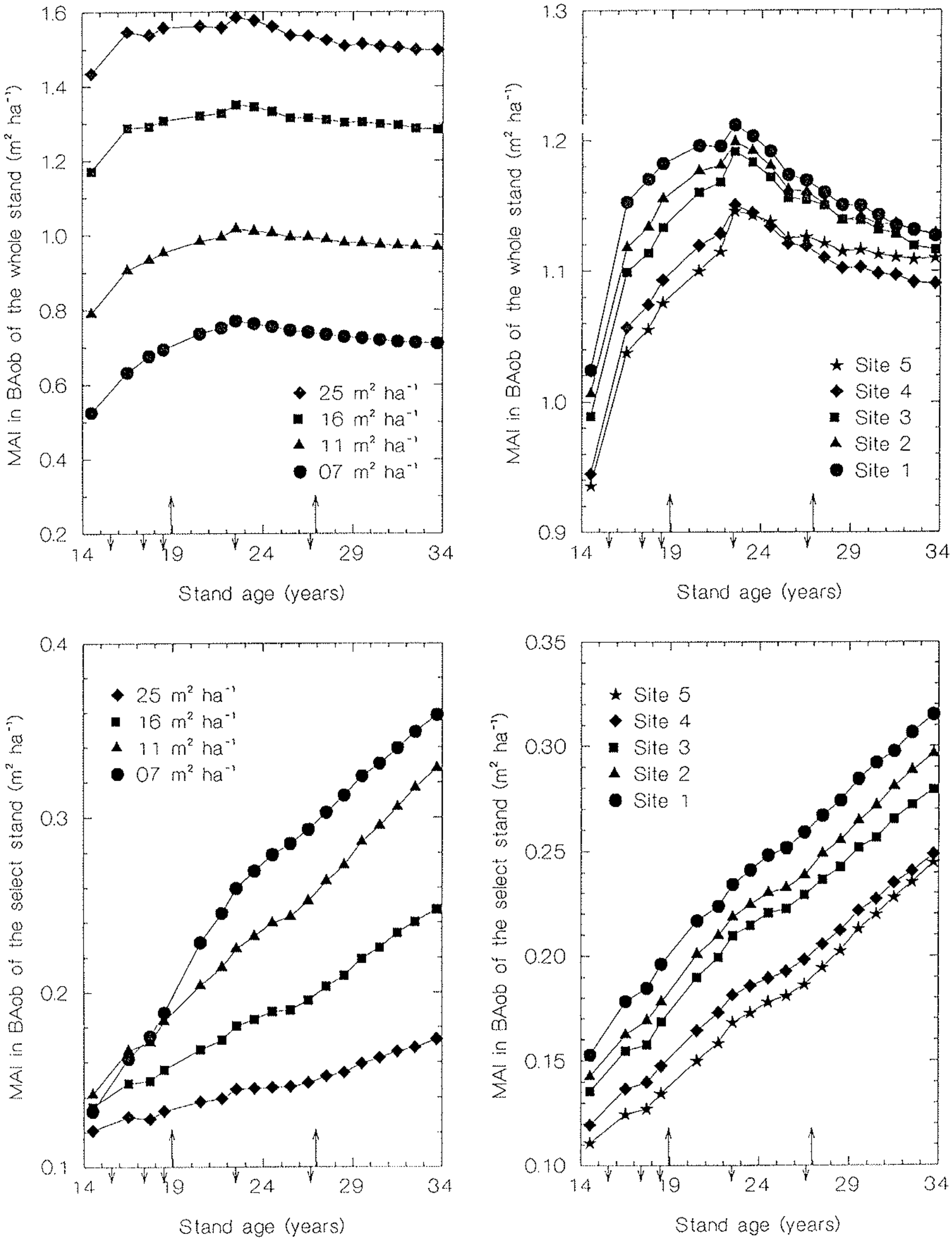


Figure 5. Variation in the mean annual increment in basal area with stand density and site class for the whole stand and select stand at Yanchep. The small downwards pointing arrows on the horizontal axis show major thinning events and the upward pointing arrows show fertiliser events.

The control of stand density achieved until thinning ceased in 1980 separated density classes with about a 10 per cent overestimate in the 7, 11 and 16 m^2 ha^{-1} treatments (Table 8). Separation between treatment groups was satisfactory (Fig. 4).

Total basal area (including that removed by thinning) production was favoured by increasing stand density class and was lowest in the heavily thinned stands over the study period (Table 7, Fig. 5). At Gnangara, on the best site class, the mean total basal area produced by the density class 37 m^2 ha^{-1}, established at age 19, was 72 m^2 ha^{-1} at age 38 years.

Basal area development of the Select Crop responded strongly to decrease in density in the surrounding stand (Table 7, Fig. 5) and for the lowest density classes required removal of Select Crop trees to maintain the prescribed densities.

Site Class - Adjustment of the basal areas and plot allocation ensured that mean basal areas for each site class were similar at any one time (Table 7).

TABLE 7

Distribution of BAob within the total stand (All) and select crop (SC) for critical measurements in the Gnangara trial. Values summarised into stand density treatments and site class Blocks are prior to thinning adjustment and are in square metres per hectare.

Date	1965		1970		1974		1979		1984	
Stand	All	SC	All	SC	All	SC	All	SC	All	SC
Treat	Basal area (m^2 ha^{-1})									
7	7.2	3.1	11.3	6.0	9.1	7.0	9.8	7.7	11.0	11.0
11	11.1	3.0	15.3	5.3	13.2	7.0	13.0	6.7	14.3	14.0
16	17.1	2.8	21.1	4.4	18.6	6.3	19.2	4.5	21.4	13.9
25	25.8	2.8	28.9	4.0	26.6	5.2	25.8	7.0	29.3	9.5
37	37.6	3.1	40.8	4.2	39.3	5.2	38.3	6.5	41.3	8.4
Site	Basal area (m^2 ha^{-1})									
1	19.9	3.3	23.8	5.4	21.6	7.2	21.1	5.0	24.3	12.7
2	20.1	3.1	23.9	5.1	21.4	6.8	21.9	7.5	23.6	12.0
3	19.8	2.9	23.6	4.8	21.9	5.5	20.7	7.2	23.4	11.5
4	19.5	2.6	22.9	4.1	20.6	5.3	21.3	6.9	22.7	9.5
5	19.5	2.6	22.9	4.1	20.6	5.3	21.3	6.9	22.7	9.5
Age	19.0 year		23.8 year		27.5 year		32.5 year		37.5 year	

TABLE 8.

Mean values for total basal area (m^2 ha^{-1}) of density treatments obtained before (BT) and after (AT) thinning during the trials at Gnangara and Yanchep. The last thinning was carried out in 1979 and the stands were left to increase after that date.

Gnangara				Yanchep			
Density	BT	AT	Mean	Density	BT	AT	Mean
7	9.17	7.36	8.27	7	9.16	7.11	8.13
11	13.13	10.61	11.87	11	13.32	10.78	12.05
16	18.99	15.89	17.45	16	19.38	16.07	17.73
25	26.87	23.76	25.31	25	26.35	23.33	24.85
37	39.04	35.63	37.34				

Mean Annual Increment

The record for mean annual increment was commenced for the stands after the initial thinning at age 19.5 years at Gnangara and at 14.5 years at Yanchep. 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 and 25 m^2 ha^{-1} at Yanchep approximate the increment for unthinned stands at time of plot selection for each location.

Density - For the first five years at both centres mean increment tended to increase with age for all density classes (Table 9, Fig. 5). With further development at Gnangara, increment plateaued at age 29.5 years to provide a small increase, or nil increase with time for the 7, 11, and 16 m^2 ha^{-1} treatments. The denser treatments plateaued earlier, at age 25.5 years for the 25 m^2 ha^{-1} treatment and at 23.8 years for the 37 m^2 ha^{-1} treatments. Thereafter they decreased in MAI due to stand mortalities (Table 9). At Yanchep the means for all density classes decreased in the latter stand ages (Fig. 5).

For the 100 ha^{-1} select stems of the stand, mean increment continued to increase with stand age for the duration of both trials (Table 9, Fig. 5). The influence of reduced competition with decreasing stand density class was strong and at the termination of both trials the mean increment in the 7 m^2 ha^{-1} class doubled that of the least thinned treatment.

Site Class- Following the initial thinning mean increment increased for the whole stand on all sites to maxima at age 30 years at Gnangara (Table 9) and 22 years at Yanchep (Fig. 5).

TABLE 9

Mean annual increment in basal area over bark (m^2 ha^{-1}) for the whole stand and the select stand at Gnangara. Means for stand density and site classes are included.

Age	Stand Density					Site Class				
	7	11	16	25	37	1	2	3	4	5
					Whole stand					
19.0	0.37	0.58	0.90	1.35	1.97	1.04	1.05	1.04	1.02	1.01
20.6	0.43	0.65	0.96	1.40	2.01	1.11	1.11	1.10	1.07	1.07
21.8	0.50	0.72	1.01	1.43	2.01	1.16	1.15	1.14	1.10	1.11
23.8	0.56	0.77	1.06	1.44	1.97	1.20	1.18	1.17	1.13	1.12
25.5	0.59	0.81	1.09	1.47	1.98	1.23	1.22	1.20	1.15	1.15
26.5	0.60	0.83	1.10	1.47	1.66	1.23	1.22	1.20	1.16	1.14
27.5	0.60	0.84	1.12	1.47	1.97	1.24	1.23	1.24	1.17	1.13
29.5	0.62	0.87	1.16	1.48	1.93	1.26	1.25	1.23	1.18	1.14
30.5	0.63	0.87	1.16	1.48	1.93	1.26	1.25	1.23	1.19	1.14
31.5	0.63	0.87	1.15	1.46	1.89	1.24	1.23	1.22	1.18	1.13
32.5	0.63	0.86	1.15	1.44	1.85	1.23	1.23	1.20	1.16	1.12
33.6	0.62	0.86	1.15	1.42	1.84	1.22	1.22	1.19	1.15	1.11
34.5	0.63	0.86	1.15	1.42	1.82	1.22	1.22	1.19	1.15	1.10
35.5	0.63	0.87	1.17	1.43	1.83	1.23	1.23	1.20	1.16	1.11
36.5	0.63	0.87	1.17	1.43	1.82	1.23	1.23	1.20	1.16	1.11
37.5	0.63	0.86	1.17	1.43	1.82	1.23	1.22	1.19	1.16	1.11
38.5	0.63	0.86	1.17	1.42	1.81	1.22	1.22	1.19	1.16	1.10
					Select Stand.					
19.0	0.16	0.16	0.15	0.15	0.16	0.17	0.16	0.15	0.14	0.13
20.6	0.18	0.18	0.16	0.15	0.17	0.19	0.18	0.17	0.16	0.15
21.8	0.22	0.20	0.17	0.16	0.17	0.21	0.20	0.18	0.17	0.16
23.8	0.25	0.22	0.18	0.16	0.17	0.23	0.21	0.20	0.18	0.17
25.5	0.29	0.25	0.20	0.18	0.18	0.25	0.24	0.22	0.20	0.19
26.5	0.28	0.26	0.21	0.18	0.18	0.26	0.24	0.23	0.20	0.18
27.5	0.33	0.29	0.23	0.18	0.18	0.28	0.26	0.25	0.23	0.20
29.5	0.36	0.33	0.27	0.20	0.19	0.31	0.29	0.29	0.25	0.22
30.5	0.38	0.35	0.28	0.22	0.20	0.32	0.31	0.30	0.27	0.24
31.5	0.39	0.36	0.29	0.22	0.20	0.32	0.31	0.30	0.27	0.24
32.5	0.38	0.37	0.30	0.22	0.20	0.33	0.31	0.31	0.28	0.25
33.6	0.41	0.38	0.31	0.24	0.21	0.34	0.33	0.33	0.29	0.26
34.5	0.42	0.40	0.33	0.24	0.21	0.35	0.34	0.34	0.30	0.27
35.5	0.43	0.41	0.35	0.25	0.22	0.36	0.35	0.35	0.31	0.28
36.5	0.44	0.43	0.37	0.26	0.22	0.37	0.36	0.36	0.32	0.28
37.5	0.44	0.43	0.38	0.27	0.23	0.38	0.37	0.37	0.33	0.29
38.5	0.44	0.44	0.39	0.27	0.23	0.39	0.37	0.37	0.34	0.29

The further decline with increasing stand age was slight at Gnangara but considerable at Yanchep (Fig. 5). Analysis of variance (Tables 10, 11) showed that although mean increment for the whole stand was strongly associated with site class at Gnangara from age 24 years onwards, at Yanchep, except for several years after trial establishment, there was only a weak asssociation between increment and site (Table 11).

TABLE 10

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 closely associated with site class in both trials (Tables 10 and 11). It increased at a steady rate for all site classes over the course of the trials, at both centres (Table 9, Fig. 5).

Fertiliser - At Gnangara the two fertiliser additions gave a highly significant effect for the F2 treatment for mean increment of the whole stand (Tables 10 and 12). The effect on the Select Crop was less and largely related to the influence of the second addition at 34 and 35 years of age (Table 10, Fig. 6). At Yanchep the response in mean annual increment of the whole stand to fertiliser was slight but generally present after stand age 22.5 years (Table 11, Fig. 6). Within the Select Crop little fertiliser influence was noticeable in the mean increment (Table 12, Fig. 6). Fertiliser addition had a significant effect (0.05 level) only for stand ages 29.5 to 31.5 (Table 11).

Generally, fertiliser was less important as a stimulant of mean increment at Yanchep than at Gnangara, particularly as the response recorded at Gnangara was that of doubling a base level known to be essential to the crop. At both locations the impact was mainly on the whole crop rather than on the dominant portion (the Select Crop) of the stand (Tables 10 and 11).

TABLE 11

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.

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

Current Annual Increment

Stand Density - Current increment in basal area for the whole stand increased with increasing stand density treatments 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 at Gnangara (Table 13). This sequence continued, with the regular maintenance of the treatment stand densities, throughout the life of both trials (Fig 7, Table 13). Differences between stand densities were highly significant at all stages (Tables 14, 15). Treatment responses varied greatly between years (Fig. 7) depending on the length and nature of the period between measurements and climatic, fertiliser and stand aging effects. The pattern of variation was consistent between stand densities in any one year (Fig. 7).

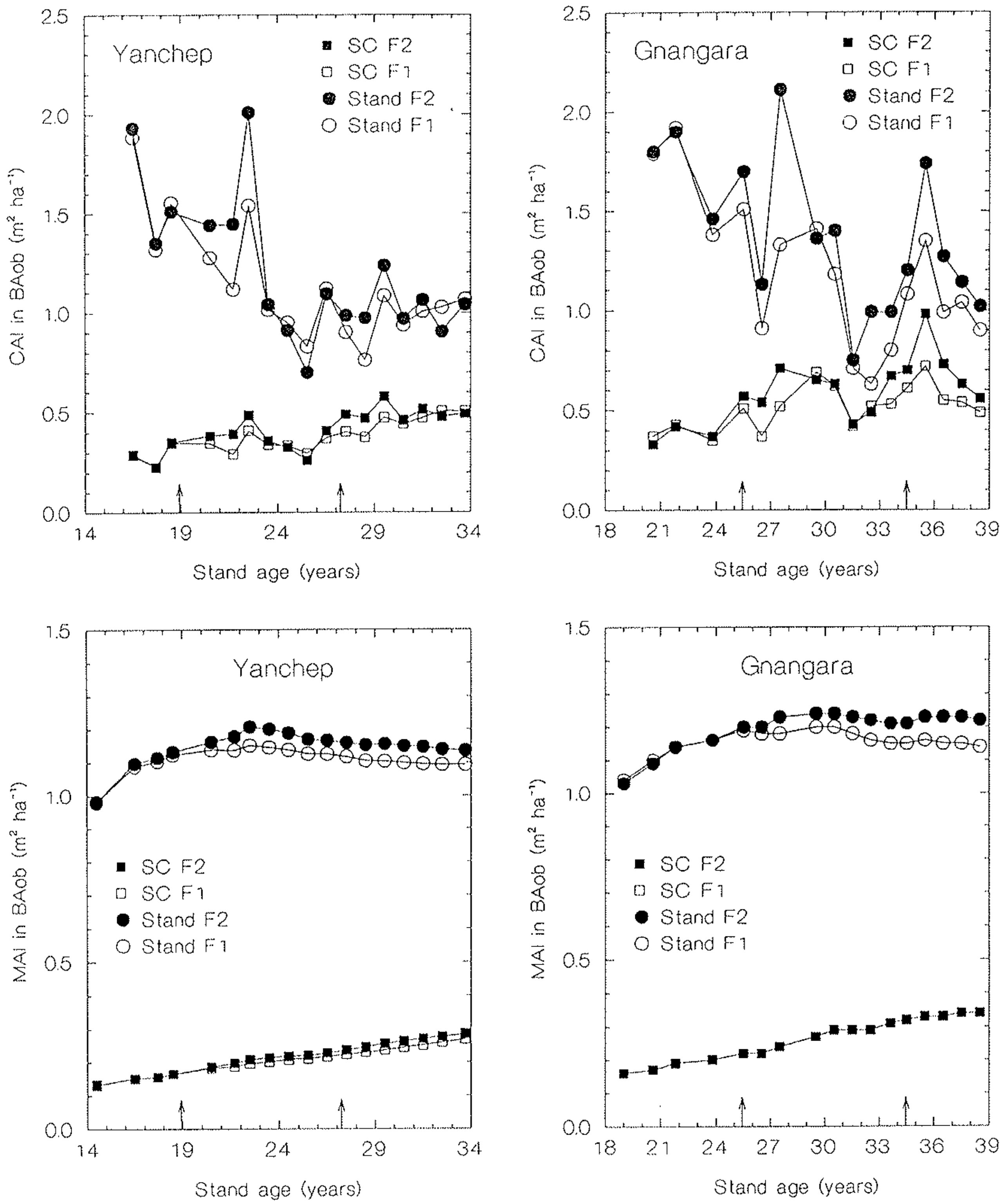


Figure 6. Response in the mean annual increment and current annual increment in basal area to fertiliser for both the whole stand and the select crop at Yanchep and Gnangara. The arrows on the horizontal axis mark fertiliser events.

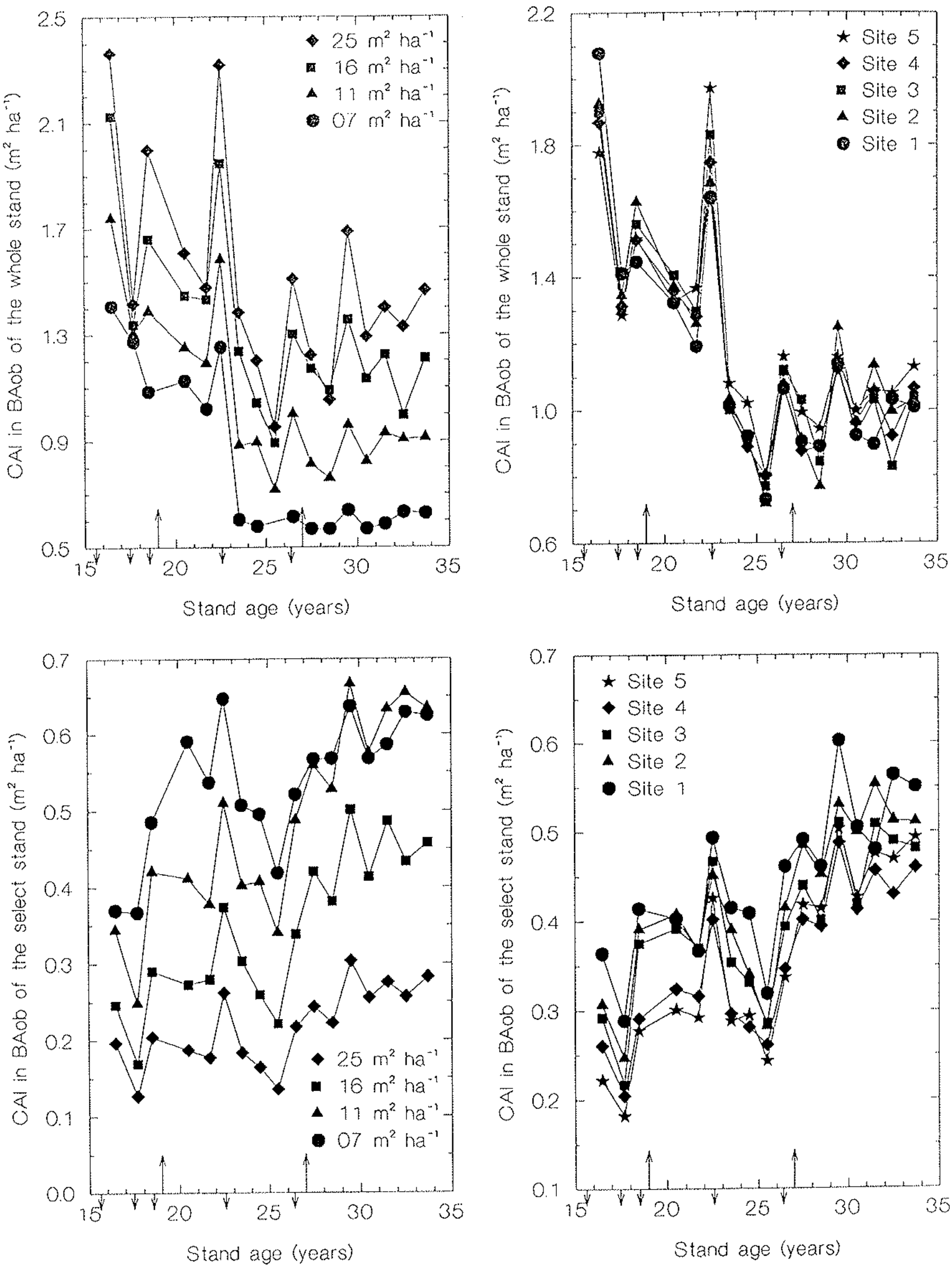


Figure 7. Variation in current annual increment in basal area of the whole stand and select stand with stand density treatments and site classes at Yanchep. The small downwards pointing arrows on the horizontal axis show major thinning events and the upward pointing arrows show fertiliser events.

Annual increment for the Select Crop was the reverse of that for the whole stand, increasing with decreasing stand density as a result of the varying release of a fixed number of the best trees (Table 13). Results were similar for both trials (Fig. 7) and the pattern was consistent for all density classes each year. Response to the artificially maintained density classes was highly significant each year (Tables 14, 15). The trend of results (Table 13, Fig. 7) recorded some relative decreases in the increment of the Selects in the lowest density classes, in the later stages of the trial. This was due to the decrease in the number of select crop trees (Table 4, Figs. 2, 3, 4) resulting from thinning to maintain the stand density treatments.

TABLE 12

Mean annual increment and current annual increment in basal area over bark (m^2 ha^{-1}) for fertiliser treatments for the whole stand and select crop at Gnangara.

	MAI BAob (m^2 ha^{-1})					CAI BAob (m^2 ha^{-1})			
Age	Whole stand		Select crop		Age	Whole stand		Select crop	
	F1	F2	F1	F2		F1	F2	F1	F2
19.0	1.04	1.03	0.16	0.16					
20.6	1.09	1.09	0.17	0.17	20.6	1.79	1.80	0.37	0.33
21.8	1.14	1.13	0.19	0.19	21.8	1.92	1.90	0.43	0.42
23.8	1.16	1.16	0.20	0.20	23.8	1.38	1.46	0.35	0.37
25.5	1.18	1.19	0.22	0.23	25.5	1.51	1.70	0.51	0.57
26.5	1.18	1.20	0.22	0.23	26.5	0.91	1.13	0.37	0.54
27.5	1.18	1.22	0.24	0.26	27.5	1.33	2.11	0.52	0.71
29.5	1.19	1.23	0.27	0.28	29.5	1.41	1.36	0.69	0.65
30.5	1.19	1.24	0.29	0.30	30.5	1.18	1.40	0.62	0.63
31.5	1.18	1.22	0.29	0.30	31.5	0.71	0.75	0.42	0.43
32.5	1.16	1.22	0.29	0.31	32.5	0.63	0.99	0.52	0.49
33.6	1.15	1.21	0.31	0.32	33.6	0.80	0.99	0.53	0.67
34.5	1.14	1.21	0.32	0.33	34.5	1.08	1.20	0.61	0.70
35.5	1.15	1.22	0.33	0.35	35.5	1.35	1.74	0.72	0.98
36.5	1.15	1.22	0.33	0.36	36.5	0.99	1.27	0.55	0.73
37.5	1.14	1.22	0.34	0.37	37.5	1.04	1.14	0.54	0.63
38.5	1.14	1.22	0.34	0.37	38.5	0.90	1.02	0.49	0.56

Generally, fertiliser was less important as a stimulant of mean increment at Yanchep than at Gnangara. At both locations the impact was mainly on the whole crop rather than on the dominant portion (the Select Crop) of the stand (Tables 10 and 11).

Site Classes - Current annual increments of whole stand for site classes tended to grade downwards from the superior site 1 to the poorest site 5 at Gnangara (Table 13) but the differences were significant on only 5 occasions (Table 14). The differences at Yanchep (Fig. 7) were slight and only significant at the initial increment measurement at age 16.5 years (Table 15).

TABLE 13

Current annual increment in basal area over bark (m^2 ha^{-1}) for the whole stand and select crop at Gnangara. Means for density and site classes are included.

Age	Density					Site Class				
	7	11	16	25	37	1	2	3	4	5
Whole stand										
20.6	1.15	1.57	1.73	2.08	2.46	1.93	1.85	1.85	1.63	1.72
21.8	1.72	1.88	2.00	1.96	1.99	2.12	1.98	1.94	1.76	1.76
23.8	1.17	1.34	1.53	1.50	1.55	1.55	1.51	1.43	1.34	1.25
25.5	1.00	1.38	1.65	1.89	2.13	1.69	1.68	1.62	1.54	1.52
26.5	0.58	0.96	1.09	1.24	1.24	1.09	1.10	1.11	0.96	0.84
27.5	1.10	1.53	1.74	1.66	2.56	1.66	1.60	2.33	1.79	1.20
29.5	0.90	1.23	1.69	1.72	1.36	1.56	1.54	1.21	1.38	1.21
30.5	0.80	0.98	1.37	1.45	1.87	1.27	1.30	1.23	1.55	1.12
31.5	0.63	0.69	0.90	0.78	0.65	0.71	0.75	0.79	0.71	0.69
32.5	0.63	0.74	1.08	0.84	0.78	0.98	1.01	0.47	0.72	0.89
33.6	0.54	0.76	1.01	0.82	1.36	0.79	1.03	1.01	0.84	0.82
34.5	0.70	0.91	1.33	1.37	1.40	1.20	1.25	1.13	1.17	0.96
35.5	0.86	1.09	1.79	1.89	2.09	1.57	1.55	1.59	1.56	1.45
36.5	0.66	0.85	1.27	1.37	1.50	1.21	1.21	1.11	1.17	0.95
37.5	0.55	0.76	1.19	1.37	1.58	1.12	1.05	1.04	1.12	1.12
38.5	0.48	0.66	1.09	1.16	1.42	0.96	0.98	0.99	0.97	0.90
Select crop										
20.6	0.49	0.40	0.33	0.25	0.27	0.39	0.39	0.37	0.28	0.31
21.8	0.75	0.53	0.37	0.25	0.21	0.51	0.45	0.43	0.38	0.35
23.8	0.62	0.47	0.32	0.23	0.17	0.44	0.40	0.37	0.32	0.29
25.5	0.87	0.69	0.49	0.33	0.30	0.60	0.59	0.53	0.51	0.46
26.5	0.80	0.60	0.40	0.26	0.20	0.49	0.46	0.49	0.55	0.27
27.5	0.93	0.91	0.62	0.33	0.29	0.72	0.70	0.64	0.57	0.45
29.5	0.81	0.96	0.88	0.40	0.31	0.74	0.72	0.83	0.62	0.46
30.5	0.80	0.90	0.71	0.40	0.31	0.68	0.70	0.63	0.62	0.48
31.5	0.63	0.63	0.49	0.23	0.14	0.41	0.48	0.45	0.43	0.34
32.5	0.71	0.67	0.56	0.35	0.25	0.55	0.60	0.45	0.53	0.40
33.6	0.79	0.74	0.68	0.43	0.34	0.66	0.52	0.81	0.53	0.47
34.5	0.70	0.89	0.90	0.47	0.30	0.69	0.73	0.66	0.70	0.48
35.5	0.86	1.08	1.16	0.67	0.50	0.89	0.88	0.87	0.87	0.74
36.5	0.66	0.84	0.88	0.48	0.35	0.72	0.69	0.67	0.67	0.46
37.5	0.55	0.75	0.79	0.48	0.36	0.64	0.59	0.59	0.58	0.52
38.5	0.48	0.65	0.74	0.39	0.36	0.56	0.53	0.52	0.58	0.44
	7	11	16	25	37	1	2	3	4	5

Site influenced increment of the Select Crop stand significantly at both trial locations in most years (Tables 13, 14, 15, Fig. 7).

TABLE 14

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 application of fertiliser at Gnangara 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 (Tables 12, 14, Fig. 6). The differences between the F1 and F2 means were significant for three years after treatment for the whole stand (Table 14) and for two years for the Select Crop. Similarly for the second application, split between ages 34.2 and 35.2 years of age, response was immediate and significant for at least three years after the first part application (Tables 12, 14, Fig. 6).

Significant (0.05 level) density by fertiliser interactions were obtained in 1981, 1982 and 1983 for the initial analysis for the Select Crop.

At Yanchep response times to fertiliser additions and residual effects (Table 15, Fig. 6) were similar to those at Gnangara for both the whole stand and the Select Crop. For the Select Crop the density by fertiliser interaction was significant in 1980 and 1986 and approaching significance in 1973, 1974 and 1975 (Table 15).

TABLE 15

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.

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

Height.

Introduction - Mean stand height and the mean height of Select Crop stems (100 ha^{-1}) were determined for all measurements. Predominant height (mean height of the tallest 250 trees ha^{-1}) and top height (mean height of the tallest 75 trees ha^{-1}) were determined for measurements spanning the major development phases of the study period by the 'pine sp' program. For several measurements, particularly in the latter stage of the trials, only Select Crop stems were measured in each plot (Tables 2 and 3). From these data heights of the remaining stems were estimated through regression to allow stand volumes to be calculated.

Stand Density - Mean heights for the stands of different treatment densities (Table 16) are not comparable due to the variable stem numbers and the impact of selective thinning on mean height. Mean height of the Select Crop stems are comparable with allowance that for the lowest stand density on the best sites, the number of select crop stems was reduced in latter stages of the trial (Table 4). At Gnangara the differences in mean Select Crop height with stand density are specifically related to the reduced number of stems remaining in the 7 m^2 ha^{-1} class after the reductions in 1972, 1976 and 1979 (Table 16, Fig. 8). The increase was found to be

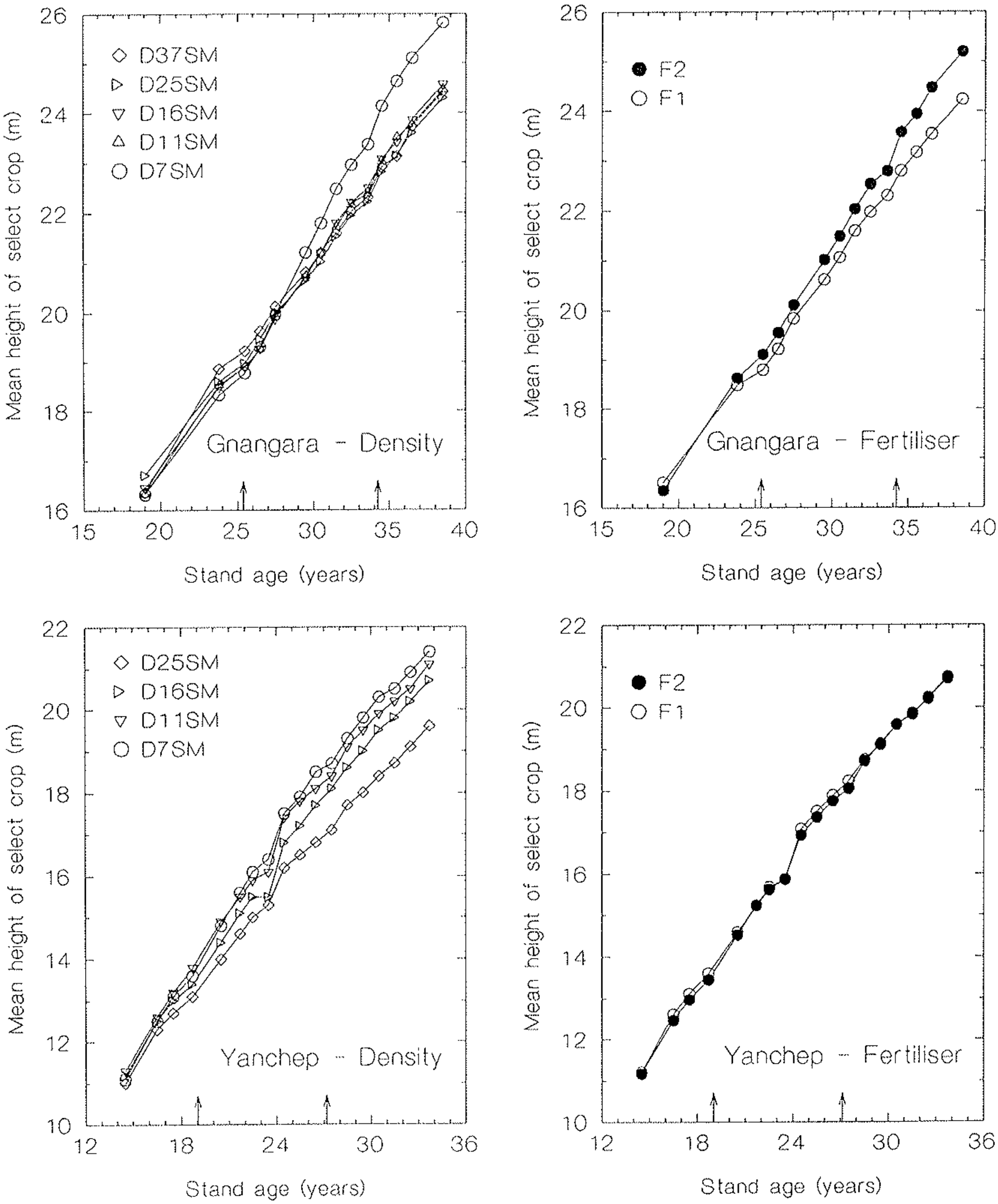


Figure 8. Development of mean height of the Select Crop trees within stand density and fertiliser classes at Gnangara (Top) and Yanchep (Bottom). The arrows on the horizontal axis mark fertiliser events.

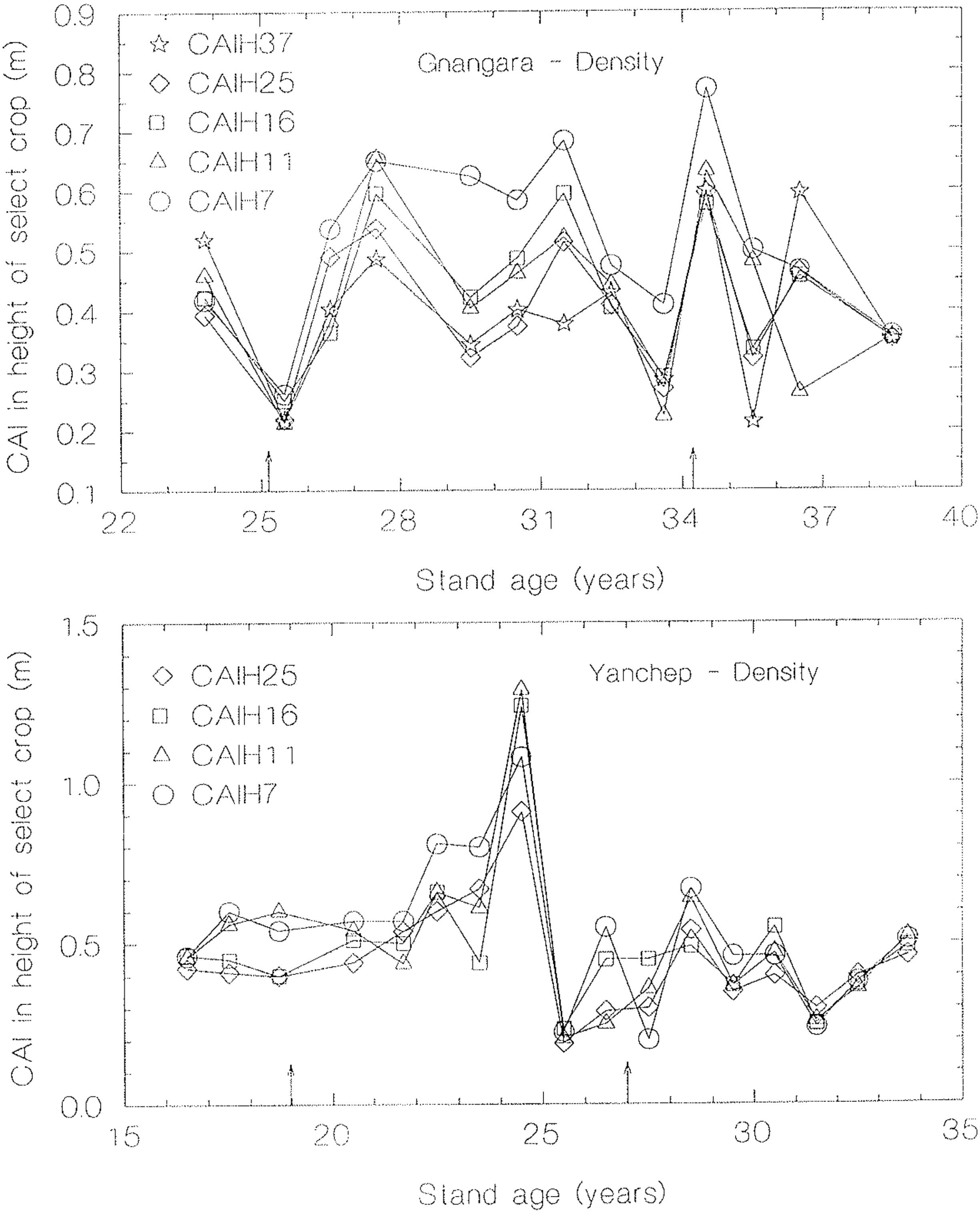


Figure 9. Current annual increment in height of Select Crop trees within stand density classes at Gnangara (top) and Yanchep (bottom). Fertiliser events are marked by arrows on the horizontal axis.

significant at the .08 level at age 32.6 (Table 17) by which time the 7 m^2 ha^{-1} treatment had been reduced to only 48 s ha^{-1} (Table 4). At Yanchep, however, the treatment height means increased with decreasing stand density with continued stand development (Fig. 8). Analysis of variance (Table 18) showed the effect of stand density to be highly significant from stand age 18.5 years (4 years after the initial thinning) for mean Select Crop height. This occurred prior to any removals of the Select Crop in the lowest density classes.

TABLE 16

Distribution of mean heights (m) within the stand (All) and select crop (SC) for critical measurements in the Gnangara trial. The means, summarised into Stand Density and Site Classes, are the values prior to thinning adjustment.

Date	1965		1970		1974		1979		1984	
Stand	All	SC	All	SC	All	SC	All	SC	All	SC
Treat	Mean height (m) for density class									
7	16.2	16.3	18.1	18.3	19.8	20.1	22.9	23.0	25.1	25.1
11	16.0	16.3	18.2	18.5	19.7	19.9	22.1	22.1	24.0	24.0
16	16.0	16.4	18.0	18.4	19.6	19.8	21.8	22.2	23.8	24.1
25	16.0	16.7	17.8	18.6	19.4	20.0	21.6	21.9	23.2	23.8
37	15.6	16.3	17.7	18.8	19.3	20.1	21.2	22.0	23.0	23.9
Block	Mean height (m) for site class									
1	17.2	17.5	19.6	19.7	20.8	21.0	23.0	23.2	24.7	25.0
2	16.6	17.5	19.6	19.7	20.8	21.0	23.0	23.2	24.7	25.0
3	15.8	16.1	17.8	18.4	19.4	19.8	22.1	22.4	24.0	24.2
4	16.2	16.6	18.0	18.5	19.6	20.0	21.7	21.9	23.7	24.1
5	13.8	14.5	16.0	16.7	17.7	18.3	20.0	20.4	21.9	22.3
Age	19.0	year	23.8	year	27.5	year	32.5	year	37.5	year

Removals in the Select Crop after age 27 years favoured this discrepancy as the mean in the lowest density stands is derived from only the 75 or 50 best trees per hectare rather than the 100 Select Crop stems in the other plots. The development trend for the Select Crop means over the progress of the trial (Fig. 8) revealed that improvement in Select Crop height, with decreasing density, was present in all classes, including the 11 and 16 m^2 ha^{-1} densities which retained the original total of Select Crop stems.

Increment data for select crop height (Table 17, Fig. 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. As explained, 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 17).

TABLE 17

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

For Yanchep (Fig. 9, Table 18) highly significant differences between density treatment increment during the period 16.5 to 18.5 years result from increased growth in the two lowest density classes. Significant differences in increment to age 26.5, 31.5 and 33.7 years were again associated with better growth in the thinned rather than the unthinned stands.

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. For Yanchep, the trend was similar to that of the mean for the Select Crop trees (Fig. 8), and the density effect was highly significant from the measurement at age 25 onwards.

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 (Fig. 8). 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 increment, the periods 15 to 24 years, 32.5, 34.5 and 35.5 years onwards registered significant fertiliser effects (Table 17).

TABLE 18

Probabilities that mean values for density class, site class and fertiliser response obtained for height of the select crop and current annual increment in select crop height at Yanchep 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.
14.5	0.886	0.000	0.845			
16.5	0.447	0.000	0.333	0.808	0.383	0.291
17.7	0.121	0.000	0.324	0.003	0.956	1.000
18.5	0.011	0.000	0.282	0.002	0.433	0.802
20.5	0.001	0.000	0.659	0.105	0.147	0.236
21.7	0.000	0.000	0.942	0.049	0.292	0.300
22.5	0.000	0.000	0.700	0.681	0.678	0.454
23.5	0.002	0.000	0.963	0.221	0.556	0.868
24.5	0.000	0.000	0.373	0.353	0.585	0.330
25.5	0.001	0.000	0.379	0.114	0.653	0.856
26.5	0.000	0.000	0.422	0.034	0.032	0.897
27.5	0.000	0.000	0.304	0.072	0.562	0.495
28.5	0.001	0.000	0.825	0.378	0.373	0.097
29.5	0.001	0.000	0.892	0.059	0.085	0.810
30.5	0.001	0.000	0.981	0.758	0.181	0.840
31.5	0.002	0.000	0.845	0.023	0.001	0.016
32.5	0.001	0.000	0.879	0.363	0.176	0.525
33.7	0.001	0.000	0.873	0.026	0.047	0.479
DF	3	4	1	3	4	1

Fertiliser application at Yanchep had no significant effect on standing height (Fig. 8, Table 18). Differences between fertiliser treatments for increment of the select crop were only significant for the 30.5 to 31.5 age period. This resulted from the increment of the control, non-fertilised treatment being greater than that of the fertilised treatments and had no association with time of fertiliser application.

Site index. - Height-age curves plotted for both the Gnangara and the Yanchep data sets and examination of subsets regressions of height values with site and age data showed excellent fit for Yanchep and good fits for Gnangara. Height data at age 19 years of age was common to both data sets and the nominal (1 to 5) site values in the original regression sets were replaced by the site values at age 19 years (SI19). Heights were also transformed to square root and natural log and examined for homoscedasticity and reduction in the deviations. Results for all transforms were similar with possibly the log values providing most satisfactory homoscedasticity. Non transformed values only are provided to indicate the extent of the error term involved in the relationships.

The regression equation for Gnangara is

SCHTGN = - 5.60 + 0.827 SI19 + 0.436 Age

s = 0.8558 R^2(adj) = 89.6% n = 700.

The regression equation for Yanchep is

SCHTY = - 11.0 + 1.09 SI19 + 0.498 Age

s = 0.4922 R^2(adj) = 97.3% n = 720.

TABLE 19.

Best subsets regression relating mean select stand height with trial location, stand density, site class, stand age and fertiliser treatment.

Response is Log(Select crop height).

Vars	R^2	Adj. R^2	C-p	s	Location	Density	Site	Fert	Age	I/Age	SI19	SI19/Age
1	83.1	83.0	9379.2	0.0843						X		
1	82.4	82.4	9797.7	0.0859					X			
2	96.3	96.3	962.0	0.0395						X		X
2	96.2	96.2	1002.3	0.0399						X	X	
3	97.3	97.3	320.3	0.0338					X	X		X
3	96.6	96.6	758.8	0.0378					X	X	X	
4	97.5	97.5	192.8	0.0325		X			X	X		X
4	97.5	97.5	203.3	0.0326			X		X	X		X
5	97.7	97.6	89.0	0.0314		X	X		X	X		X
5	97.6	97.6	116.8	0.0317		X		X	X	X		X
6	97.8	97.8	18.2	0.0306		X	X	X	X	X		X
6	97.7	97.7	77.8	0.0313	X	X	X		X	X		X
7	97.8	97.8	11.0	0.0305	X	X	X	X	X	X		X
7	97.8	97.8	19.1	0.0306		X	X	X	X	X	X	X
8	97.8	97.8	9.0	0.0305	X	X	X	X	X	X	X	X

The two data sets overlap, Yanchep covering site indices at age 19 years from 12 m to 14.5 m and Gnangara covering indices from 15 m to 18.5 m. Both data sets were combined and the best subsets regression for the natural log transform of the height data is shown in Table 19. Again there was little alteration in the variation explained by regression between the arithmetical values and the square root or log transform but the log data and the reciprocal appeared to have improved homoscedasticity.

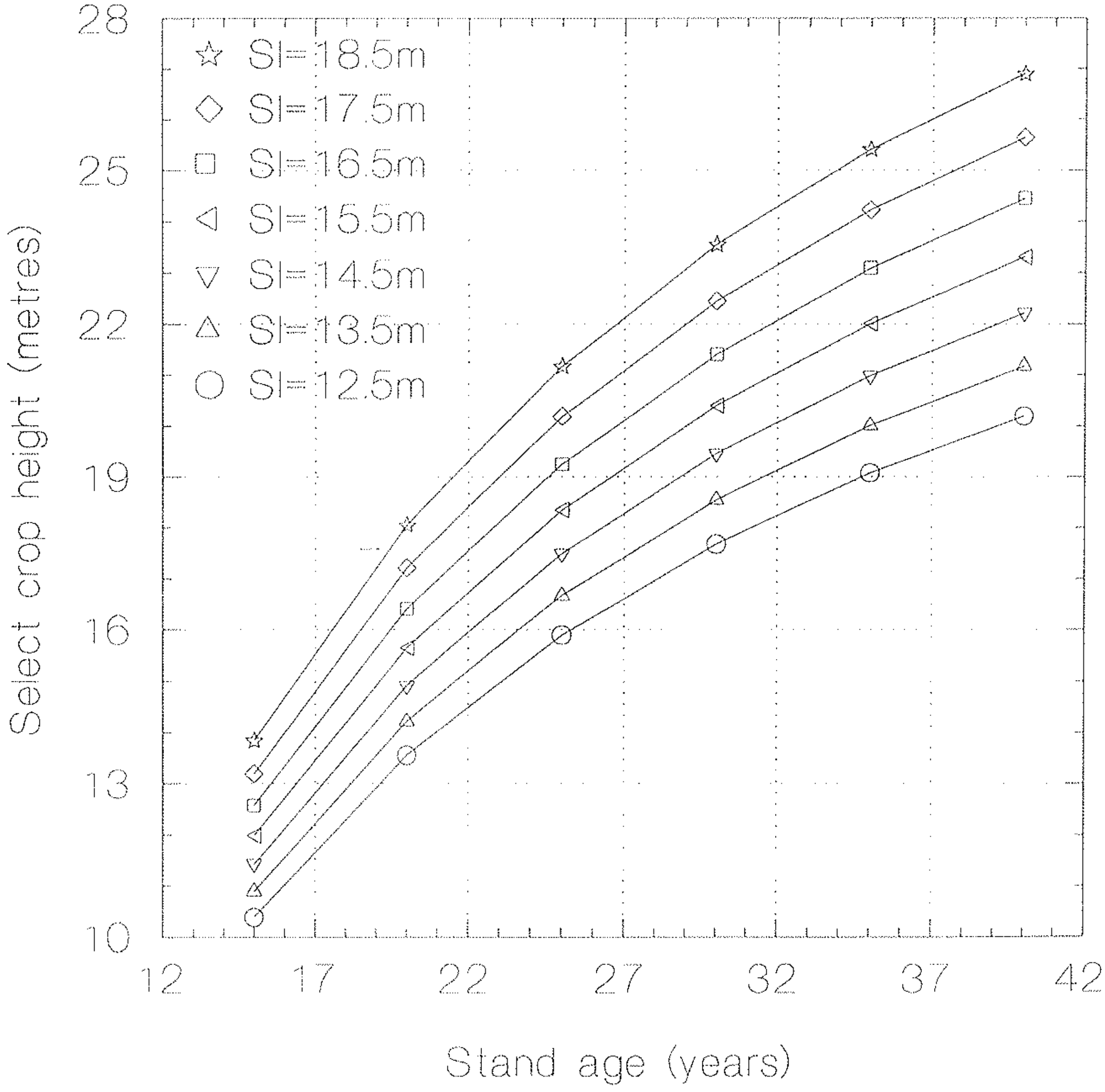


Figure 10. Site index relationships for combined data from both trials. Lines refer to one metre Site Index classes based on the mean height of the 100 best stems per hectare at age 19 years. The measurement range is from 14 to 40 years.

Relevant regressions calculated for Select crop height are as follows.

The regression equation is

SCHeight = - 7.05 + 0.464 Age + 0.867 SI19

s = 0.733 R^2(adj) = 95.9% n = 1420

The regression equation is

LOGSCHeight = 2.81 - 16.0 I/Age + 0.0478 SI19

R^2(adj) = 96.5% n = 1420.

Select crop height trends for one metre Site Index classes between the ages of 14 and 40 years are plotted Figure 10. For SI in the 12.5 to 14.5 range data are available from the Yanchep trial for stand ages 14.5 to 33.7 years. Site Index data from 15.0 to 18.0 relate to stand ages of 19.0 to 37.5 years.

Top heights were determined from a selection of measurements spanning the critical stand development periods subject to analysis by the 'pine sp' program. Top height is often more accessible than select stand height (100 s ha^{-1}) and regressions for the combined Top height data were also calculated.

The regression equation is

TopHeight = - 4.48 + 0.443 Age + 0.747 SITH19

s = 0.684 R^2(adj) = 96.4% n = 800.

The regression equation is

LOGTopHeight = 2.90 - 14.7 1/Age + 0.0395 SITH19

R^2(adj) = 96.4% n = 800.

Stand Volume

Mean Annual Increment.

Total volume produced in each trial is presented as mean annual increment for the main effects for density, site and fertiliser treatments in Figures 11 and 12. Results from analysis of variance for MAI (Tables 20 and 21) of volume data were similar to those presented for basal area in Tables 10 and 11. Interactions were not significant and for volume measurement at Gnangara the total stand volume was less sensitive to treatment than total stand BAob. The reverse is the case for the Select crop.

At Yanchep, site classes for total volume data (Tables 11, 21, Fig. 11) were more distinct than for basal area measurement.

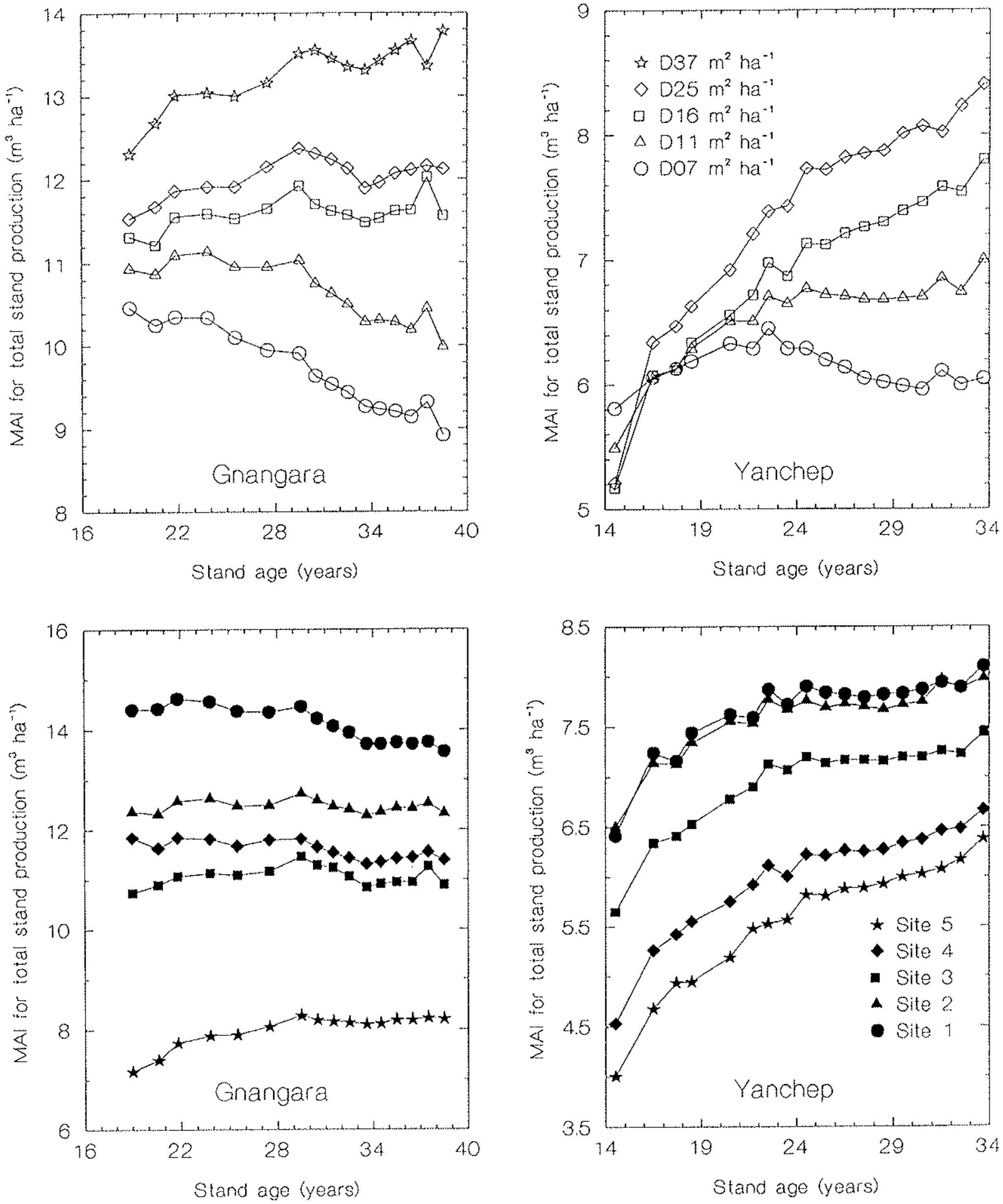


Figure 11. Mean annual increment for total volume for the main effects of density (Top) and site (bottom) classes at Gnangara and Yanchep

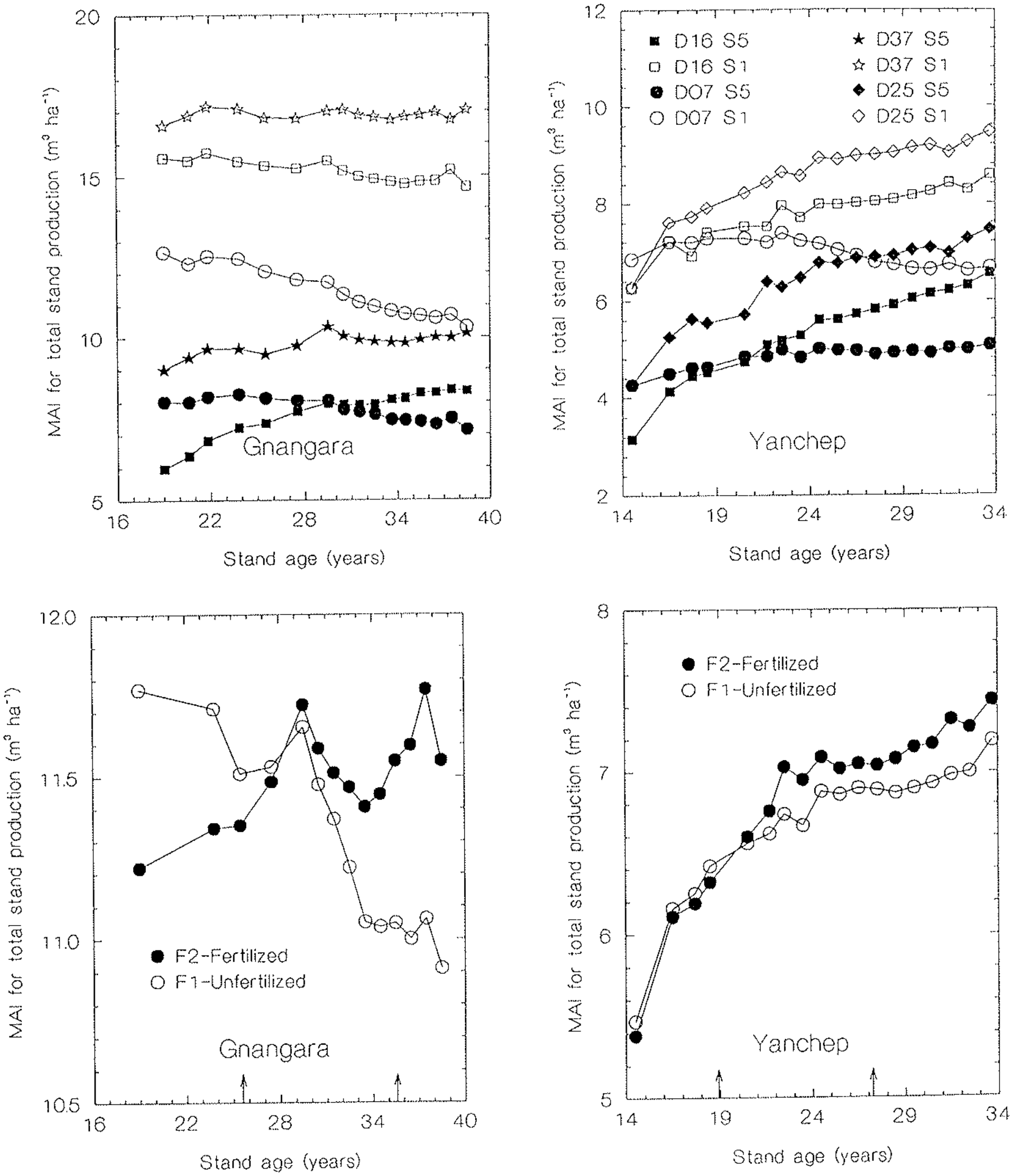


Figure 12. Mean annual increment for the fertiliser main effect(bottom) and extreme density and site classes (top) at Gnangara and Yanchep. Fertiliser events are marked by arrows on the horizontal axis.

TABLE 20

Significance of main effects of mean annual increment of total under bark volume and select crop volume produced for WP 20/65 at Gnangara plantation. Values are the probability that the F value obtained in analysis of variance would be exceeded by chance. No interactions were significant.

Date	Age	Total Stand			Select Crop		
		Site	Fert	Den	Site	Fert	Den
1965	19.0	.000	.380	.198	.000	.705	.774
1970	23.8	.000	.462	.002	.000	.729	.002
1972	25.5	.000	.819	.000	.000	.285	.000
1974	27.5	.000	.951	.000	.000	.133	.000
1976	29.5	.000	.687	.000	.000	.163	.000
1976	30.5	.000	.589	.000	.000	.117	.000
1978	31.5	.000	.510	.000	.000	.089	.000
1979	32.5	.000	.328	.000	.000	.106	.000
1980	33.6	.000	.199	.000	.000	.093	.000
1981	34.5	.000	.147	.000	.000	.053	.000
1982	35.5	.000	.087	.000	.000	.028	.000
1983	36.5	.000	.047	.000	.000	.009	.000
1984	37.5	.000	.027	.000	.000	.002	.000
1985	38.5	.000	.033	.000	.000	.007	.000

TABLE 21

Significance of main effects of mean annual increment of total under bark volume and select crop volume produced in WP 54/66 at Yanchep. Values are the probability that the F value obtained in analysis of variance would be exceeded by chance. No interactions were significant.

Date	Age	Total Stand			Final Crop		
		Site	Fert	Den	Site	Fert	Den
1966	14.5	.000	.704	.893	.000	.781	.050
1970	17.7	.000	.817	.060	.000	.988	.000
1973	20.5	.000	.843	.008	.000	.518	.000
1974	21.7	.000	.410	.000	.000	.281	.000
1975	23.5	.000	.107	.000	.000	.198	.000
1976	24.5	.000	.250	.000	.000	.372	.000
1978	25.5	.000	.330	.000	.000	.486	.000
1979	26.5	.000	.358	.000	.000	.980	.000
1980	27.5	.000	.336	.000	.000	.894	.000
1981	28.5	.000	.198	.000	.000	.581	.000
1982	29.5	.000	.122	.000	.000	.287	.000
1983	30.5	.000	.138	.000	.000	.417	.000
1984	31.5	.000	.038	.000	.000	.150	.000
1985	32.5	.000	.089	.000	.000	.216	.000

Stand Density - Trends for total volume were similar to those for basal area with volume decreasing with decreasing stand density (Fig. 11) and decreasing site potential. The 37 m^2 ha^{-1} and 25 m^2 ha^{-1} stand densities at Gnangara produced 2.1 and 1.7 times, respectively, the stem volume produced by the 7 m^2 ha^{-1} density, over the course of the trial. Thinning to maintain stand density classes led, initially, to maximum volume production at age 24 in the lowest stand density (7 m^2).

Site Class - Site 1 produced approximately 30 per cent more total volume than site 5 for the whole stand (Fig. 11) and 50 per cent more within the Select crop .

In Figure 12 (upper) the association of site and density classes for extreme treatments at both Gnangara and Yanchep show thinning effects have similar responses across the range of site classes. There was an indication that fertiliser addition was relatively more effective in the denser stand treatments (37 and 25 m^2 ha^{-1}) than in the heavily thinned treatments (Fig. 13, upper). This is not supported by comparisons of the sensitivity of the fertiliser main effect for the total stand than that for the select crop. It was less sensitive at Gnangara (Table 20) but the reverse was the case at Yanchep (Table 21). No significance could be found in the DxF interaction in either trial. Nutrition also appears to have a similar effect over the range of site classes (Fig. 13, lower) at Gnangara. At Yanchep, however, the nutrition effect appears to be concentrated on Sites 2 and 3 (Fig. 13, lower).

The lower productivity of the northern, Yanchep site to that at Gnangara is again clearly depicted in Figure 11. Sites 1 and 2 at Yanchep have MAI's slightly lower than Site 5 at Gnangara.

Current Annual Increment.

Significance for analyses of variance for total volume and select crop volumes at each trial location are presented in Tables 22 and 23. Interactions were not significant and are not included in the summaries. Results are similar to those obtained for basal area (Tables 12 and 13) but possibly not as consistent, indicating reduced sensitivity. As volume data for some measurements were obtained from estimates of heights and or bark thickness (Tables 1 and 2) it is not constructive to explore in detail, the minor discrepancies in general trends in CAI in comparison to that already discussed for increment in basal area. Calculated values for CAI volume for the stand and select crop in both trials are depicted in Figures 14 and 15. Yanchep data are essentially similar to the pattern for basal area in Figure 7.

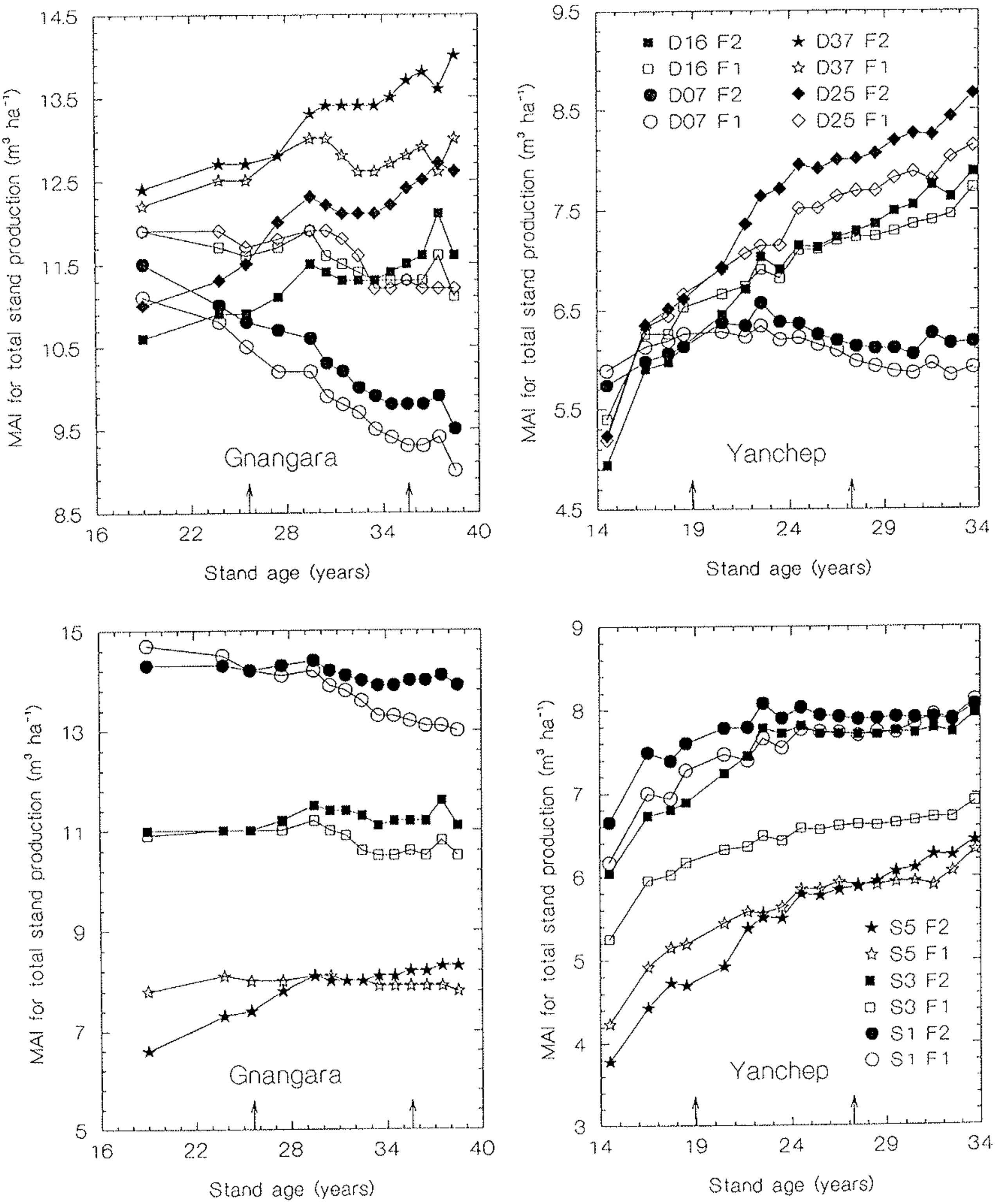


Figure 13. Mean annual increment for fertiliser treatments within the range of stand density (top) and site classes (bottom) at Gnangara and Yanchep. Fertiliser events are marked by arrows on the horizontal axis.

TABLE 22

Significance of main effects of current annual increment of total under bark volume and select crop volume produced by the stand for WP 20/65 at Gnangara plantation. Values are the probability that the F value obtained in analysis of variance would be exceeded by chance. No interactions were significant.

Period	Age Class	Total Stand			Select Crop		
		Site	Fert	Den	Site	Fert	Den
68-70	21.8-23.8	.002	.453	.004	.000	.832	.000
70 72	23.8-25.5	.121	.002	.000	.006	.026	.000
72-74	25.5-27.5	.070	.135	.000	.008	.079	.000
74-76	27.5-29.5	.002	.065	.000	.004	.987	.000
76-76	29.5-30.5	.799	.339	.000	.526	.280	.291
76-78	30.5-31.5	.384	.171	.013	.040	.278	.000
78-79	31.5-32.5	.358	.052.	.463	.408	.882	.000
79-80	32.5-33.6	.472	.023	.004	.082	.410	.094
80-81	33.6-34.5	.030	.042	.000	.045	.088	.002
81-82	34.5-35.5	.022	.000	.000	.052	.008	.000
82-83	35.5-36.5	.030	.000	.000	.023	.000	.002
83-84	36.5-37.5	.030	.047	.000	.019	.003	.000
84-85	37.5-38.5	.033	.001	.000	.016	.013	.000

TABLE 23

Significance of main effects of current annual increment for total under bark volume and select crop volume produced by WP 54/66 at Yanchep. Values are the probability that the F value obtained in analysis of variance would be exceeded by chance.

Period	Age Class	Total Stand			Select Crop		
		Site	Fert	Den	Site	Fert	Den
66-69	14.5-16.6	.000	.480	.000	.000	.824	.000
69-70	16.6-17.7	.201	.987	.305	.932	.789	.000
70-71	17.7-18.5	.201	.133	.008	.013	.634	.000
71-73	18.5-20.5	.015	.014	.047	.001	.269	.000
73-74	20.5-21.7	.096	.019	.000	.009	.027	.000
74-75	21.7-23.5	.252	.902	.000	.088	.792	.080
75-76	22.5-24.5	.587	.139	.000	.196	.231	.000
76-78	24.5-25.5	.522	.002	.000	.007	.124	.000
78-79	25.5-26.5	.164	.606	.000	.018	.389	.000
79-80	26.5-27.5	.072	.410	.000	.006	.389	.000
80-81	27.5-28.5	.166	.002	.000	.052	.023	.000
81-82	28.5-29.5	.345	.007	.000	.851	.003	.000
82-83	29.5-30.5	.178	.930	.000	.039	.768	.005
83-84	30.5-31.5	.013	.004	.019	.161	.017	.000
84-85	31.5-32.5	.152	.017	.068	.624	.213	.787

Volume Regressions.

Volume regressions against stand variables were calculated separately for the Gnangara and Yanchep data and for the combined data sets (Table 24).

TABLE 24.

Best subsets regression for total volume of combined data from both trials.

Response is Total volume

Vars	R^2	Adj. R^2	C-p	s	AGE	DENSITY	SITE	LOCATION	SI19	FERT	SCHT	TOTBA	SCHT*TBA
1	99.2	99.2	922.8	5.998									X
1	83.2	83.2	4E+04	26.735								X	
2	99.4	99.4	262.6	5.072					X				X
2	99.4	99.4	370.2	5.234			X						X
3	99.5	99.5	86.8	4.795			X		X				X
3	99.4	99.4	135.1	4.872			X	X					X
4	99.5	99.5	54.3	4.740			X		X	X			X
4	99.5	99.5	57.7	4.746		X	X		X				X
5	99.5	99.5	30.2	4.699		X	X		X	X			X
5	99.5	99.5	31.2	4.701			X		X	X		X	X
6	99.5	99.5	14.6	4.671	X		X		X	X		X	X
6	99.5	99.5	22.1	4.684	X	X	X		X	X			X
7	99.5	99.5	11.6	4.665	X	X	X		X	X		X	X
7	99.5	99.5	13.1	4.667	X		X		X	X	X	X	X
8	99.5	99.5	10.6	4.662	X	X	X		X	X	X	X	X
8	99.5	99.5	10.7	4.662	X	X	X	X	X	X		X	X
9	99.5	99.5	10.0	4.659	X	X	X	X	X	X	X	X	X

The regression equations for total volume and select crop volume(100 s ha^{-1}) are listed below.

Gnangara

a) TOTVOL = 14.0 + 0.314 SCHT*TOTBA - 2.45 SITE

s = 5.697 R^2(adj) = 99.4% n = 676

b) SCVOL = - 13.7 + 0.331 SCHT*FCB + 0.907 S119

s = 2.606 R^2(adj) = 99.2% n = 662

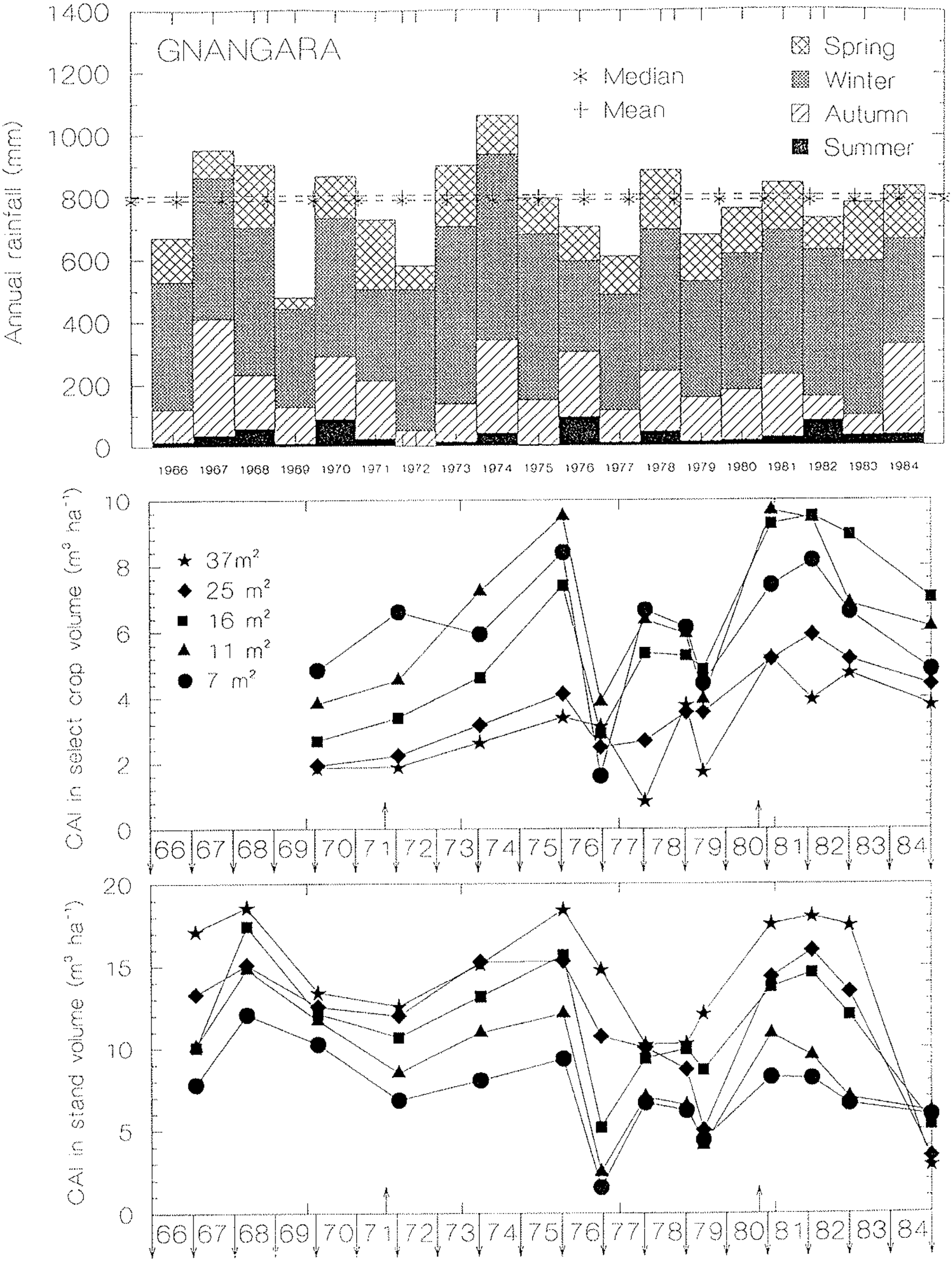


Figure 14. Seasonal and annual rainfall received at Gnangara and current annual volume increments of stand density classes for total volume of the whole stand and select crop over the period of the trial. Fertiliser events are marked by arrows on the horizontal axis.

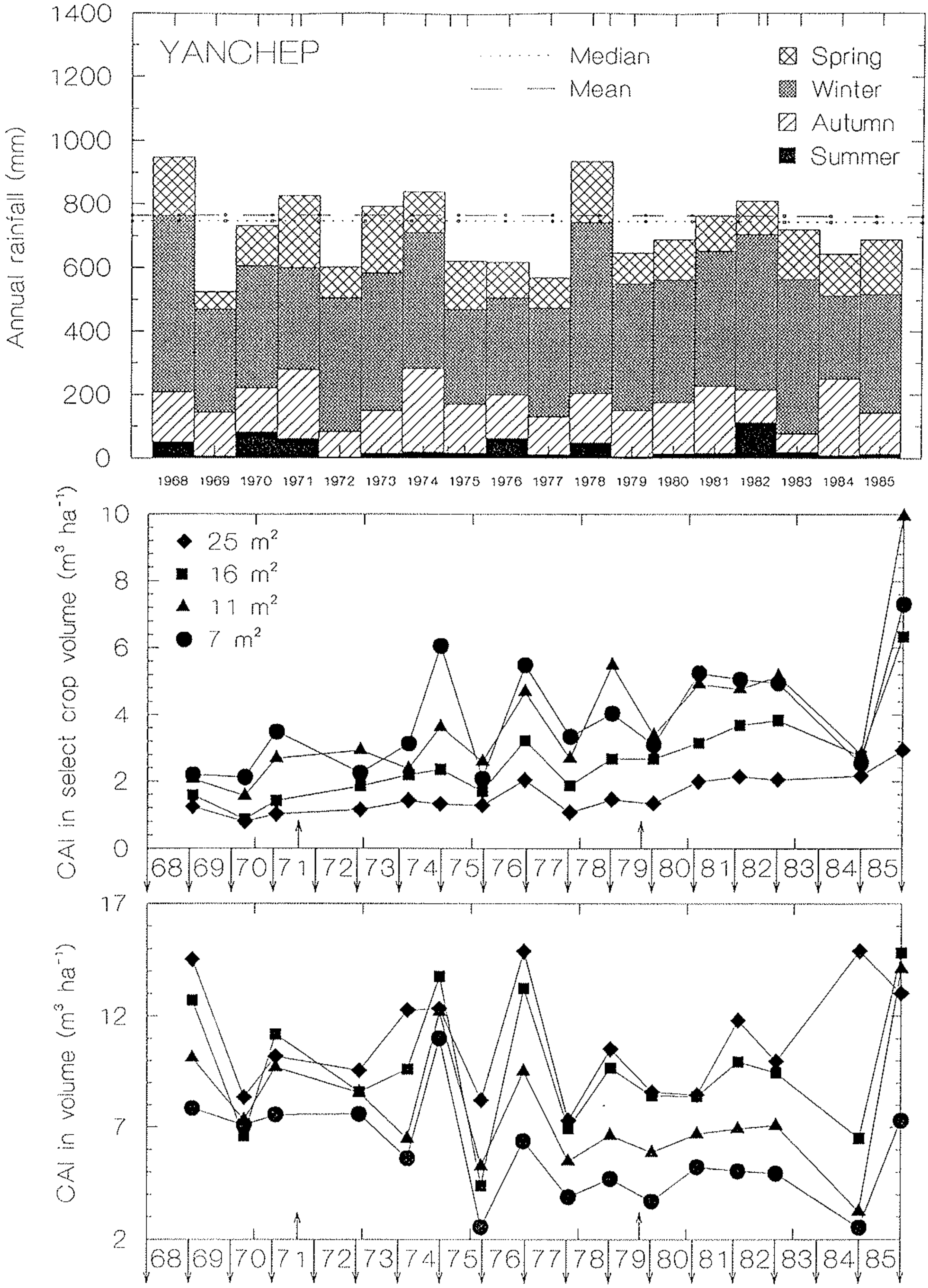


Figure 15. Seasonal and annual rainfall received at Yanchep and current annual volume increments of stand density classes for total volume of the whole stand and select crop over the period of the trial. Fertiliser events are marked by arrows on the horizontal axis.

Yanchep

c) $TOTVOL = -33.5 + 0.310\ SCHT*TOTBA + 2.79\ SI19$

$s = 3.112 \quad R^2(adj) = 99.4\% \quad n = 707$

d) $SCVOL = -9.93 + 0.335\ SCHT*SCBA + 0.749\ SI19$

$s = 1.126 \quad R^2(adj) = 99.7\% \quad n = 699$

Combined

e) $TOTVOL = 18.4 + 0.312\ FCHT*TOTBA - 2.19\ SITE - 4.14LOCN$

$s = 4.805 \quad R^2(adj) = 99.5\% \quad n = 1401$

f) $SCVOL = 0.002 + 0.338\ SCHT*SCBA$

$s = 2.307 \quad R^2(adj) = 99.4\% \quad n = 1386$

G) $SCVOL = 4.53 + 0.353\ SCHT*SCBA - 0.240\ AGE$

$s = 2.244 \quad R^2(adj) = 99.4\% \quad n = 1389$

TABLE 25.

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

Virtually all variation within volume data was explained by the product of mean select crop height and basal area of the total stand or select crop (Table 24). Standard error may be reduced by including another parameter into regression if required. Homoscedasticity was satisfactory for total volume but less satisfactory for select crop volumes.

TABLE 26.

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

Year	Den	N	K	P	Ca	Mg	Mn	Zn
		Per cent					ppm	
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

Foliar Nutrients

Mean values for main effects of Sites 1 and 5 sampled at Gnangara in April 1973 are summarised in Table 25. The increase in per cent N and P from fertiliser added in September 1971 was highly significant and significant (.03 level) for Mn. Per cent foliar K was significantly greater (.000 level) on the better site while content of Mn was significantly higher on the poorer site.

Mean values for the main effects for foliar nutrients sampled at Yanchep in 1971, 1973 and 1976 are summarised in Table 26. Significance for treatment differences in each year of sampling are presented in Table 27.

TABLE 27.

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

The significant effect of site for P in 1971 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 results 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 was associated with a progressive decrease in K content with increasing stand density.

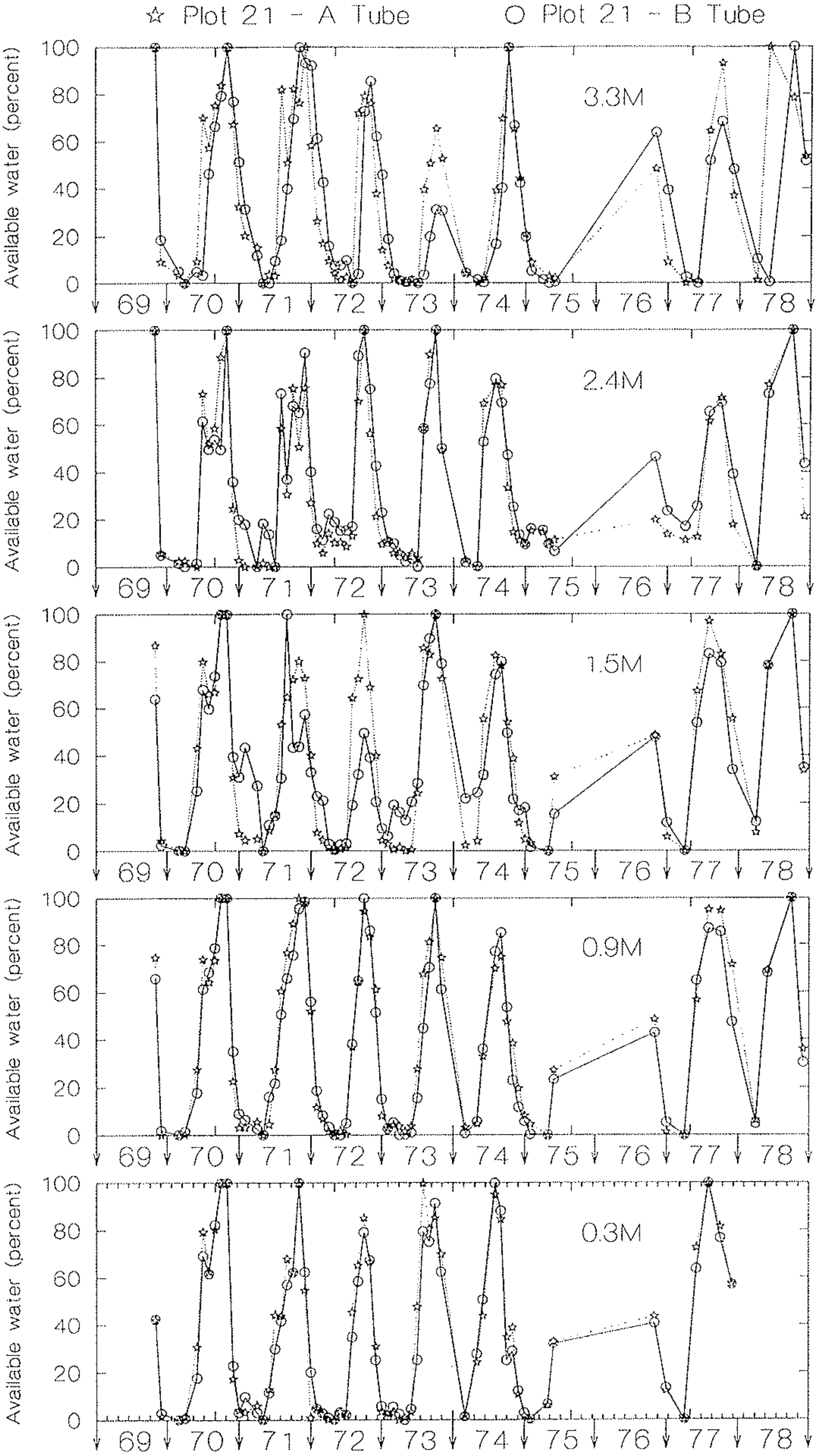


Figure 16. Comparison of the available water traces for the two access holes in Plot 21 (25 m^2 ha^{-1}) to demonstrate the uniformity within the plot area.

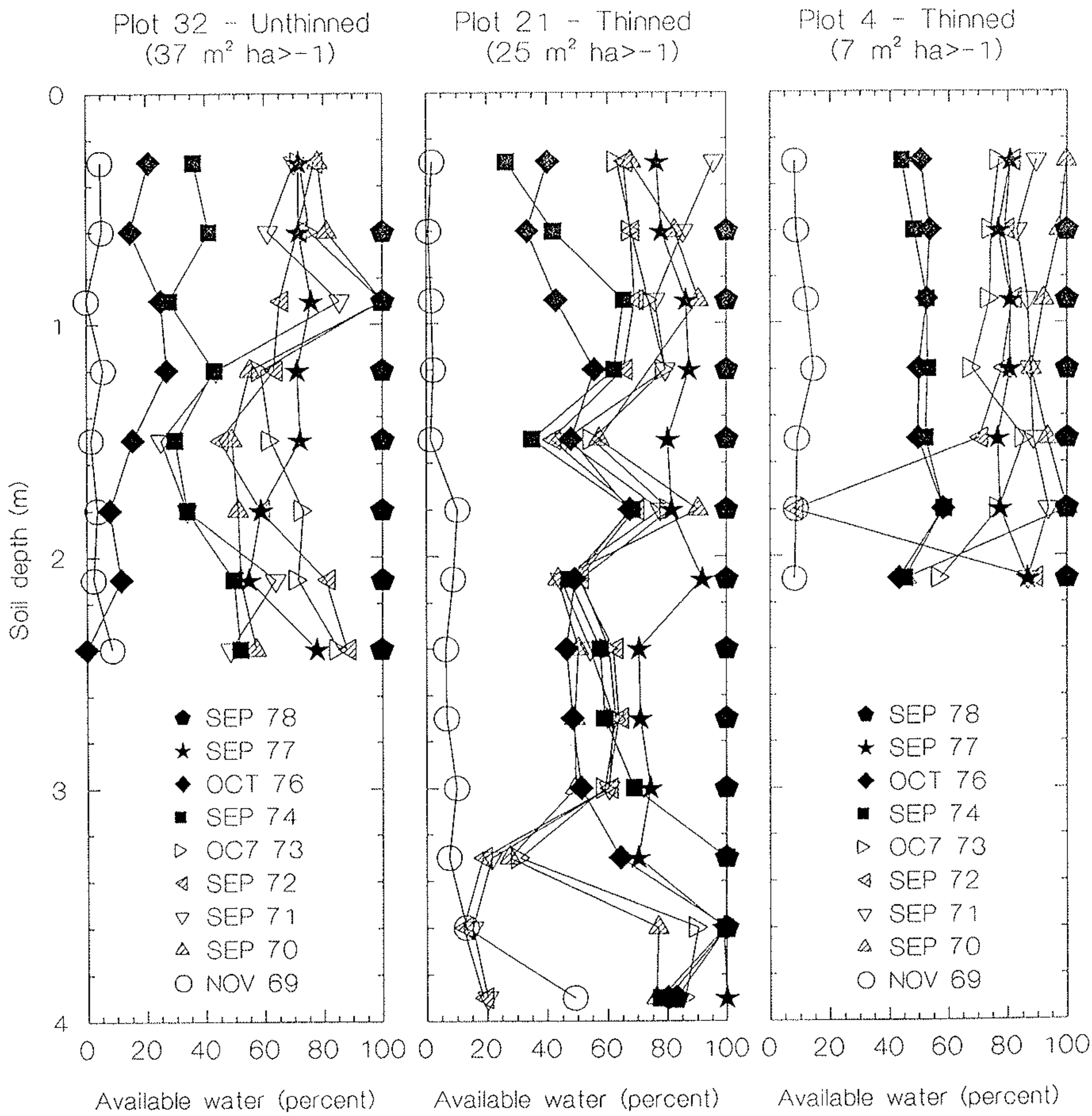


Figure 17. Comparison of available water levels within the soil profile for 37, 25 and 7 m^2 ha^{-1} stand density plots. September can be expected to have the annual maximum and the variation of annual water deficits with stand density is apparent. The serious water deficits associated with drought in 1975-1978 were present in all density treatments.

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.

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

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 28). 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 .

TABLE 28.

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					

Rainfall and Soil Moisture

Rainfall for Gnangara and Yanchep over the course of the trial are summarised in Figures 14 and 15 to show seasonal and annual totals received.

At Gnangara soil moisture measurements commenced in November 1969 and terminated in December 1978. The presence of a coffee rock layer within the profiles for the better site qualities generally restricted access depth for the neutron probe assessment to 2-3 metres. At this depth there was the upper influence of the ground water table in winter. The probe measurements hence represent the periodic moisture status in the surface 2 metres of the root zone but provide no indication of water below the friable coffee rock zone which was accessed by roots.

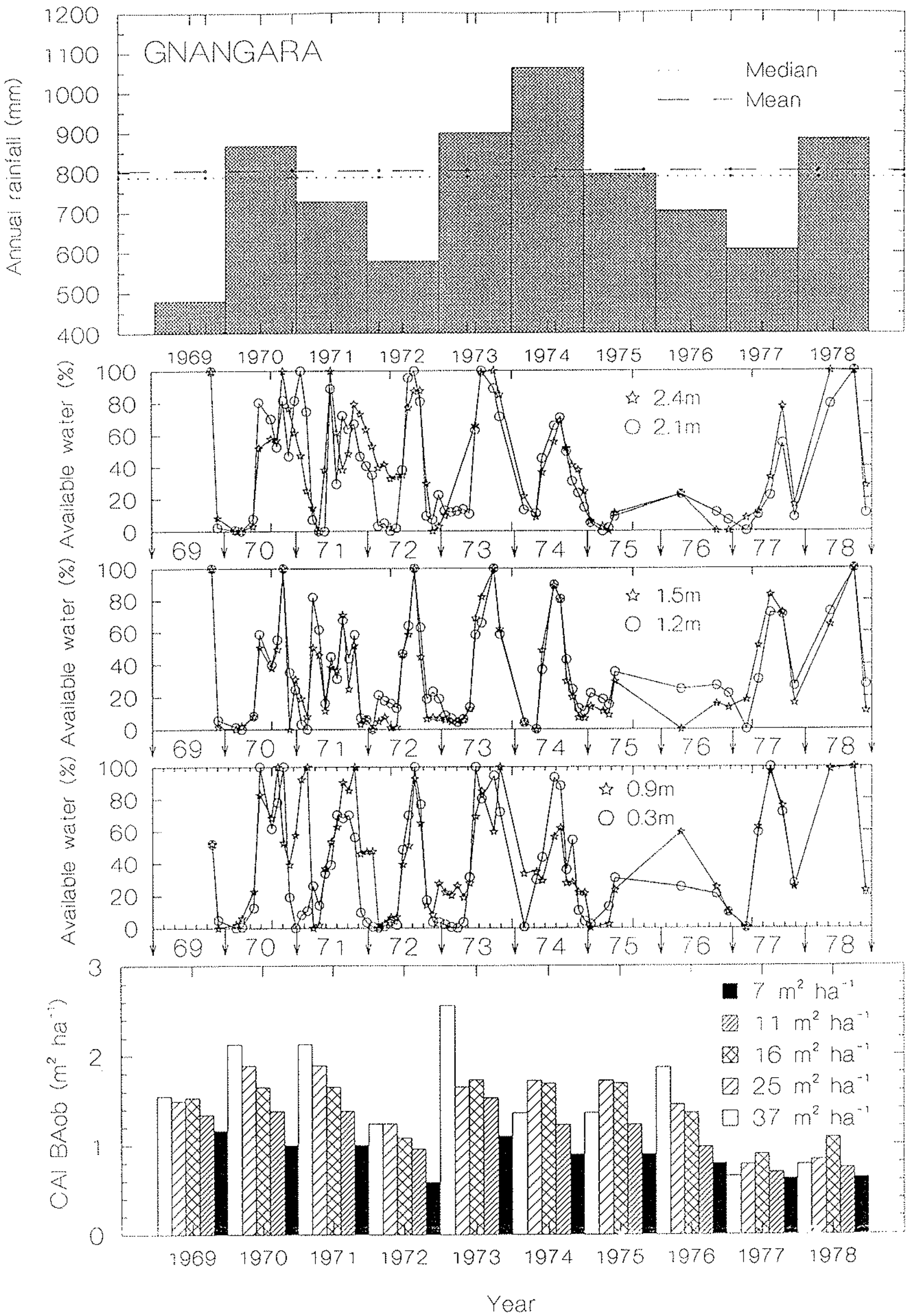


Figure 18. Association of rainfall, soil moisture availability and basal area increment at Gnangara for the period of soil moisture monitoring (1969 to 1978).

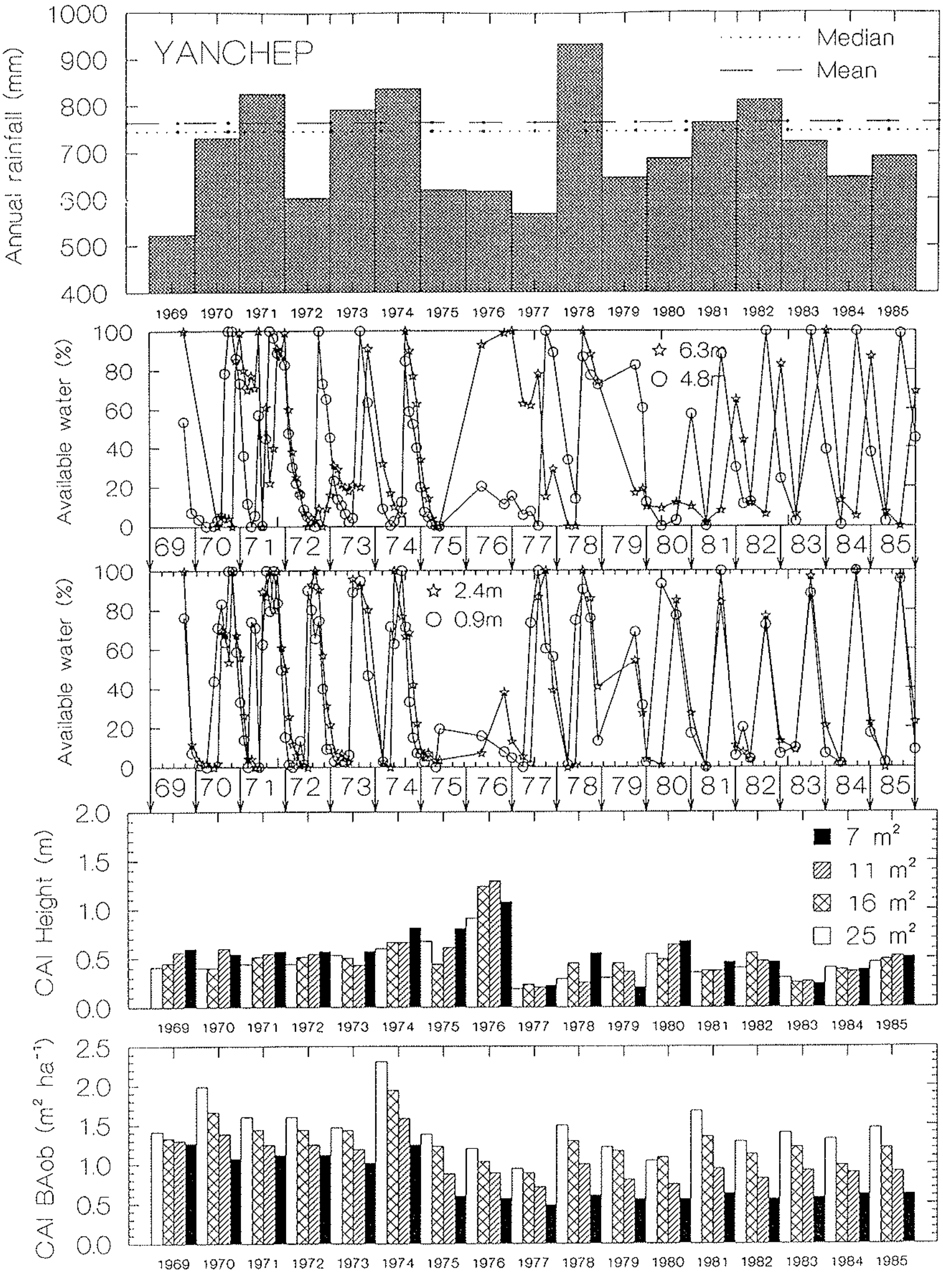


Figure 19. Association of rainfall, soil moisture availability and basal area and height increment at Yanchep for the period of soil moisture monitoring (1969 to 1978).

Two probe holes were randomly allocated to each soil measurement plot (Appendix 1). Examination of the dual probe traces on each plot showed them to be virtually identical (Figure 16) and a single measurement tube would have sufficed. For soil moisture examination the probe data was related to available soil moisture i.e. that between 100 per cent at soil maximum with drainage (field capacity) and zero per cent at soil minimum when withdrawal was the lowest. These high and low points were reliably estimated and consistent within the traces (Figure 16).

Differences measured in soil moisture status associated with stand density are demonstrated in Figure 17 in which the spring measurements are compared for 37, 25 and 7 m^2 ha^{-1} stand density classes. The heavily thinned plots contained more soil moisture at equivalent times than the lightly thinned plots. Soil moisture availability was generally at a seasonal maximum in September. The figure also shows that in most years in the high stand density plots and in September 1974 to 1976 in the low stand density plot, a water deficit was carried over from one year to the next. Soil water availability is related to rainfall and basal area increment for the Gnangara trial in Figure 18.

At Yanchep most sites were on deep yellow sands with no evidence of a water table within the profile. Soil moisture probe measurements generally accessed a depth of 6.6 m. With no evidence of a water table the moisture sampling was considered to monitor a true picture of water use by the stands and measurements were continued at strategic periods up to 1986 (Fig. 19). Differences between available moisture over the range of stand densities were not simple to compare. Moisture was used by the roots over the entire 6.6 m access tube depth and to save time probe counts were not taken at the 6.0+ depths in the high density plots (25 m^2 ha^{-1}, 16 m^2 ha^{-1}) when it was considered to be obvious from experience, results for the plots with low stand densities and the surface samples that they were depleted at depth.

DISCUSSION

Increment

Mean annual increment (MAI) 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.

The expression for current stand increment (CAI) compared was the mean annual value between the last two measurements. This provided useful comparisons between measurement periods in most cases. As measurements were usually carried out in January or February each year the periods related to equivalent growth potentials and closely tracked the impact of fertiliser addition, rainfall variation and recent thinning maintenance. For several measurement periods however, namely March 1974 to December 1974 (Table 3), the reduced period excluded the December, January and February months, which tend to be the dormant part of the year for cambial growth. The CAI calculated on an annual basis in these instances is considerably inflated (Fig. 8). Comparisons of magnitude between CAI's for different periods may therefore be misleading in several cases, depending on the interval averaged. Treatment comparisons within CAI's for the same period are valid.

Density - For the first five years at both plantations MAI tended to increase with age for all density classes (Table 9. Fig. 5). With further development at Gnangara, increment plateaued at age 29.5 years to provide a small increase, or nil increase with time for the 7, 11, and 16 m^2 ha^{-1} treatments. The denser treatments plateaued earlier, at age 25.5 years for the 25 m^2 ha^{-1} treatment and at 23.8 years for the 37 m^2 ha^{-1} treatments. Thereafter they decreased in MAI due to stand mortalities (Table 9). At Yanchep the means for all density classes decreased in the latter stand ages (Fig. 5).

For the Select portion of the stand, MAI continued to increase with stand age for the duration of both trials (Table 9, Fig. 5). The stimulus of reduced competition with decreasing stand density class was great and at the termination of both trials the mean increment in the 7 m^2 ha^{-1} class doubled that of the least thinned treatment.

Mean increment of Select crop height for the 7 m^2 ha^{-1} treatment grew at a greater rate than that of the other density classes at Gnangara (Table 16, Fig. 8). The differences were not significant (Table 17) and are associated with a relative increase in the 7 m^2 mean as thinning to maintain treatment values reduced the select crop stem numbers from 100 to 50 stems ha^{-1} (Table 6). At Yanchep however, there was a progressive increase in Select crop height with decreasing stand density and trial development (Fig. 8). The differences favouring growth in the heavily thinned treatments were highly significant after age 18 years (Table 18) and prior to any thinning reduction in numbers of trees in the Select Crop. It is believed that the variable height growth with stand density is a result of greater soil water availability at lower stand densities on these drought prone sites (Fig. 19).

CAI in basal area for the whole stand increased with increasing stand density treatments in the early years following the initial thinning. This sequence continued throughout the life of both trials (Fig. 7) with the regular maintenance of the treatment stand densities. The value for the 7 m^2 ha^{-1} treatment averaged 52 per cent of that of the 37 m^2 ha^{-1} treatment at Gnangara (Table 13) and 58 and 53 per cent of that of the 25 m^2 ha^{-1} treatments at Gnangara and Yanchep, respectively. Differences between stand densities were highly significant at all stages except for measurements at ages 21.8, 27.5 and 32.5 years to correspond to rainfall years 1967, 1973 and 1978, respectively at Gnangara (Tables 14, Fig. 14) and 1969 at Yanchep (Table 15, Fig. 15). Treatments varied greatly between years (Fig. 7) with the length and nature of the period between measurements and climatic, fertiliser and stand aging effects. The pattern of variation was reasonably consistent between stand densities in any one year and no significant interaction was evident.

TABLE 29

Significance of volume means for stand density treatments with stand development at Gnangara. Differences are separated by Bonferroni adjustment of paired comparisons. Means linked by solid lines do not differ significantly.

Year	Density class				
	7 m^2	11 m^2	16 m^2	25 m^2	37 m^2
1965	—	—	—	—	—
1967	—	—	—	—	
		—	—	—	—
1970	—	—	—	—	
		—	—	—	
			—	—	—
1974	—	—			
		—	—	—	
			—	—	—
1978	—	—			
		—	—		
			—	—	
				—	—
1983	—	—			
		—	—		
			—	—	
				—	
					—
Year	7 m^2	11 m^2	16 m^2	25 m^2	37 m^2

CAI for the Select Crop was the reverse of that for the whole stand, increasing with decreasing stand density as a result of releasing a fixed number (100 s ha^{-1}) of the best trees (Table 13). Results were similar for both trials (Fig. 7) and the pattern was consistent for all density classes each year. Response to the artificially maintained density classes was highly significant for most years (Tables 14, 15). The trend of results (Table 14, Fig. 7) records some relative decreases in the increment of the Selects in the lowest density classes, in the later stages of the trial. This was due to the decrease in the number of Select crop trees (Table 4, Fig. 2) by thinning to maintain the stand density treatments.

CAI for volume data followed the trends set by basal area increment (Table 14). Basal area data is considered in detail

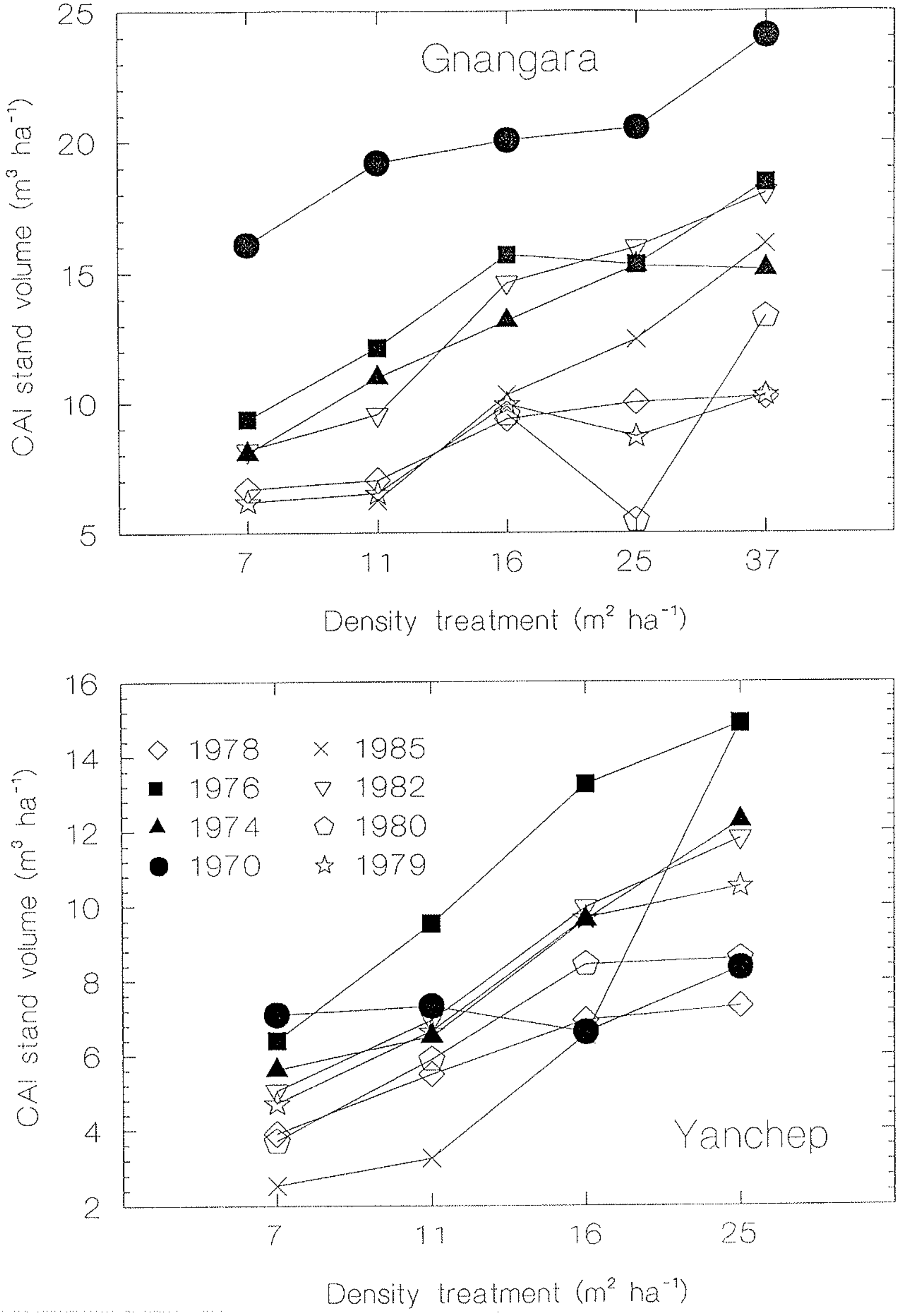


Figure 20. Average values for stand volume of density classes within different increment periods at Gnangara and Yanchep. The periods straddle the severe drought in the 1976-1979 period.

as it is more accurate than the full data set for volume which in some cases was obtained from estimates for height and bark thickness (Tables 2 and 3).

Drought - Butcher and Havel(1976) reporting on development of the trials up to 1967 hypothesised that for drought prone areas, such as Yanchep, the increment of wood produced in a year is dependent on the amount of water available in the soil profile. The growth potential could be produced on a dense stand rapidly with an early growth cessation once the water was depleted or through slow growth over the summer months by a lower stand density. This was not the general case, even though the trial embraced the worst drought in the history of the region in 1977-1978. Volume production of the whole stand increased directly with stand density (Fig. 11). Significant differences between MAI for the density treatments (Table 29) showed that at Gnangara in 1983 (age 36.5), 18 years after the density treatments were established, the 37 m^2 ha^{-1} most dense treatment was significantly greater than the lower 25 m^2 ha^{-1} treatment. This was despite mortalities which were concentrated in the highest density classes. At Yanchep the situation was similar with the 16 and 25 m^2 ha^{-1} treatments being the highest volume producers (Fig. 11) and not significantly different in themselves. The average CAI's for volume of the whole stand for the 7, 11 16 and 25 m^2 treatments at Gnangara were 54, 65, 87 and 86 per cent of that of the 37 m^2 treatment over the course of the trial. At Yanchep the average CAI's for the 7, 11 and 16 m^2 density treatments were 57 (62), 75 (75) and 91 (100) per cent of the densest 25 m^2 treatment. Figures in brackets are the relevent percentages of the 25 m^2 treatment at Gnangara. CAI at Gnangara in particular, revealed differences between stand densities as a result of drought (Figs. 14, 17, 18). For the initial period following trial establishment (1967-1970) growth for each density treatment was significantly greater than that in the lower class (Fig. 20). With the onset of soil drought in 1974, 1975 and 1976 (Fig. 18) growth of the densest and then the two densest treatments declined relative to that of the 16 m^2 treatment which was still significantly greater than the 7 and 11 m^2 treatments. During the drought in 1977, 1978, 1979 and 1980 (stand ages 30, 31, 32 and 33 years) CAI declined in all treatments. Differences between treatments were not significant in the 1978-1979 period (Table 22) and the marked drop in the 25 m^2 CAI (Fig. 20) was the result of drought mortalities in two plots. Following the drought, CAI of the dense treatments (in 1982 and 1985) again exceeded those of less dense treatments. It should be noted that CAI's of the 7 and 11 m^2 treatments were also greatly reduced during the drought period. At Yanchep, CAI associated with low rainfalls in 1969 and 1970 were not significantly different. The densest 25 m^2 ha^{-1} treatment declined in growth during the 1978-1980 drought years and recovered after the drought (Fig. 20). In both trials 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) at Yanchep (Table 23), Butcher (1977) concluded that, under soil water stress, as much wood was produced on heavily thinned as unthinned stands. It can be seen from Figures 7, 15, 19 and 20 that this was an abnormal result. The 1969-70 result was the only measurement at Yanchep with non significant differences between density classes in the whole period of study (Table 23) and was not duplicated even in the sustained, severe drought from stand age 24.5 to 27.5 years (Figs. 15, 19). For both BAob and total volume, increments of the higher density classes were significantly better over this drought period (Tables 15, 23, Figs. 15, 19) which is due to the lowest annual rainfall throughout the study period (Fig. 19). Non significant improvement in CAI volume for the total stand of the higher over lower stand densities was present at Gnangara in 1978-79 (Table 22, Figs. 14, 20) in the severest drought. Hence, although an effect of limiting increment with increasing stand density is associated with low water availability in both studies, it influenced all density classes studied and the effect over the the stand rotation is not important on these sites.

The use of merchantable volume to 10 cm top diameter to compare increments between density classes also obscured the true growth situation for Havel and Butcher. For the young stands at Yanchep the less dense treatments with favoured diameter development registered relatively higher merchantable yields than the denser treatments. This was not the case with the older stands at Gnangara which were not considered to show drought effects on volume production by Butcher and Havel (1976).

CAI data for Select crop height is interesting. It is generally assumed that height growth is independent of stand density (Spurr 1953, Carmean 1975). Significant differences in CAI of the mean Select Crop height between density classes was found for the periods 19.0-23.8 and 27.5-29.5 years at Gnangara (Table 17, Figs. 8 and 9). In the first instance the high density treatment had a greater mean height of the select crop than the others as a result of the initial tree selection. In the second case the lowest density class had the greatest height. At Yanchep means between density classes were significantly different for 6 periods (Table 18, Figs. 8 and 9). With the exception of the result at age 31.5 years increments were greater in the lower density classes than in the higher classes. The differences appeared before thinning had any influence on stem numbers in the select crop of density treatments and must be associated with improved height growth with decreasing stand densities. In Figure 19 the significant differences occurring in 1969, 1970, 1973 1978 and 1985 are associated with years of lowest rainfall and or measured soil moisture deficits. In 1984 the highest density class had significantly greater increment and although rainfall was low there was no evidence of soil moisture deficit. There are indications that the impact of drought on height growth may be maximised in the years following low rainfall rather than within the year of measured low rainfall.

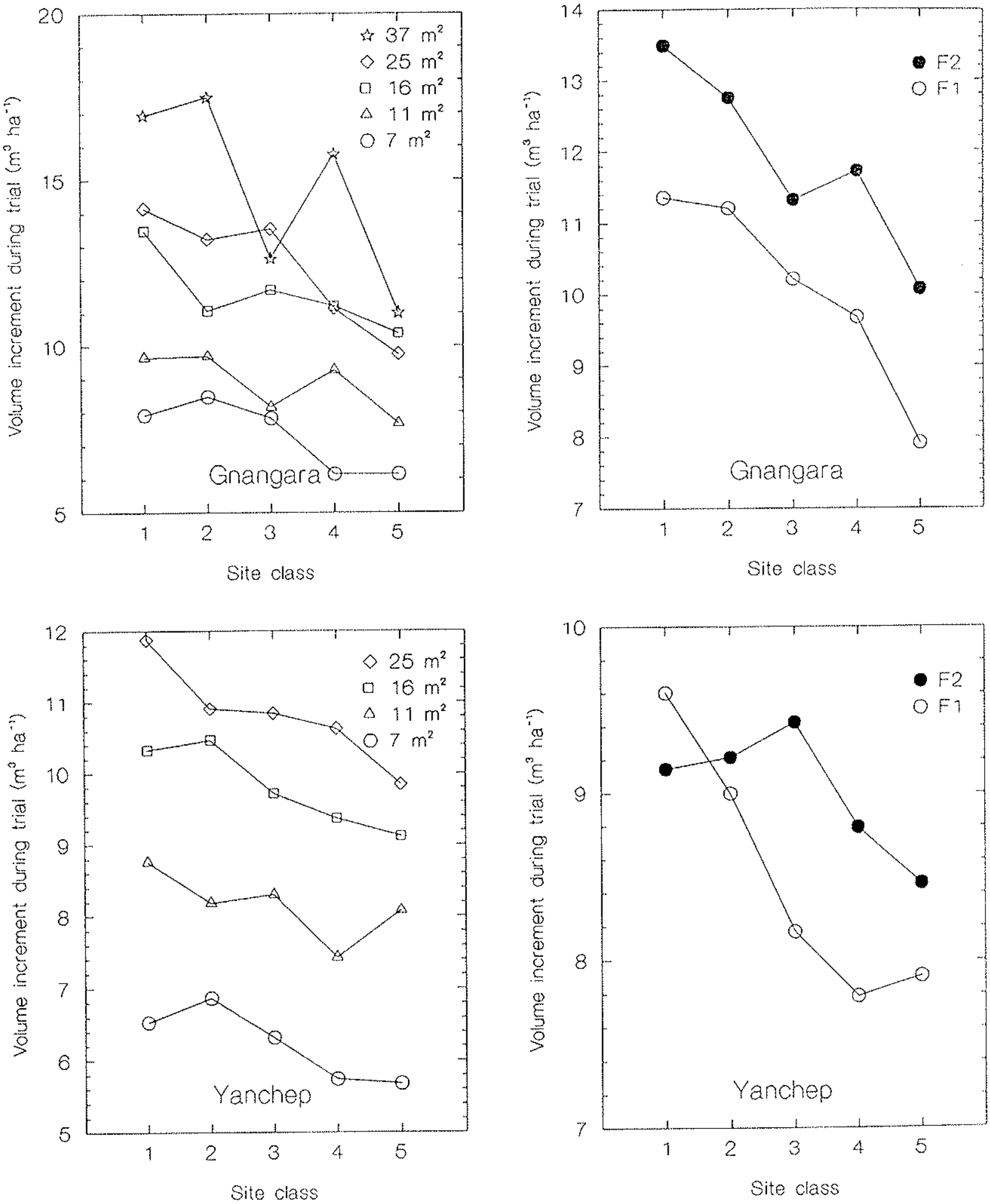


Figure 21. Mean values for volume produced during the trial period in stand density and fertiliser treatments for each site class at Gnangara and Yanchep.

Site Class- Following the initial thinning, mean increment in basal area increased for the whole stand on all sites to maxima at age 30 years at Gnangara (Table 9) and 22 years at Yanchep (Fig. 5). Further decline with increasing stand age was slight at Gnangara but considerable at Yanchep (Fig. 5). For volume data MAI declined after age 30 years at Gnangara but continued to increase over the study period for all sites at Yanchep (Fig. 11). It was previously noted from Site Index that the best site class separated at Yanchep was only equivalent to the poorest in the Gnangara trial. This is also shown in the means for stand increment and the maximum increment at Yanchep in Site Class 1 is only equivalent to that in Site class 4 at Gnangara (Fig. 11). Analysis of variance (Tables 10 and 11) revealed that although mean increment for the whole stand was strongly associated with site class at Gnangara from age 24 years onwards, there was only a weak association at Yanchep, except for several years after trial establishment (Table 11).

For the Select Crop, mean increment was closely associated with site class in both trials (Tables 10, 11, 20, 21). It increased at a steady rate on all site classes, over the course of the trials at both centres (Table 9, Fig. 5).

Current annual increments of BAob of the whole stand for site classes tended to grade downwards from the superior site 1 to the poorest site 5 at Gnangara (Table 13). The differences were significant on only 5 occasions for basal area (Table 14) but, due to differential height growth, volume differences over the site range were significant in most increment periods except during the 1976-80 drought (Table 22). Site differences at Yanchep (Fig. 7) were slight and only significant at the initial increment measurement at age 20.5 years for BAob (Table 15) and for 3 measurement intervals for CAI volume (Table 23).

Site influences had highly significant effects on increment of the Select Crop stand at both trial locations in most years (Tables 14, 15, 22, 23). The trend for all sites was consistent at both plantations (Fig. 7, Table 13).

The possibility that stand density and or fertiliser effects interacted significantly with site class could not be tested statistically within the trial design. In Figure 21 (upper and lower left) there is little suggestion that any density treatment was more favourable on any individual site block at either Gnangara or Yanchep. Similarly for the response to fertiliser application at Gnangara (top right). At Yanchep however, there was little response to fertiliser on sites 1 and 2 and similar responses on the other 3 sites. From data analysed the likelihood of significant density by site or fertiliser interactions are ruled out for Gnangara. At Yanchep there also seems little possibility of significance of density by site interaction but the fertiliser addition is probably only effective on the poorest sites in the area.

Fertiliser - Fertiliser was applied at Gnangara as a single dressing F1 at ages 25.2 and 34.2 years. F2 was applied singly at age 25.2 and as a split application at 34.2 and 35.2 years of age. Treatment F1 applied 500 kg ha^{-1} of 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. F1 is the minimum base application proven necessary from earlier plantation experience. F2, which incorporated nitrogenous fertiliser, was regarded as possibly desirable for stand maintenance in the latter stages of the rotation.

Response to the initial application was immediate being detected in the measurement at age 25.5 years, some 7 months after application, for both the whole stand and Select Crop (Tables 12, 22, Fig. 9). The differences between the F1 and F2 means for basal area were significant for four years after treatment for the whole stand (Table 14) and for two years for the Select Crop. Similarly, for the second application split between ages 34.2 and 35.2 years of age, response was immediate and significant for at least three years after the first part application (Table 14, Fig. 9).

Significant (0.05 level) density by fertiliser interactions were obtained in 1981, 1982 and 1983 in the initial analysis for the Select Crop. An examination for homoscedasticty showed that a desirable natural log transformation removed interaction in 1981 and 1982 but not in 1983 (Table 14). The natural values for these three measurements have high F2/F1 ratios for the 11, 16 and 25 m^2 ha^{-1} treatments and relatively low ratios for the extreme 7 and 37 m^2 ha^{-1} density treatments. It is not believed therefore, that these limited trends for interaction need to be taken seriously.

For the whole stand at Gnangara both fertiliser additions gave a highly significant effect for the F2 treatment for mean increment (Tables 10, 12, 20, 21, Figs. 6, 12). The effect on the Select Crop was relatively minor and largely related to the influence of the second addition at 34 and 35 years of age (Tables 10, 12, 20, 21, Fig. 9).

At Yanchep no added fertiliser (F1) was compared with a heavy dressing of superphosphate + nitrogen + zinc (F2) at ages 19.0 and 27.0 years. The response in mean annual increment of the whole stand to fertiliser was slight but generally present after stand age 22.5 years (Table 11, 21, Figs. 6, 12). Within the Select Crop the impact of fertiliser was relatively minor as at Gnangara (Fig. 6, 7). Little fertiliser influence was noticeable in the mean increment for the stand (Fig. 6). Fertiliser addition had a significant effect (0.05 level) only for stand ages 29.5 to 31.5 (Table 11).

Response times and residual effects (Table 15, 23, Figs. 6, 7) were similar to those at Gnangara for CAI in both the whole stand and the Select Crop. For the Select Crop the density by fertiliser interaction was significant in 1980 and 1986 and approaching significance in 1973, 1974 and 1975 (Table 15). It has also been explained above that interaction between fertiliser and site at Yanchep indicates that fertiliser is only effective on the poorer yellow sands in the area. This could explain why fertiliser generally was not as important a stimulant of mean increment at Yanchep as at Gnangara (Figs. 12, 21), particularly as the response recorded at Gnangara was that of a doubling a base level known to be essential to the crop. At both locations the impact was dispersed over the whole crop rather than concentrated on the dominant portion (the Select Crop) of the stand (Tables 10, 11, 20, 21).

Site index.

Site index equations were obtained for each trial and as the site groups overlap, for the combined data set (Fig. 22). Height-age data within the age range 7 to 35 years, with variable stand density and fertiliser application, are also available for the Pilot Plot Trials (WP 48/66), the Free Growth Series (WP 16/58) and the Late Thinning series (WP 14/57). The former are restricted to the limestone soils but extend the site range to the most northerly locations of the sands considered for reforestation. The later two trials are at Gnangara representing poor to average and very good sites, respectively. The graphic comparisons of the different data sets (Fig. 22) and an examination of the deviation of regression estimates of data in WP 15/58 (Table 30) revealed that all data sets provide reasonable fits for the higher site quality data of the Late Thinning trial, the best fits being obtained by combining the Basal Control data with the Pilot Plot data.

The regression equation is

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

Predictor	Coefficient	Stdev	t-ratio	p
Constant	-2.7265	0.1836	-14.85	0.000
Age	0.3801	0.0036	105.20	0.000
I/Age	-51.8440	0.9644	-53.76	0.000
SI19	0.8673	0.0103	84.07	0.000

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

The further inclusion of the Late Thinning data with the Basal Area Control and Pilot Plot data gave the relationship

FcHT = - 3.42 + 0.400 Age + 0.854 SI19 - 2.93 S1/Age

Predictor	Coefficient	Stdev	t-ratio	p
Constant	-3.4206	0.1552	-22.04	0.000
Age	0.4000	0.0037	108.35	0.000
SI19	0.8542	0.0091	94.21	0.000
S1/Age	-2.9291	0.0628	-46.58	0.000

s = 0.6985 R^2 = 98.2% R^2(adj) = 98.2% n = 2382

The data sets both complement and supplement that of the Basal Area Series (Fig. 22) and the three sets combined provide an

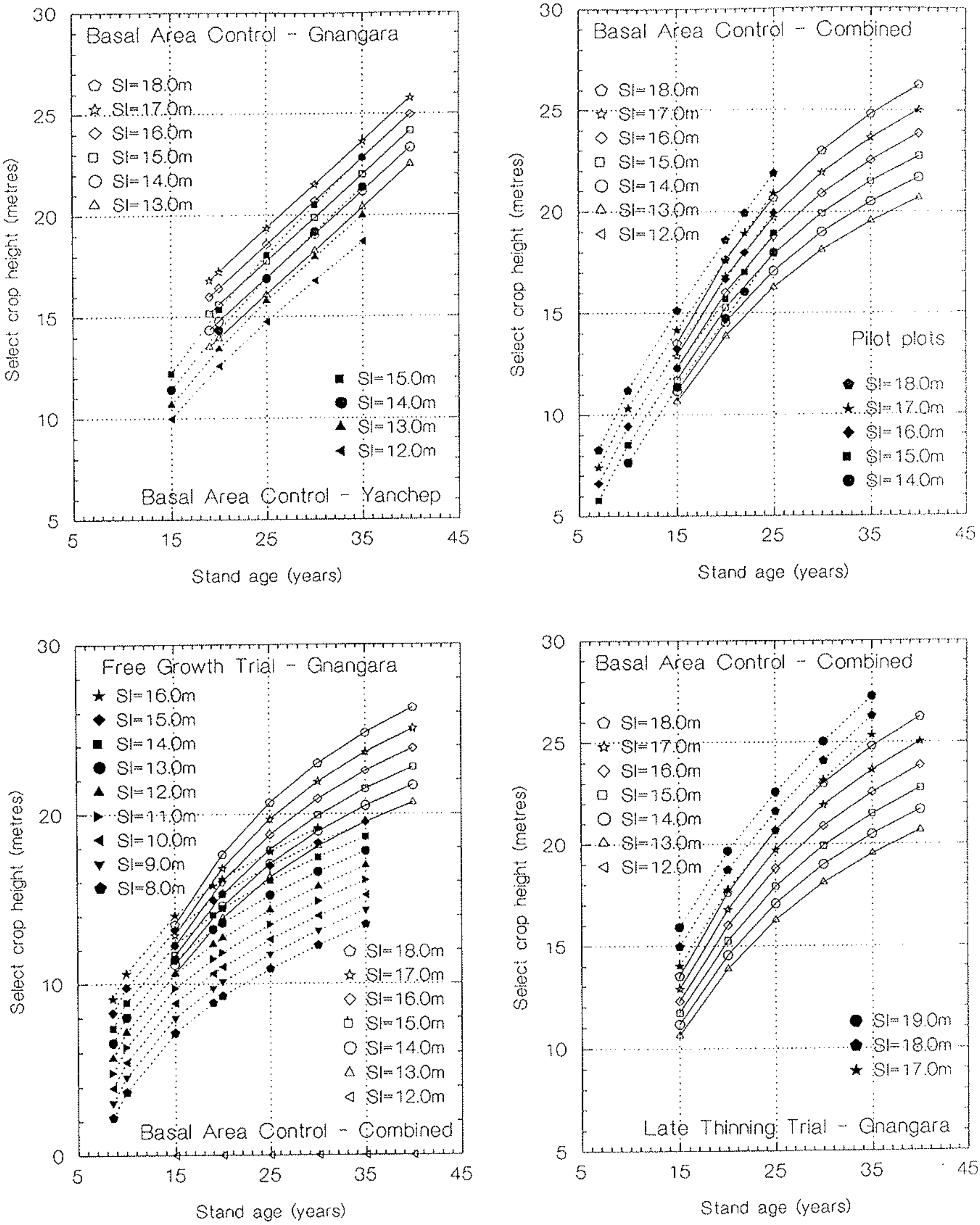


Figure 22. Height-age curves for the Basal Area Control series compared with similar curves obtained for the Pilot Plots (WP 48/66), Free growth Trial (WP 16/58) and Late Thinning Trial (WP 14/57). Data are indexed to site classes at age 19 years.

TABLE 30.

Per cent deviation of Select crop (100 s ha^{-1}) heights of the Late Thinning Trial (WP 15/57) from height indices calculated for 1 - Basal Area Control at Gnangara, 2 - Basal Area Control at Yanchep, 3 - Pilot Trial data and 4 - The three data sets combined

Age	Data set number																			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
10.8	-	-	-	-	-	-	-		-20	-20	6	-8	-18	-20	8	-9	-20	-20	6	-8
16.2	-17	-16	-10	-6	-14	-15	-6	-6	-12	-14	-3	-6	-3	-7	6	-1	-12	-13	-4	-5
17.2	-11	-11	-7	-3	-6	-7	-0	-0	-2	-4	4	1	3	-0	10	4	-3	-5	3	1
19.4	-8	-9	-8	-2	-4	-6	-2	0	0	-3	3	3	3	-0	7	5	-1	-4	1	2
22.6	-11	-13	-15	-5	-6	-8	-8	-2	-3	-7	-4	0	1	-4	1	2	-4	-7	-6	-1
24.6	-7	-9	-12	-2	-4	-8	-9	-1	1	-3	-2	3	0	-5	-2	2	-2	-5	-5	1
26.6	-3	-5	-10	1	-1	-5	-7	2	4	-1	-1	5	5	-1	1	5	1	-3	-4	3
28.6	-0	-3	-9	3	0	-4	-7	3	3	-1	-3	5	1	-5	-5	2	2	-3	-6	4
30.6	-2	-6	-13	1	-2	-7	-12	0	2	-4	-6	3	2	-4	-5	3	-0	-5	-8	2
32.6	-3	-7	-15	1	-0	-5	-10	2	2	-3	-7	4	3	-4	-5	4	1	-4	-8	3
34.5	-2	-7	-15	1	0	-4	-11	3	3	-3	-8	4	3	-3	-6	4	1	-4	-10	3
ALL	-7	-9	-11	-1	-4	-7	-7	0	-3	-6	-1	1	-0	-5	1	2	-3	-7	-4	1
	16				17				18				19				ALL			
Site index (m) for the Select crop at age 19.0 years.																				

extended site index equation for the range of sandy sites planted with *Pinus pinaster* on the coastal plain north of Perth. This combined equation has a standard error less than that for the combined Basal Area Control data but which covers almost the full height class and age range for data available for *P. pinaster* on the coastal plain sands north of Perth (Appendix 111).

TABLE 31.

Per cent deviations from Free Growth select height data of predictions from regressions for 1. Basal Area Control, 2. Basal Area Control + Pilot trial and 3. Basal Area Control + Pilot trial + Late Thinning trial. The deviations are tabled by age and site index(age 19 years) classes.

	Site index (m) for the select crop at age 19 years														
	8			9			10			11			12		
Age	Data set number														
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
8.6	32	36	-55	13	22	-49	-0	12	-41	-7	9	-28	-8	9	-15
13.5	26	-8	-35	21	-5	-27	19	-1	-17	16	-0	-12	12	1	-7
17.5	22	-11	-26	20	-7	-19	18	-4	-12	18	-1	-7	16	2	-2
23.6	19	-9	-17	18	-6	-12	14	-7	-12	10	-8	-12	10	-6	-8
31.6	7	-17	-22	0	-21	-26	-1	-21	-25	-4	-20	-23	-4	-18	-20
All	21	-2	-31	15	-3	-27	10	-4	-22	6	-4	-16	5	-2	-11

	Site index (m) for the select crop at age 19 years														
	13			14			15			16			All		
Age	Data set number														
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
8.6	-12	6	-9	-13	6	-2	-18	2	-1	-28	-6	-5	-7	9	-22
13.5	9	1	-3	7	2	-0	6	3	3	4	3	5	13	-0	-9
17.5	15	4	2	15	6	5	14	7	8	13	8	10	17	0	-4
23.6	10	-2	-4	7	-4	-4	8	-0	-0	3	-5	-4	11	-6	-9
31.6	-1	-12	-14	0	-9	-10	1	-7	-7	-8	-15	-14	-2	-17	-19
All	4	-1	-6	3	0	-2	2	1	1	-4	-3	-1	6	-2	-13

The Free Growth Trial includes poorer site indices of interest to management but the rate of height growth falls of rapidly after mid age (Fig. 22) due to nutrient deficiency. Fertiliser addition terminated at age 16 years and on such poor sites it is essential to add superphosphate at approximately 4 year intervals to maintain growth rates. For this reason the data was not used in the general site index equation. For growth under such circumstances the BA Control + Pilot regression provides the best estimate of the combined equations (Table 31).

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	Coefficient	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%

Volume production.

Examination of volume data revealed an excellent association with the product of final crop height and total standing basal area. This association was also excellent for the Pilot Plot trials on the adjacent brown limestone sands which, however, cover earlier age classes and a more northerly range of sites. In Figure 23 the three associations are compared showing the Pilot data to be slightly better 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	Coefficient	Stdev	t-ratio	p
Constant	4.5486	0.3201	14.21	0.000
FcHt*TBA	0.3189	0.0008	405.40	0.000

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

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 24.

The regressions for volume for the combined Basal Area Control and combined Basal Area Control + Pilot Trial data were tested against data sets for the Late Thinning Plots (WP 15/57) and the Free Growth Trial (WP 16/58). Volumes for the Late Thinning Trial were consistently overestimated by 4 to 5 per cent (Table 32). The data set includes site indices of 19, 20 and 21 (m) which are not present in the data for regressions. Inclusion of the data for WP 15/57 in the combined regression equation reduced total deviations to a 2 per cent overestimate.

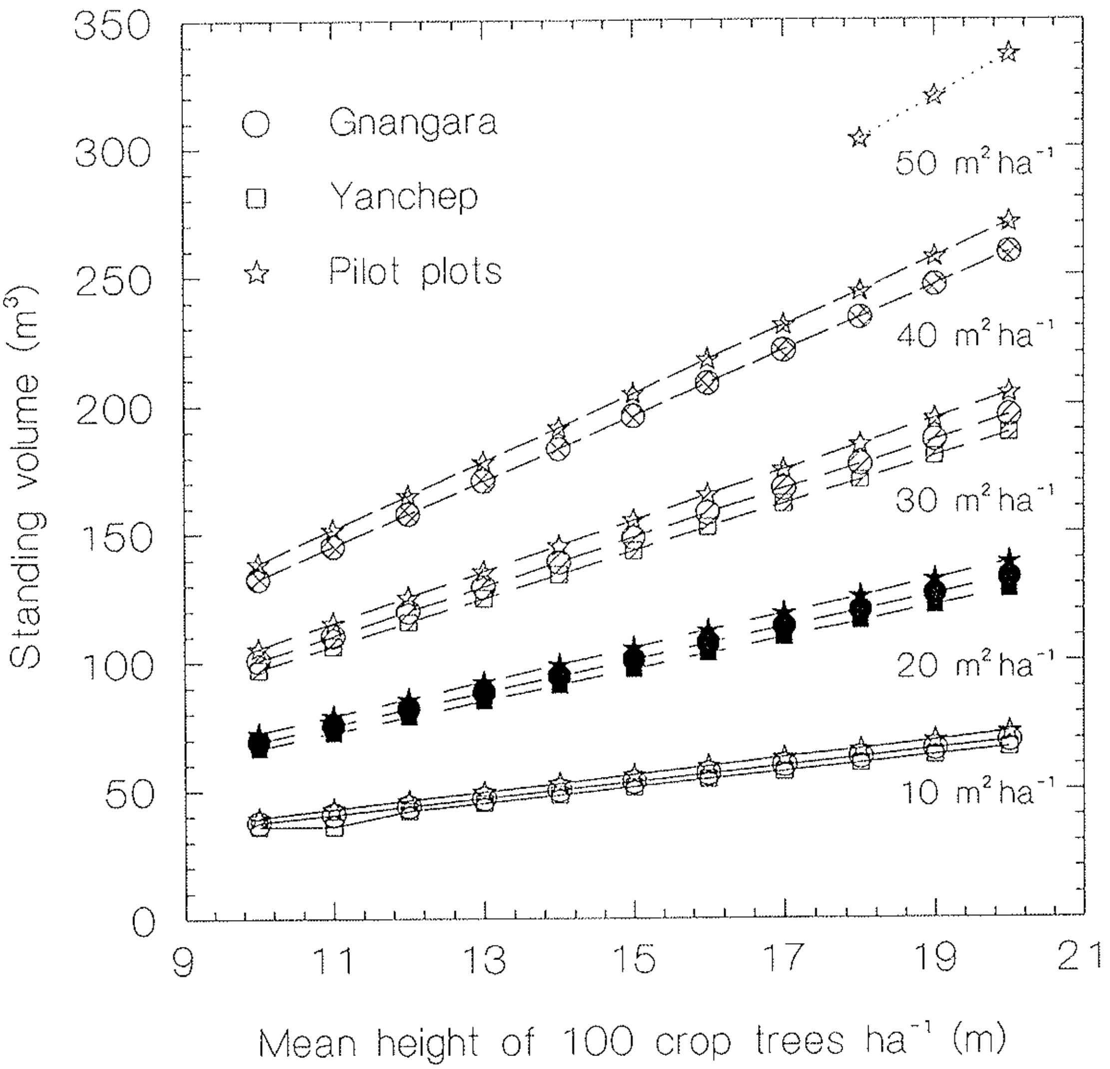
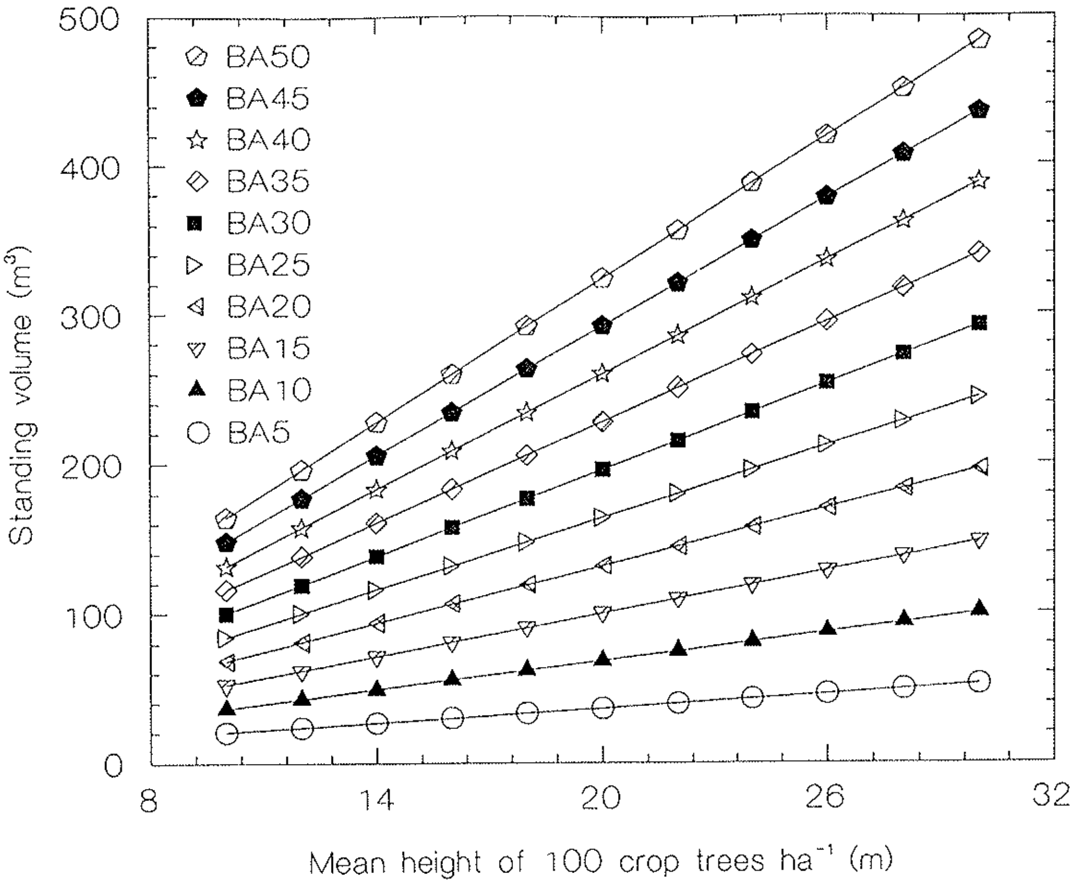


Figure 23. Variation of standing total volume (m^3 ha^{-1}) with height and basal area within the Pilot plots and the Basal Area Control Series at Gnangara and Yanchep.



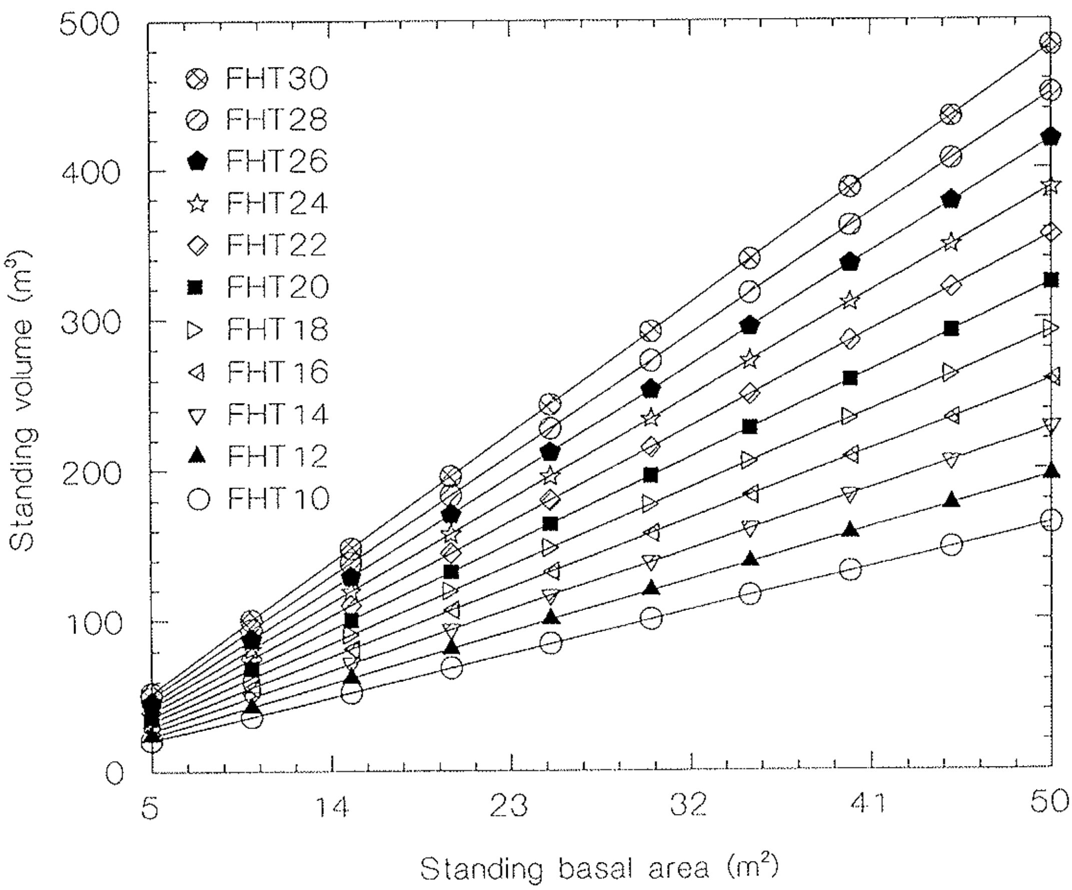


Figure 24. Association of standing volume under bark with stand height and basal area for all data on the Coastal Plain sands north of Perth.

TABLE 32.

Per cent deviation from Total Volume of WP 15/57 by volume equations for 1. Basal Area Control Combined and 2. Basal Area Control + Pilot Trial. The deviations are tabled within age and site index (at age 19 years) cells.

	Site index (m) at age 19 years											
	15		16		17		18		19		All	
	Number of data set											
Age	1	2	1	2	1	2	1	2	1	2	1	2
17.2	-7	-8	-9	-7	-10	-5	-15	-5	-7	-0	-10	-5
19.4	-8	-9	-10	-9	-9	-6	-10	-3	-5	-0	-9	-6
22.6	-7	-8	-6	-6	-5	-4	-4	-0	8	11	-4	-3
24.6	-7	-8	-6	-6	-6	-6	-3	-1	0	2	-5	-5
26.6	-6	-7	-4	-4	-5	-5	-1	1	2	4	-3	-3
28.6	-7	-9	-4	-5	-4	-4	3	4	1	2	-3	-3
30.6	-3	-5	-2	-3	-2	-2	2	3	7	7	-1	-1
32.6	-6	-7	-4	-6	-3	-4	2	2	4	5	-2	-3
34.5	-8	-9	-6	-7	-6	-7	2	2	4	4	-4	-5
All	-6	-8	-6	-6	-6	-5	-3	0	1	4	-5	-4

TABLE 33.

Per cent deviation from Total Volume of the Free Growth Trial by volume equations for 1. Basal Area Control Combined and 2. Basal Area Control + Pilot Trial. The deviations are tabled within age and site index (at age 19 years) cells.

	Site index (m) at age 19 years																			
	9		10		11		12		13		14		15		16		17		All	
	Number of data set																			
Age	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
14	-27	-34	-13	-17	-6	-9	-2	-5	-1	-3	4	3	5	3	4	3	6	4	-5	-8
18	-22	-27	-11	-14	-6	-8	-3	-5	-0	-2	2	1	3	2	4	3	9	8	-5	-7
32	-7	-9	-3	-4	1	-1	6	5	8	7	10	9	10	10	8	7	8	7	3	2
All	-19	-23	-9	-12	-4	-6	0	-2	2	1	6	4	6	5	5	4	8	6	-2	-4

The regression equation is

TotVOL = 7.54 + 0.309 FcHT*TBA

Predictor Coefficient Stdev t-ratio p

Constant	7.5408	0.3515	21.45	0.000
FCHT*TBA	0.3089	0.0008	403.49	0.000

s = 8.117 R^2 = 98.8% R^2(adj) = 98.8% n = 1932

Deviations of predicted values from volume data for the Free Growth Trial showed the combined regressions to over estimate the poor 9-12 m site indices and to under estimate the volumes for the 14-17 m height indices (Table 33). Except for the 9 and 10 m height classes, not present in the combined data sets, the estimates were reasonably satisfactory. For the reasons explained above for site index the Free Growth data sets was not combined with that of the Basal Area Control or Pilot Trial.

Merchantable volumes - For each measurement the following tree volumes were calculated :-

1. Total volume of the tree.
2. Volume to height 10 m.
3. Volume to height 7.5 m (pruned height of the Select Crop).
4. Volume to height 5.0 m (pruned volume of the remaining final crop).
5. Volume of logs within a top diameter limit (TDL) of 6.0 -10.0 cm diameter.
6. Volume within the TDL 10.0 - 18.0 cm.
7. Volume within the TDL 18.0 - 23.0 cm.
8. Volume within the TDL 23.0 - 30.0 cm.
9. Volume within the TDL 30.0 + cm.

Each of the above volume estimates were separated for the Select Crop (7.5 m), Final Crop (5.0 m), Other than Selects and Thinned Stems with totals before and after thinning. The detailed per hectare summary provided by the "pine s" program (Appendix 2) also separates the volumes to TDL's into 2.0 cm DBHob classes.

Volume to 10.0, 7.5 and 5.0 m stand height represent expressions of volume assortments of particular interest to the market. Volume to 10.0 m approximates the average log length available to the saw log market from a stand on a high site quality maintained, at least initially, with closely spaced trees. Volumes above this height limit are influenced by the large branches of the permanent, mature crown and are mainly suited for pulp. Volume to 7.5 m represents the stem volume of select trees high pruned under early regimes and is of a veneer or peeler quality. In practice all 250 s ha^{-1} of the current final crop selections were pruned to 5.0 m and hence provide quality wood even when grown at wide initial spacings and or low stand densities. Without this pruning the butt log of stands maintained at low stand densities in early life will generally be impaired due to heavy branch defects.

The relationship between these volumes and total volume are expressed as percentages in Table 34. The merchantable percentages decrease with increasing stand development mainly due to the continued height growth. Values calculated for the

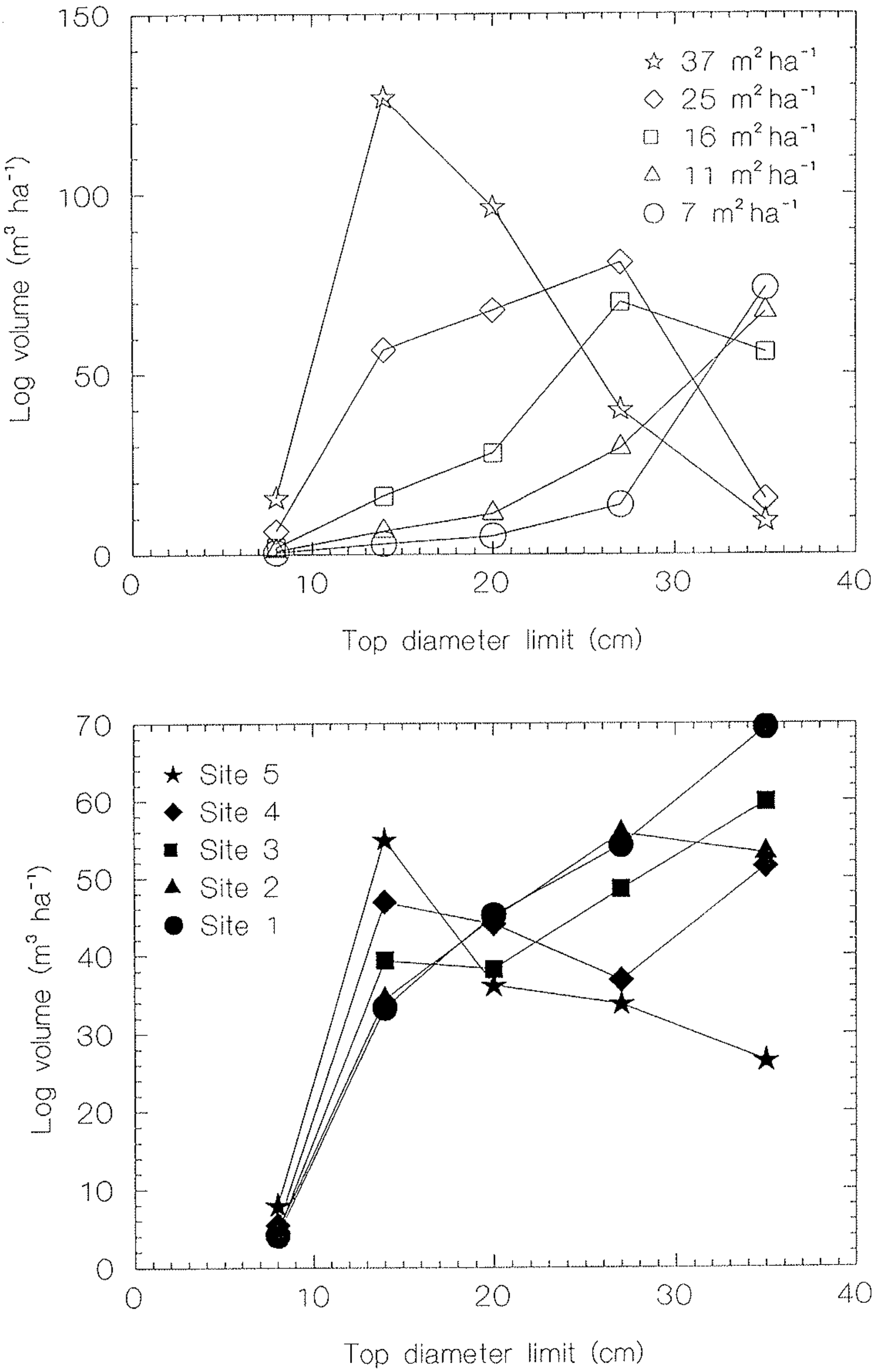


Figure 25. Volume assortments obtained for different top diameter limits for logs over a range of fixed stand density classes and site classes at Gnangara.

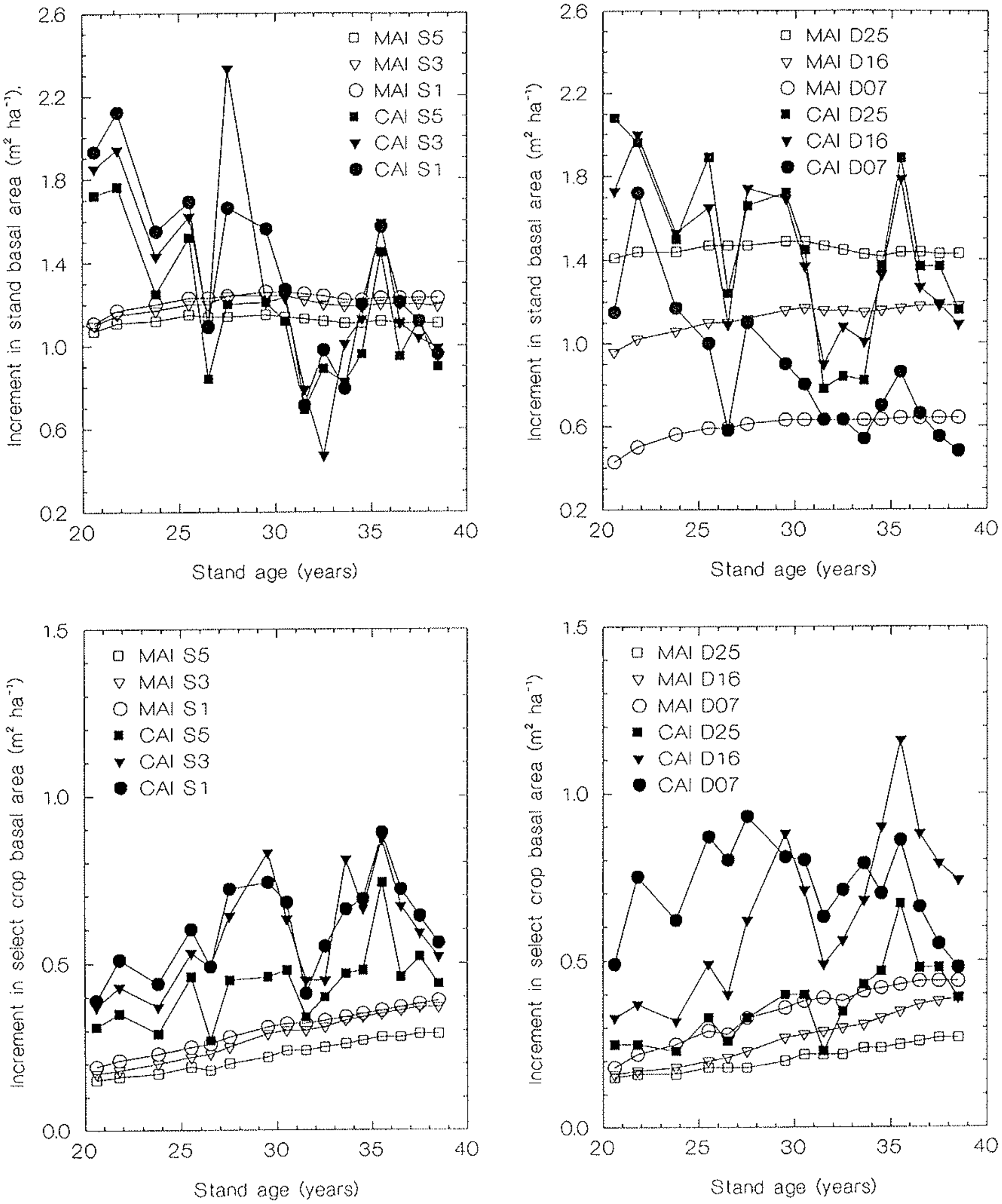


Figure 26. CAI and MAI curves for site classes and density treatments of the total stand and Select crop at Gnangara.

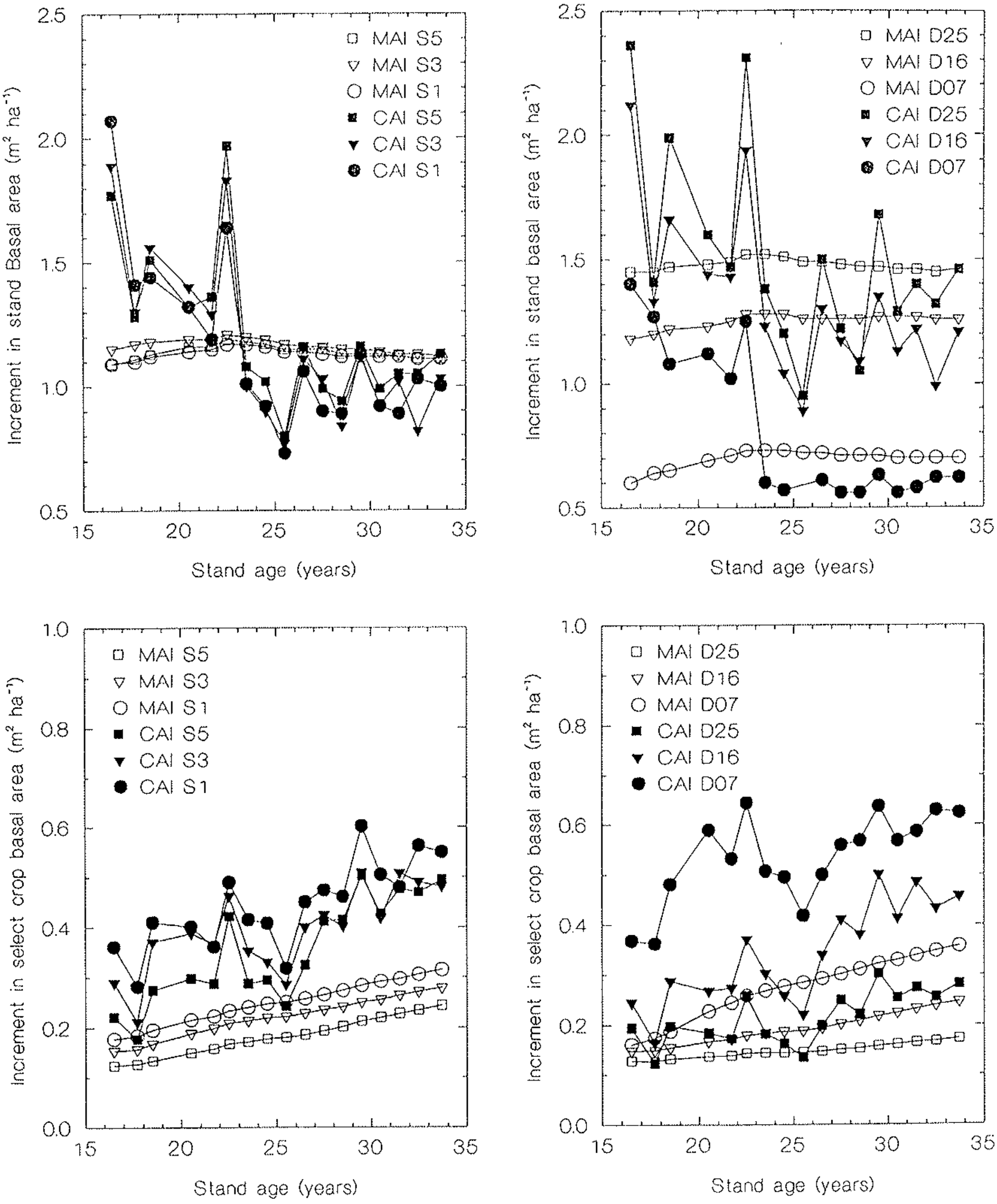


Figure 27. CAI and MAI curves for site classes and density treatments of the total stand and Select crop at Yanchep.

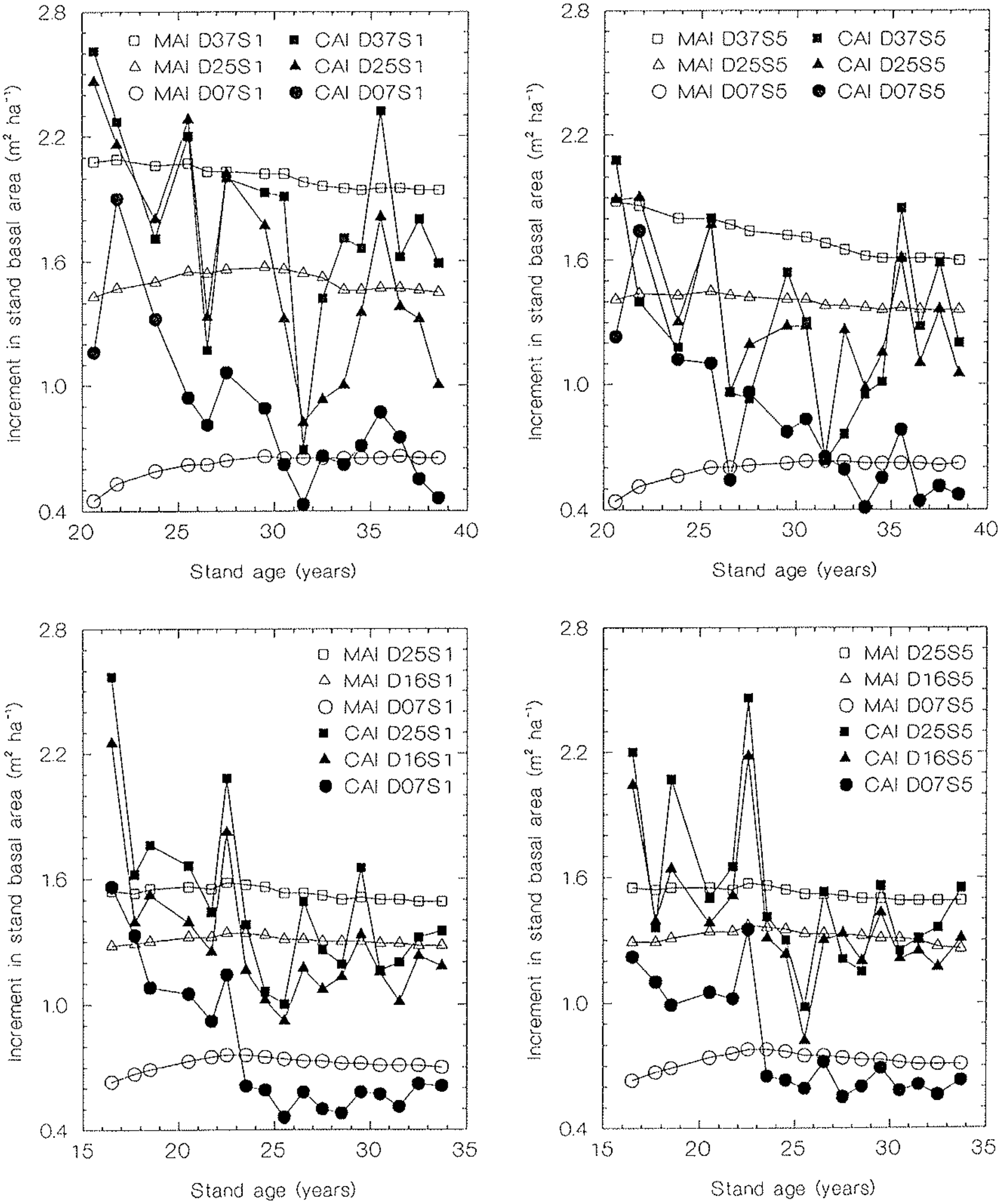


Figure 28. CAI and MAI curves for extremes of stand density and site classes at Gnangara and Yanchep.

Select Crop are virtually identical to those for the whole stand and have not been included.

TABLE 34.

Merchantable volumes (m^3 ha^{-1}) to 10.0 (V10), 7.5 (V7.5) and 5.0 (V5.0) metres stand height expressed as a percentage of the total stand volume under bark at Gnangara. Values are summarised into stand density and site classes.

	19 years			28 years			38 years		
Type	V10	V7.5	V5.0	V10	V7.5	V5.0	V10	V7.5	V5.0
Class				Stand density					
7	85.6	71.0	52.0	75.4	43.7	61.0	63.5	50.5	35.7
11	86.1	71.7	52.5	75.8	44.1	61.4	66.0	52.6	37.2
16	85.9	71.5	52.3	76.2	44.3	61.8	66.0	52.6	37.3
25	85.6	71.2	52.1	76.2	44.4	61.8	67.2	53.7	38.1
37	86.8	72.5	53.1	76.5	44.6	62.1	67.6	54.0	38.2
Class				Site Class					
1	82.6	68.0	49.3	73.2	42.2	59.0	64.6	51.4	36.3
2	84.5	69.9	50.9	74.2	42.9	60.0	64.8	51.5	36.5
3	87.0	72.6	53.2	76.9	45.0	62.5	66.7	53.3	37.7
4	85.9	71.5	52.4	76.4	44.5	61.9	66.7	53.2	34.7
5	91.9	78.3	58.3	81.2	48.1	66.5	71.2	57.2	40.8

Past management prescriptions to prune 250 s ha^{-1} to 5.0 m guaranteed that 35-40 per cent of the total volume produced will be available as quality mill logs, even in stands subject to heavy and early reductions in stand density.

Total volume is separated into log volumes to 6-10, 10-18, 18-23, 23-30 and 30+ cm top end diameter (TDL) classes for each of the 5 stand density classes (top) and site classes (bottom), at stand age 38 years, in Figure 25. Virtually the whole crop for the 7 and 11 m^2 ha^{-1} classes, which in practice were pruned to at least 5 metres height, meets saw log sizes of minimum TDL of 25 cm. Most volume in the lightly thinned 37 m^2 ha^{-1} treatment is in logs under 20 cm TDL and is suitable for particle board logs and or small saw logs. The most favourable distribution is the 16 m^2 ha^{-1} treatment which provided near maximum for volumes above the 20 cm TDL and total volumes similar to those of the 37 m^2 ha^{-1} treatment.

Culmination of Increment

The stand ages or conditions at which the Current Annual Increment commenced to decline, and intersected or fell below the Mean Annual Increment are usually regarded as important from the viewpoint of stand timber production. These trends for both the Gnangara and Yanchep data are presented in Figures 26, 27 and 28.

Stand Age - For the whole stand CAI decreased with age for all site classes and the range of stand densities compared (Figs. 26, 27). For the select crop it increased over the trial period (Figs. 26, 27).

Site Class - Site class, excepting the obviously poorest S5, had little influence on increment of the whole stand and select crop at Gnangara (Fig. 26). MAI for the stand was reasonably level for site classes over the trial period at both centres, with a tendency for a decline at Yanchep after age 27 years (Fig. 27). For the select crop it continued to increase over the trial period with a greater distinction between productivity on extreme sites (Table 28).

Curves fitted to the current and mean increment data cross at about 30 to 35 years of age for the whole stand at Gnangara and 23 years of age at Yanchep. For the select crop there is no apparent culmination of increment pattern over the range of sites studied.

Stand Density - MAI decreased within the study period for the densest 37 m^2 ha^{-1} treatment as a result of mortality. This was also the case, to a lesser extent, with the 25 m^2 treatment at both centres (Figs. 26, 27). For the 16-7 m^2 treatments there was a consistent, gradual increase at Gnangara while at Yanchep MAI remained static for these densities. MAI for the select crop continued to increase with time at both centres with no indication that MAI and CAI would intersect or culminate at Yanchep but with an indication of intersection after age 40 years at Gnangara. Within the range studied there is a stand density at which increment appeared to decrease least for the whole stand while approaching the maximum increase for the select crop. In Figure 26 it can be seen that this optimum density was the 16 m^2 ha^{-1}. This treatment provided near maximum CAI and although less than the highest MAI, it tended to approach this with increasing stand age, due largely to mortalities in the highest densities. It has previously been suggested that the 16 m^2 ha^{-1} treatment provided a very favourable log size distribution (Fig. 25), but at the expense of some total volume loss (Table 27, Fig. 11). Volume loss at this stand density was not significantly different to the 37 m^2 ha^{-1} treatment until 1978 at age 32 years at Gnangara. The 16 m^2 treatment was not significantly less than the 25 m^2 treatment volume at either Gnangara or Yanchep throughout the trials.

Figure 28 is included to indicate the range of MAI and CAI,s measured in the trials.

Combined Affects of Treatments

All treatments had a positive influence on increment during the trial period. The relative effect of site, stand density and fertiliser addition on stand development can be appreciated by comparing their impact on stand dimensions at the final measurement (Figs. 29 and 30). Treatment responses in the trials at the two sites were similar.

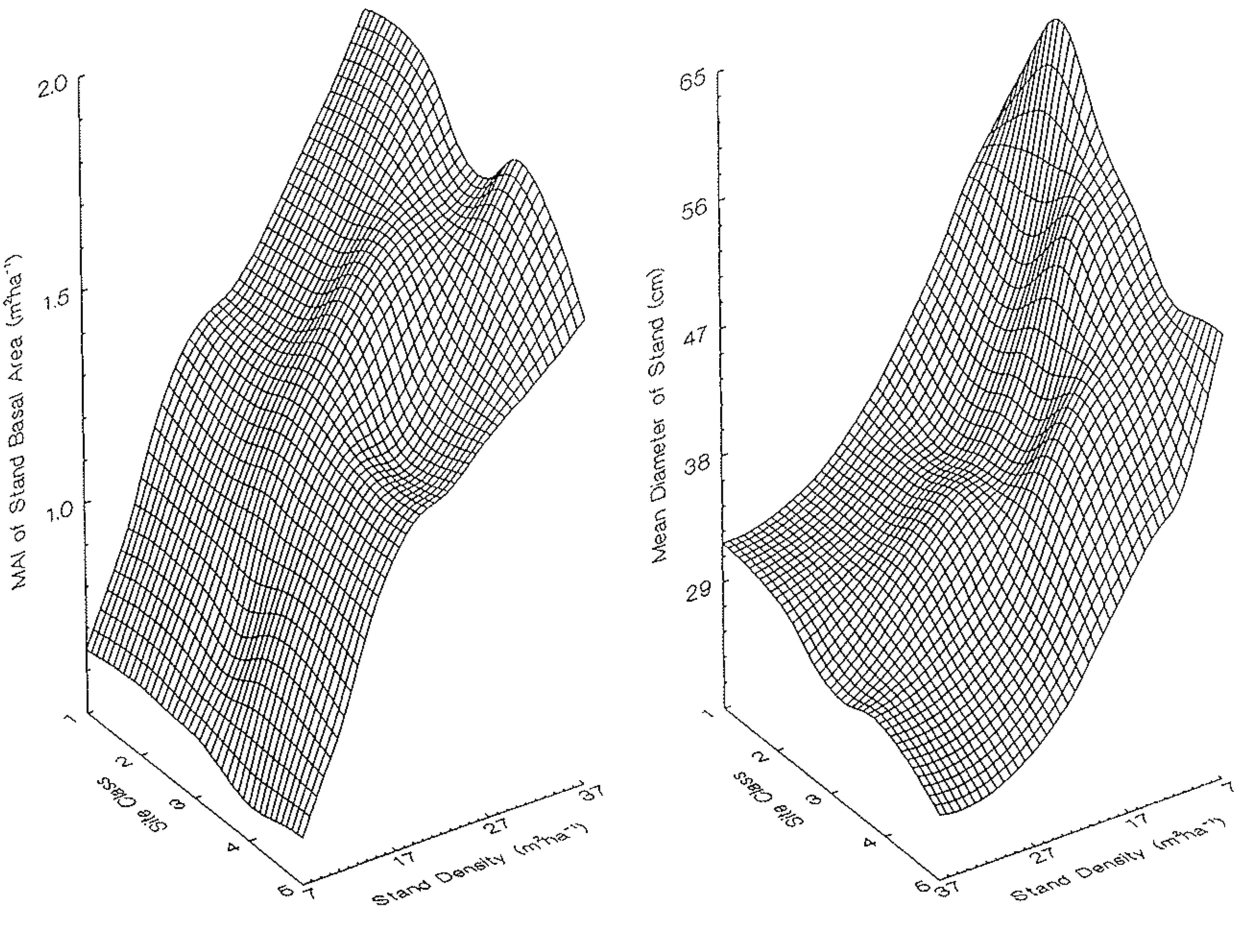


Figure 29. Graphic representation of combined effects for stand basal area and diameter at Gnangara.

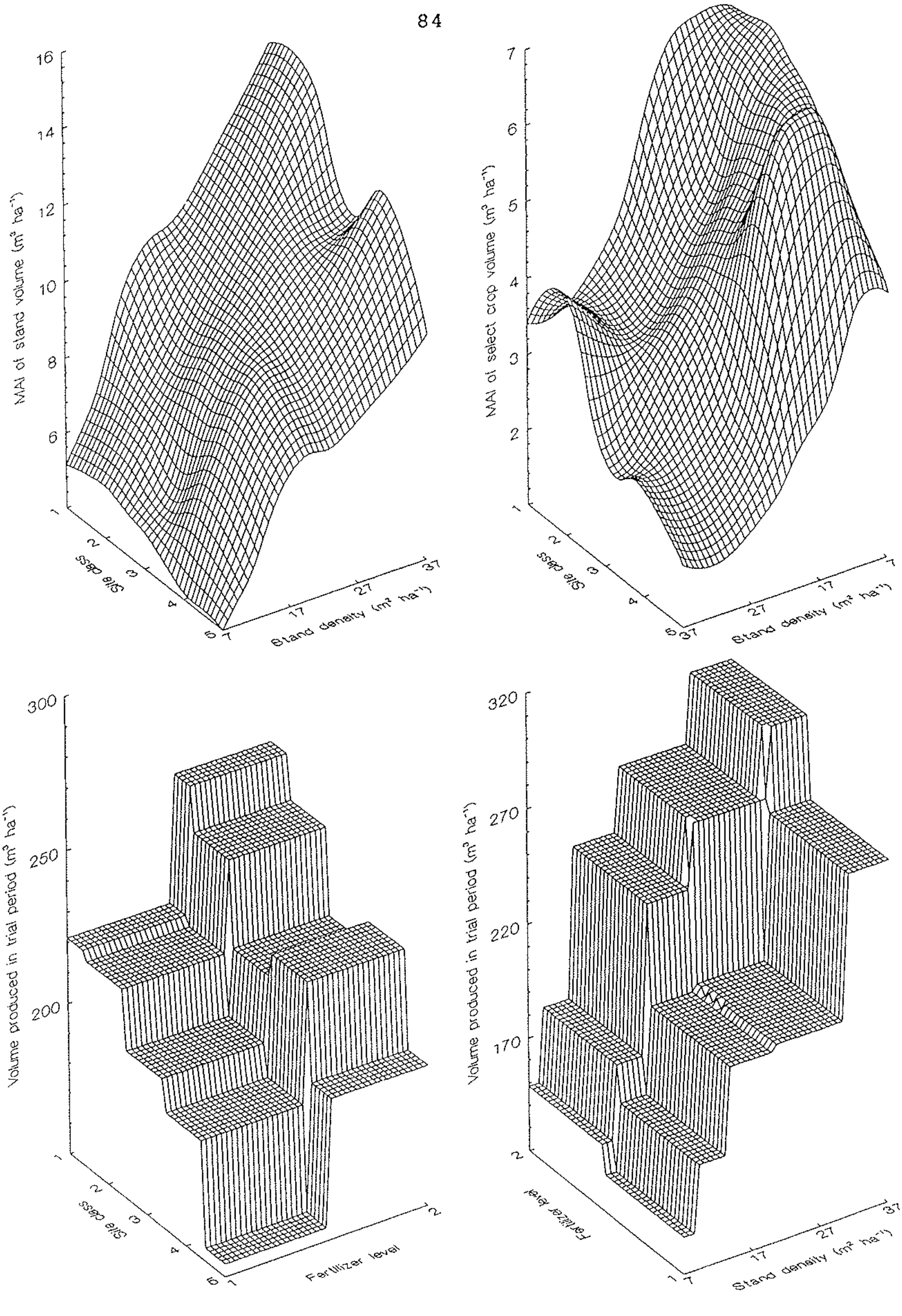


Figure 30. Graphic representation of volume production for the combined effects of treatments at Gnangara.

The combined effects considered for the older, Gnangara trial which also represent the better site classes at Yanchep. Volume production over the trial period and MAI volume (Fig. 30 upper) increased with increasing stand density and with improved site class (Fig. 11). There was no evidence for significant interaction between density and site for basal area, height or volume production (Fig. 21) detected at either centre. Drought mortality occurred in the 25 and 37 m^2 ha^{-1} treatments (Table 5) but these had no important influence on the overall volume production. Volume increase was proportional to increasing stand density for both poor and good site potentials and medium (or nil) and high fertiliser applications at both sites. Fertiliser response was of the same proportion of the total stand over all site classes at Gnangara (Figs. 29, 30(lower)) but as discussed above was less on the higher site classes than the lower site classes at Yanchep (Fig. 21).

The importance of stand density to quality log production results from the response of diameter to reduced competition. Although MAI for basal area and volume decrease significantly with decreasing stand density (Figs. 29 and 30) stand diameter increases significantly with decreasing stand density for all site classes (Figs. 3, 29). Lowering stand density to reduce competition on a fixed number of stems, such as the Select Crop (100 s ha^{-1}), produces significantly greater volumes on this portion of the crop (Tables 20, 21, Fig. 30 (upper)). Thus early and regular thinning favour both diameter size and volume of a selected portion of the initial stocking (Fig. 24).

Strategies for plantation thinning rest on a balance of the size of the tree that can be marketed and the price that is paid for that commodity. Where a market offers for small sized material, such as for medium density particle board, high initial stockings and increasing stand density favour maximum return of this product. Where minimum diameter is a limitation to markets, thinning will favour earlier yields by allowing mean diameter to increase more rapidly, but at the cost of total volume available. The current local trend favours particle board material and high stand densities, even on the less fertile and drought prone sites, will favour maximum product amount of total volume that can be marketed. Mean diameter of the crop remaining after the particle board thinning will not have maximum diameter potential but, in the absence of current interest in pruning, will have smaller branch stubs resulting from the high initial stand density. This probably compensates for larger returns which may result from maximum diameter, from decreased stand density, but with quality defect due to heavy, more persistent lower branches in the absence of pruning.

The studies show that volume growth increases directly with stand density on all sites and fertiliser regimes and that mean stand diameter increases directly with decreasing stand density on all sites and fertiliser regimes. Plantation strategies are hence an economic compromise between product quality, market demand and price.

The question of a critical basal area does not come into effect within the range of densities studied at Gnangara. An associated study with Free Growth plots revealed that volume increment decreased significantly for stockings below a threshold of 1200 stems ha^{-1} but did not differ with stockings above this threshold. Obviously it is the density at any age and not stocking which will determine the critical limit and in the Free growth trial for age 19 years (at which age the Gnangara Basal Area trial started) the 25 m^2 density represented the critical limit. The 37 m^2 basal area was associated with the critical limit after 40 years. Table 4 shows that the 25 m^2 treatment in the current Basal area trial went below the 1000 stem stocking at age 22 years and the 37 m^2 treatment went below 1000 stems at age 28 years. Densities below 37 m^2 ha^{-1} are below any critical basal area on these sites. At Yanchep there was no significant difference in volume increment between the 16 and 25 m^2 ha^{-1} treatments and it may be surmised that the 16 m^2 treatment is the critical level as well as a good compromise between total volume and quality volume production. In the associated Pilot Plot trials where unthinned stand densities were measured, however, Total volme increment was increased significantly by basal areas above 25 m^2, which was the maximum studied in the current trial. Critical stand density limits will vary with site and species but for P. pinaster on sandy sites north of Perth the 25-30 m^2 ha^{-1} limit is suggested as a workable maximum. This corresponds to the threshold found for drought deaths in the region.

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 (Fig. 17). 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.

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 26, 27). 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 27). 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 F1 and F2 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.

TABLE 35.

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

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

Performance of treatment means for Years, Density, Site and Fertiliser main effects for repeated measures analysis (Table 28) for N, P, K, Mn and Zn are summarised in Figure 30. 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 F1 and F2 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 26). By 1976 foliar values were not significantly related to treatments except for foliar N which

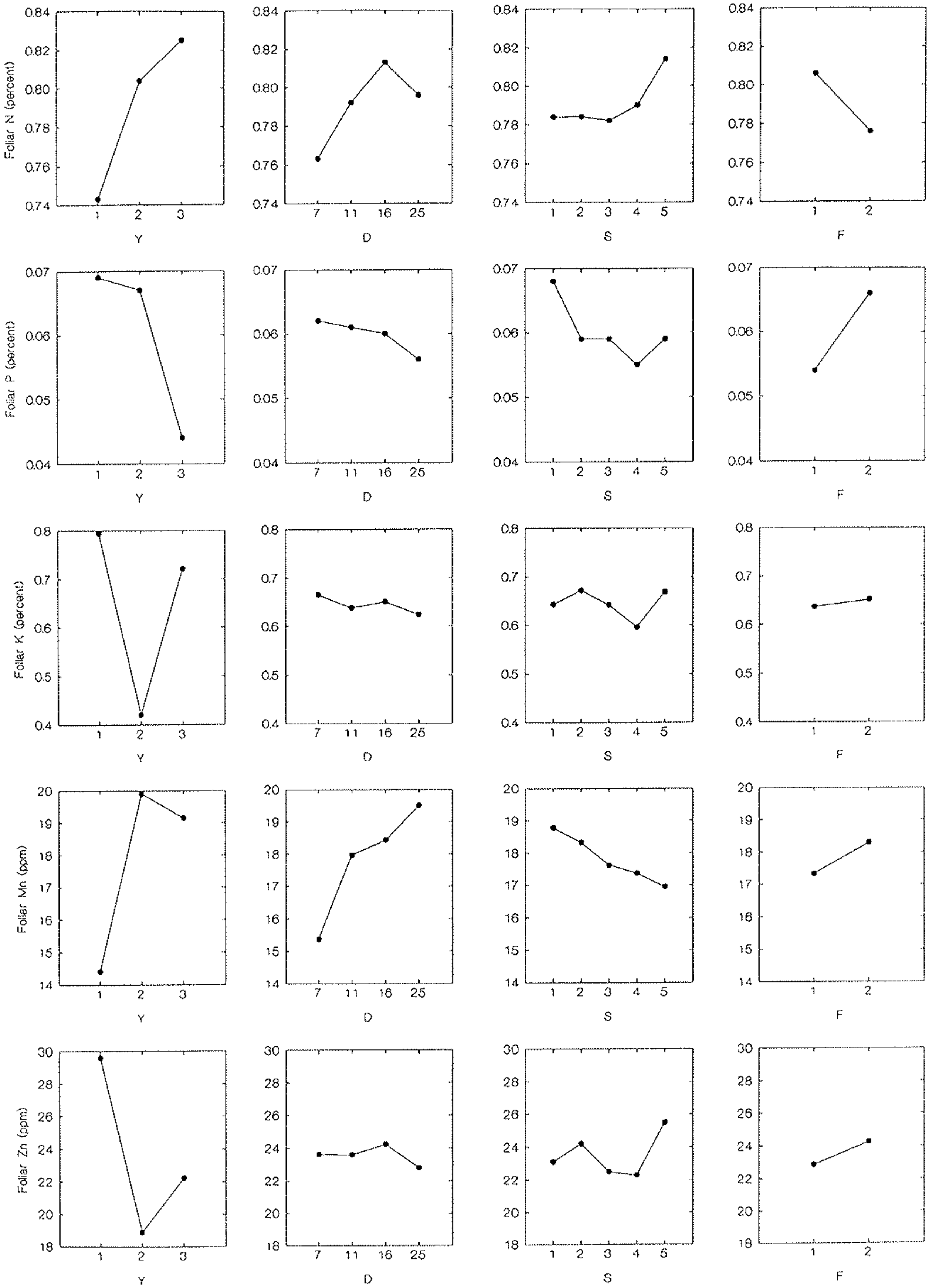


Figure 31. Main effects plots for Years, Density, Site and Fertiliser treatments for foliar sampling in 1971, 1973 and 1976 at Yanchep.

showed a significant decrease (.041 level) in the fertilised treatment in 1976 (Table 27).

In Table 35 fertiliser by site data for the 1973 sampling are presented to test the assumption that variable response to fertiliser could be due to different nutrient capacities of blocks over the site range. The F1 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 F1 or F2 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 are above 0.1 per cent (Table 25) 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 (Tables 25, 26). 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.

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APPENDIX 1

Plot allocation to site groups and randomisation into density and fertiliser treatments in the trials. 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
		GNANGARA				
$37\ m^2\ ha^{-1}$	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
		YANCHEP				
$25\ m^2\ ha^{-1}$	Nil	14	37	*10	*41	*47
	P+N	5	*6	*53	21	22
$16\ m^2\ ha^{-1}$	Nil	*1	12	13	39	45
	P+N	4	30	*24	34	*46
$11\ m^2\ ha^{-1}$	Nil	54	11	17	20	*29
	P+N	*2	*16	51	55	43
$7\ m^2\ ha^{-1}$	Nil	52	*7	28	19	*23
	P+N	3	*9	8	*48	*42
Thinning	Fertiliser	1	2	3	4	5
Treatment		Site Block				

APPENDIX 11

PRODUCED BY PINE ANALYSIS ON 10/ 7/1995 USING JPL = 4 NBT = 0 MEASURED JAN80
STANDARD LOG LENGTHS= 1.8 1.8 1.8 1.8 1.8

PLOT NO. 1 W/P NO. 20/65 BASAL AREA CONTROL OF THINNING GNANGARA

PER HECTARE SUMMARY

	SELECTS (7.5M)	SELECTS (5.0M)	OTHER THAN SELECTS	FELLED	DEAD	BEFORE THINNING	AFTER THINNING
MEAN DIAM. O.B.	28.26	26.22	24.36	0.00		25.35	25.35
MEAN DIAM. U.B.	22.12	20.51	19.05	0.00		19.83	19.83
BASAL AREA O.B.	6.28	8.11	20.46	0.00	0.00	34.85	34.85
BASAL AREA U.B.	3.84	4.97	12.52	0.00		21.33	21.33
STOCKING	100.00	150.00	425.00	0.00	0.00	675.00	675.00
VOLUME TOTAL	47.50	63.58	161.21	0.00	0.00	272.29	272.29
VOLUME TO 10.0M	33.77	44.08	111.18	0.00	0.00	189.03	189.03
VOLUME TO 7.5M	27.12	35.30	89.03	0.00	0.00	151.45	151.45
VOLUME TO 5.0M	19.32	25.09	63.28	0.00	0.00	107.69	107.69
VOL TDL 6.0-10.0	1.27	3.12	11.26	0.00	0.00	15.65	15.65
VOL TDL 10.0-18.0	16.69	30.32	82.79	0.00	0.00	129.80	129.80
VOL TDL 18.0-23.0	25.66	25.17	40.66	0.00	0.00	91.49	91.49
VOL TDL 23.0-30.0	0.00	0.00	12.83	0.00	0.00	12.83	12.83
VOL TDL 30.0 +	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN HEIGHT	21.80	22.57	22.25	0.00		22.26	22.26

PREDOMINANT HEIGHT 23.6

TOP HEIGHT 24.6

NUMBER OF TREES 27 TREE AGE 33.60 PLOT AREA 0.040

APPENDIX 11 Ctd.

PLOT NO. 1 W/P NO. 20/65 BASAL AREA CONTROL OF THINNING GNANGARA

DETAILED PER HECTARE SUMMARY

SELECTS (7.5M)

DBHOB * CLASS *	VOLUME TDL* 6.0-10.0*	VOLUME TDL* 10.0-18.0*	VOLUME TDL* 18.0-23.0*	VOLUME TDL* 23.0-30.0*	VOLUME TDL* 30.0+ *	B.A.O.B * *	NUMBER OF * STEMS
26- 28	0.66	7.89	11.77	0.00	0.00	3.04	50.00
28- 30	0.61	8.80	13.89	0.00	0.00	3.24	50.00

SELECTS (5.0M)

DBHOB * CLASS *	VOLUME TDL* 6.0-10.0*	VOLUME TDL* 10.0-18.0*	VOLUME TDL* 18.0-23.0*	VOLUME TDL* 23.0-30.0*	VOLUME TDL* 30.0+ *	B.A.O.B * *	NUMBER OF * STEMS
24- 26	2.24	20.61	13.29	0.00	0.00	5.09	100.00
26- 28	0.30	4.65	5.76	0.00	0.00	1.47	25.00
28- 30	0.57	5.05	6.12	0.00	0.00	1.56	25.00

OTHER THAN SELECTS

DBHOB * CLASS *	VOLUME TDL* 6.0-10.0*	VOLUME TDL* 10.0-18.0*	VOLUME TDL* 18.0-23.0*	VOLUME TDL* 23.0-30.0*	VOLUME TDL* 30.0+ *	B.A.O.B * *	NUMBER OF * STEMS
16- 18	1.00	2.50	0.00	0.00	0.00	0.55	25.00
20- 22	3.07	19.37	0.00	0.00	0.00	3.39	100.00
22- 24	2.68	24.13	1.22	0.00	0.00	4.04	100.00
24- 26	1.65	15.27	9.25	0.00	0.00	3.76	75.00
26- 28	1.83	14.82	15.87	0.00	0.00	4.35	75.00
28- 30	0.63	4.22	7.95	0.00	0.00	1.69	25.00
36- 38	0.39	2.49	6.38	12.83	0.00	2.69	25.00

FELLED

DBHOB * CLASS *	VOLUME TDL* 6.0-10.0*	VOLUME TDL* 10.0-18.0*	VOLUME TDL* 18.0-23.0*	VOLUME TDL* 23.0-30.0*	VOLUME TDL* 30.0+ *	B.A.O.B * *	NUMBER OF * STEMS

APPENDIX 111 - HEIGHT DATA FOR THE COMBINED SITE INDEX EQUATION

Data are the mean heights of a select crop of 100 stems ha^{-1} for progressive measurements in

1. WP 20/65 - Basal area control at Gnangara.
2. WP 54/66 - Basal Area Control at Yanchep.
3. WP 48/66 - Pilot Plot trials from Yanchep to Karakin.
4. WP 14/57.- Late Thinning Studies at Gnangara.

Number of Trees in Age-SI Classes

Site index (19 years)

Age	12	13	14	15	16	17	18	19	20	21	ALL
7	0	0	0	28	45	8	0	0	0	0	81
8	0	0	0	28	45	8	0	0	0	0	81
9	0	0	0	28	45	8	0	0	0	0	81
10	0	0	0	28	45	8	0	0	0	0	81
11	0	0	0	28	45	8	0	5	6	3	95
13	0	0	0	28	45	8	0	0	0	0	81
15	1	12	14	11	2	0	0	0	0	0	40
16	0	0	0	0	2	2	7	5	6	2	24
17	1	12	14	11	4	2	7	5	6	3	65
18	1	12	14	39	47	8	0	0	0	0	121
19	1	14	16	18	13	23	14	7	6	3	115
20	0	0	0	28	45	8	0	0	0	0	81
21	1	12	14	11	2	0	0	0	0	0	40
22	1	12	14	39	47	8	0	0	0	0	121
23	1	12	14	11	4	2	7	5	6	3	65
24	1	14	16	18	11	21	7	2	0	0	90
25	1	12	14	11	4	2	7	5	6	3	65
26	1	14	16	18	11	21	7	2	0	0	90
27	1	14	16	18	13	23	14	5	5	3	112
28	1	14	16	18	11	21	7	2	0	0	90
29	1	12	14	11	4	2	7	4	3	1	59
30	1	14	16	18	11	21	7	2	0	0	90
31	1	14	16	18	13	22	14	7	5	3	113
32	1	14	16	18	11	21	7	2	0	0	90
33	1	14	16	18	13	20	12	5	6	2	107
34	1	14	16	18	11	20	7	2	0	0	89
35	0	2	2	7	11	21	13	4	6	2	68
36	0	2	2	7	9	20	7	2	0	0	49
37	0	2	2	7	9	20	7	2	0	0	49
39	0	2	2	7	9	20	7	2	0	0	49
ALL	18	244	280	548	587	376	165	75	61	28	2382

APPENDIX 111 Ctd.

COMBINED HEIGHT DATA FOR SITE INDEX EQUATION

Minimum select height for Age - SI Classes

Site index (19 years)

Age	12	13	14	15	16	17	18	19	20	21
7	-	-	-	5.0	4.8	5.1	-	-	-	-
8	-	-	-	6.1	5.9	6.2	-	-	-	-
9	-	-	-	7.0	7.0	7.2	-	-	-	-
10	-	-	-	7.7	7.8	8.1	-	-	-	-
11	-	-	-	8.4	8.6	9.2	-	10.7	11.0	11.9
13	-	-	-	9.9	10.6	11.4	-	-	-	-
15	9.9	9.5	10.3	11.5	12.5	-	-	-	-	-
16	-	-	-	-	12.5	13.1	13.1	14.1	14.4	15.9
17	11.3	11.0	12.0	13.2	13.7	14.2	14.9	15.8	16.2	17.4
18	11.7	11.6	12.5	13.1	14.3	15.3	-	-	-	-
19	12.1	12.1	13.0	14.0	14.9	15.6	16.2	17.4	17.8	18.8
20	-	-	-	14.0	15.7	17.4	-	-	-	-
21	12.6	13.1	13.9	14.9	16.1	-	-	-	-	-
22	13.3	13.6	14.4	15.4	16.5	18.3	-	-	-	-
23	13.9	14.0	14.7	15.7	15.8	16.2	17.3	17.9	18.7	19.7
24	13.9	14.0	14.8	15.7	17.1	18.3	18.9	19.5	-	-
25	14.9	14.9	16.2	16.8	17.1	17.2	18.2	19.4	19.8	20.1
26	15.3	15.3	16.5	16.9	17.9	18.4	19.7	19.6	-	-
27	15.7	16.0	17.0	17.5	18.6	18.6	19.2	20.0	21.5	21.6
28	16.0	16.2	17.2	17.9	19.0	19.5	20.4	20.4	-	-
29	16.4	16.4	17.5	18.6	19.8	19.2	20.3	21.7	22.7	22.4
30	16.8	16.8	18.4	18.4	19.8	20.5	21.0	20.7	-	-
31	17.1	17.0	18.2	18.9	20.4	20.2	20.7	21.2	22.5	23.3
32	17.4	17.4	18.5	19.0	20.7	20.9	21.4	21.8	-	-
33	17.9	17.9	18.9	19.4	21.1	21.4	21.8	22.1	23.5	24.8
34	18.3	18.3	19.4	19.8	21.4	21.4	22.3	22.2	-	-
35	-	20.1	21.3	20.3	22.1	22.1	22.6	22.8	24.2	25.5
36	-	20.7	21.7	20.3	22.3	22.3	23.3	23.4	-	-
37	-	21.0	22.3	20.6	22.4	22.8	23.3	23.5	-	-
39	-	21.7	23.0	21.3	23.1	23.5	24.0	24.2	-	-

APPENDIX 111 Ctd.

COMBINED HEIGHT DATA FOR SITE INDEX EQUATION

Maximum select height for Age - SI Classes

Site Index (19 years)

Age	12	13	14	15	16	17	18	19	20	21
7	-	-	-	6.6	6.8	7.0	-	-	-	-
8	-	-	-	7.8	8.0	8.1	-	-	-	-
9	-	-	-	9.0	9.1	9.4	-	-	-	-
10	-	-	-	9.6	9.9	10.6	-	-	-	-
11	-	-	-	10.2	10.5	11.1	-	11.9	12.5	12.8
13	-	-	-	11.6	12.4	12.7	-	-	-	-
15	9.9	11.3	12.3	12.4	12.6	-	-	-	-	-
16	-	-	-	-	12.8	13.4	14.4	14.7	15.3	16.8
17	11.3	12.2	13.4	13.6	14.0	14.9	15.7	16.6	17.3	18.4
18	11.7	12.6	13.8	14.7	15.9	16.8	-	-	-	-
19	12.1	13.4	14.4	15.4	16.3	17.3	18.4	18.6	18.3	19.1
20	-	-	-	15.6	17.1	18.2	-	-	-	-
21	12.6	14.0	15.1	16.2	16.5	-	-	-	-	-
22	13.3	14.9	15.9	16.9	18.5	19.5	-	-	-	-
23	13.9	15.4	16.5	17.7	17.0	17.2	17.8	18.5	19.2	20.2
24	13.9	15.6	16.7	18.3	19.2	19.8	20.4	21.0	-	-
25	14.9	17.0	18.0	19.0	18.8	17.7	19.6	20.7	20.7	21.2
26	15.3	17.4	18.4	19.5	19.2	20.6	20.7	21.6	-	-
27	15.7	17.7	18.9	19.9	19.2	20.9	21.2	22.0	22.4	23.1
28	16.0	18.0	19.2	20.3	20.1	21.3	21.9	22.3	-	-
29	16.4	18.8	19.9	20.9	20.5	20.5	22.2	22.8	23.2	22.4
30	16.8	19.0	20.5	21.1	22.3	22.3	22.7	22.9	-	-
31	17.1	20.3	20.6	22.1	22.3	23.3	23.3	23.6	23.7	24.2
32	17.4	20.5	20.8	22.3	23.3	24.4	23.9	23.5	-	-
33	17.9	20.9	21.2	22.6	23.7	24.0	24.3	24.4	24.8	24.9
34	18.3	21.4	21.7	23.2	23.7	24.4	25.3	24.0	-	-
35	-	20.6	22.1	22.2	24.5	25.1	25.4	25.0	25.5	26.1
36	-	20.9	22.5	22.6	24.6	25.7	25.9	25.3	-	-
37	-	21.5	22.8	23.2	25.3	26.2	26.5	25.7	-	-
39	-	22.2	23.5	23.9	26.0	26.9	27.3	26.5	-	-