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THE FERTILIZER FACTOR IN *PINUS PINASTER* AIT. PLANTATIONS ON SANDY SOILS OF THE SWAN COASTAL PLAIN, WESTERN AUSTRALIA

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E. R. HOPKINS

A. C. HARRIS
Conservator of Forests

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SUMMARY

TO meet future timber requirements in Western Australia it has been necessary to consider establishing softwood plantations on infertile, unexploited areas of the Swan Coastal Plain. *Pinus pinaster* is the only species that has proved suitable under plantation conditions on these heavily leached, sandy soils.

To ensure satisfactory establishment on the sands, it is generally necessary to employ a phosphatic fertilizer dressing at time of planting. Basal applications are essential at this stage to ensure the optimum P_2O_5 concentration is available to the restricted pine root system before leaching removes the nutrient out of the effective profile range. Ground rock phosphate is a suitable substitute for the superphosphate commonly used at time of planting and promises a more efficient method for adding P_2O_5 in the influence of excessive and rapid leaching losses down the profile.

With stand development on certain sites the effect of the initial fertilizer dosage fades resulting in degraded stands. Degrade may set in after the age of 10 years, depending on the particular site. Such stands can be economically returned to vigour by the use of subsequent fertilizer applications.

Broadcast treatments are essential to obtain economical stand responses in degraded stands. Phosphorus, nitrogen and zinc have been found to be deficient nutrients on such sites and growth improvement, resulting from treatment with amendments containing these materials, is maintained at a high level for at least seven years.

Nitrogenous fertilizers in conjunction with superphosphate have the most consistent and pronounced improvement effect obtained to date. The addition of 2 cwt. of ammonium sulphate to 5 cwt. of superphosphate per acre provides an economical method of improving the growth response beyond that obtained with 20 cwt. of superphosphate per acre.

Zinc may be a deficient element on most sandplain sites. In the soils with a limestone influence it may be a deficiency factor at time of planting and can be corrected by a 2½ per cent. zinc sulphate foliage spray. In the more eastern grey sand plantations, zinc has only been identified as a deficiency element in degraded stands which initially grew satisfactorily following P_2O_5 application. Here zinc deficiency symptoms can be remedied most effectively by the use of a 5 per cent. zinc sulphate spray. Soil applications of 1 cwt. and 2 cwt. zinc sulphate solid per acre have not proved as satisfactory as spray application.

INTRODUCTION

The current pine working plan for Western Australia aims to establish up to 200,000 acres of pine plantation (Harris 1957). Of this area, less than 50,000 acres of soil suitable for the desirable fast growing *Pinus radiata* is available. The remaining 150,000 acres of the estimate largely covers sandy areas of the Swan Coastal Plain which are suitable only to the more tolerant but slower growing *Pinus pinaster.*

To date 21,000 acres of this species have been established under plantation conditions mainly at Gnangara in the Wanneroo Division some 20 miles north-east of Perth. The oldest typical stands in this Division are 30 years of age. Present management information indicates that the rotation period for the pine on these sites will be 60 years.

Other sizeable plantations of *Pinus pinaster* established on the Coastal Plain are Somerville and Collier in the Perth metropolitan area, Myalup plantation west of Harvey and Ludlow plantation near Busselton. Sample plots have also recently been established in the Yanchep and Moore River areas to the north of Perth to determine the potential of these sites for the species.

As with all crop management problems on marginal sandy areas, plantation establishment on the Swan Coastal Plain has shown that nutritional factors are of prime importance. For 25 years the Forests Department of Western Australia has directed research to determine the role which fertilizers must play in the management of sandplain plantations. The majority of this work has been on a field plot basis; in certain instances fully replicated trials provide confident data for remedial fertilizer prescriptions to be drawn up. To date, however, opportunities to follow up the broad field work with detailed and controlled laboratory research have been limited and much of the investigation still remains at a general reconnaissance level.

The result of this activity is a mass of useful field data applicable to large areas of sandy soils and plantations not yet past the mid point of the estimated rotation period. This information, to be of benefit to future project planning in the nutrition field, is required in one comprehensive, cohesive report.

In this paper a summary of the general approach and findings of departmental nutrition investigations with *Pinus pinaster* on soils of the Swan Coastal Plain up to 1960, is provided. The possible part that fertilizers may play in correcting nutrition disorders is discussed where possible.

SITES AVAILABLE FOR PLANTING

Sites proposed for future *Pinus pinaster* establishment in Western Australia are confined mainly to the Swan Coastal Plain in a zone ranging from the Moore River in the north to Busselton in the south. Over much of this area a reliable, reasonably uniform rainfall of 25 to 35 inches falls; mainly during the four months of May to August. Summers are hot and dry.

The soils are sandy in nature and represent the remaining infertile portions of the Plain, which have not been cleared and utilised for agricultural purposes.

Plantation sites are located within two distinct geomorphic systems.

A.—*The Spearwood Dunes System* (McArthur and Bettinay 1960).

The Spearwood Dunes system is separated from the coast by a narrow undeveloped littoral zone and constitutes the western extent of plantation establishment. In its western margin the system consists of the Cottesloe soil association (Bettinay, McArthur and Hingston 1959) with shallow yellow and brown neutral sands overlying aeolinite. In many places limestone is exposed at the surface. The eastern portion of the system, the Karrakatta Association, is a series of sandy dunes reaching elevations of some 200 feet with soils consisting of leached, yellow and brown sands overlying limestone at depth.

Portions of Somerville, Stirling, Pinjar and Myalup plantations are sited on soils of the Karrakatta and Cottesloe associations.

B.—*The Bassendean Dunes System* (McArthur and Bettinay 1960).

The older Bassendean Dunes lie immediately to the east of the Spearwood Dunes. They occupy a far greater land area and often the two systems are separated by a narrow line of drainage depressions. The Bassendean System consists of deep grey sands in the form of dunes with maximum elevations over 200 feet. Dune soils are mainly humus podsols consisting of 3 to 12 feet of leached grey sands overlying an organic or iron hard pan. These soils are highly leached and poor in plant nutrients.

Gnangara, Collier, Coolilup and parts of Myalup and Somerville plantations are sited within the Bassendean Dunes System on the Bassendean soil association.

Soils.

The soils of both systems have an exceptionally low fertility status from the viewpoints of cation exchange capacity and percentages of the major plant nutrients. Cation exchange capacity has been found to be directly related to percentage of organic matter in the soil.

Gnangara sands have percentages of organic matter, as determined by loss on ignition, in the vicinity of 2.2 per cent. for the surface 6-inch layer and 0.3 per cent. at depth 36 inches. Chemical analysis reveals that surface P_2O_5 values of 20 to 50 parts per million, falling off to as low as 8 parts per million at a depth of 36 inches, are common on many plantation sites.

In texture the soils are coarse sands as indicated by the analysis contained in Table 1.

TABLE 1

Analyses of the Surface of Soils Supporting Average and Poor Pine Stands at Gnangara.

Location	Wetherel C. 19			Wetherel C. 18		
Site Quality	II			IV		
Sampling Depth (Inches)	0–6	6–12	12–18	0–6	6–12	12–18
Mechanical Analysis*—						
Coarse sand	88·4	86·1	90·4	93·4	93·4	93·7
Fine sand	7·5	8·5	6·4	3·3	3·5	4·2
Silt	4·1	2·3	1·4	0·5	0·6	0·8
Clay	....	3·1	1·8	2·8	2·5	1·3
Sand Fractionation*—						
0·02–0·08 mm.	1·3	2·3	1·0	0·6	0·8	0·8
0·08–0·10 mm.	0·7	1·3	0·7	0·6	0·3	·0·3
0·10–0·15 mm.	5·6	6·2	3·8	1·3	0·5	3·2
0·15–0·25 mm.	15·1	15·5	12·9	5·4	6·6	10·0
0·25–0·50 mm.	58·5	58·7	64·6	56·6	61·4	70·9
0·50–1·00 mm.	18·8	15·5	16·9	35·3	30·3	14·7
1·00–2·00 mm.	....	0·5	0·1	0·2	0·1	0·1
pH	6·0	4·6	5·7	5·7	6·2	6·0
Loss on ignition*	2·0	2·8	0·6	1·5	2·3	0·5

* Percentages.

Vegetation.

Under natural conditions the following major vegetation types occur:—

(1) Poor banksia scrub *(Banksia menziesii, B. attenuata* and *B. illicifolia)* often with intermixed jarrah *(Eucalyptus marginata)* and marri *(E. calophylla). Eucalyptus todtiana* is a common associate on the dunes and upright blackboys *(Xanthorrhoea preissii)* are common on the better banksia areas.

This type extends over the poorer parts of both dune systems and is generally associated with deep grey surface horizons and coffee rock or yellow sand at depths greater than 10 feet in the eastern section. It constitutes the poorest site quality for pine growth.

(2) Poor jarrah and marri forest with intermixed banksia understorey is often found in the better areas. This type characteristically has a friable coffee rock or yellow sand horizon within 7 feet of the surface and constitutes the best site for pine growth.

(3) Tuart *(E. gomphocephala)* forest occurs on those soils of the Spearwood Dunes system where limestone occurs reasonably close to the surface. Pine growth on this type often suffers severely from drought unless heavy thinning is maintained. The shallower phases are useless for *Pinus pinaster* growth.

(4) Paper bark *(Melaleuca parviflora)* thickets occupy isolated swampy areas of the flats. This type, often too moist for pine establishment in the first rotation, has in certain cases given rise to first class stands of pine.

THE SPECIES

Pinus pinaster is a native of southern and south-western Europe; France and Portugal in particular. Under natural conditions it is generally found growing reasonably close to the coast on a variety of poorer soils.

Growth rates and tree form are inferior in relation to the major commercial pines of the world generally used for afforestation. The species has, however, a tolerance of infertile sandy soils and summer droughts which makes it important to forestry in countries with the Mediterranean climate and poor soils available for afforestation.

Seed imported to Western Australia displays marked variations due to different geographic origin (Hopkins 1960). At least four distinct races have been separated in local plantations and of these, the Portuguese is the superior for local use. Since 1940 all seed used locally has been obtained from this source.

Species trials carried out over the past 40 years have definitely established that *Pinus pinaster* is the only softwood that can be seriously considered for large-scale plantation work on the sandy soils of the Swan Coastal Plain.

EARLY NUTRITION INVESTIGATIONS

Considerable exploratory work on *Pinus pinaster* establishment carried out within the period 1926 and 1933 proved that satisfactory strike and early growth could not be achieved on the poorer, sandy soils of the Swan Coastal Plain, without the addition of fertilizers at time of planting (Stoate 1950). Both blood and bone and superphosphate produced satisfactory results but as the former showed no superiority over the cheaper superphosphate, it was not considered for general plantation use.

It was further shown that—

(i) the optimum quantity of superphosphate required was 2 oz. per tree (approx. 1 cwt. per acre for pines at 7 ft. by 7 ft. spacing).

(ii) the position of application of the dosage is important. So long as the fertilizer is applied within a 12 inch radius of the base of the plant, results are satisfactory. Treatment effect falls off markedly if the dose is added further away or broadcast at the rate of 1 cwt. per acre over the site.

(iii) the superphosphate may be applied around the stem on the surface of the soil or in the planting hole.

Since 1933 it has been general practice in Western Australia to apply superphosphate at the rate of 2 oz. per tree either around the base of the tree by hand or in drill lines along the rows, at time of planting.

In 1935 further superphosphate trials were commenced with the aim of anticipating any further fertilizer requirements of the developing pine stands on these phosphate deficient soils. This project continued until 1952 and consisted of regularly supering* sample areas ranging from compartment size (25 acres) to small line plots of 30 trees located on representative sites within compartments. Plots were fertilized annually or biennially and applications from 2 oz. to 4 oz. per tree were tested. The fertilizer was, in most cases, applied to the base of the stem and not spread to any degree.

No positive information was obtained to show that subsequent supering had any beneficial effect further to that obtained with the initial application. It was assumed that the initial time of planting application was sufficient to carry the pines through to an age of at least 20 years (Stoate 1950).

Stoate (1950) applied zinc as a metal nail stem injection or as a 2½ per cent zinc sulphate spray on test areas in all Western Australian sandplain *Pinus pinaster* plantations. This latter application had proved essential for satisfactory growth of *Pinus radiata* on certain southern areas deficient in zinc. No response was obtained with *Pinus pinaster* growing on soils of the Bassendean association but zinc did prove to be a significant factor on southern, tuart zone soils, in certain instances.

In all plantations nitrogenous and potassium fertilizers at low concentrations were also tried. One trial indicated a treatment effect, all others proved negative or had no benefit over super alone (Stoate 1950).

Young (1948) working in Queensland with *Pinus taeda* and *Pinus elliottii* reports similar results for work with fertilizers other than phosphatic. All areas of these pines subjected to the application of phosphate fertilizers alone, or in combination with other nutrients, have given similar growth responses in accordance with the original soil phosphate value and the amount of P_2O_5 added. It is noteworthy, however, that when ammonium sulphate was used in a combination, the response to phosphate was reduced below that received when the same amount of the phosphate fertilizer was used alone. Treatment with ammonium sulphate alone seriously affected growth of plantation *Pinus taeda* and *Pinus elliottii*. Similar trends are reported for plantation fertilizing in Great Britain (Leyton 1958, Zehetmayr 1954).

Up to 1950 nutrition experimentation in local sandplain plantations had demonstrated that treatments other than a superphosphate dressing at time of planting on soils of the Bassendean system, and some phosphate dressings and zinc spray on soils of the Spearwood Dunes system, were unwarranted.

* "Supering" is used throughout this publication to mean the application of superphosphate. "Super" is used as an abbreviation for superphosphate.

RECENT NUTRITION INVESTIGATIONS

Since 1950, investigation into *Pinus pinaster* nutrition problems has mainly concentrated on the plantation areas to the north of Perth. Work has aimed to confirm and explain early results and to continue investigations on the use of fertilizers as second or subsequent dressings in the older stands at Gnangara. Trial nutrition plots on the previously untested soils of the Pinjar, Yanchep and Moore River areas have also been established.

PHOSPHATIC FERTILIZERS AT TIME OF PLANTING

Regular observational trials installed up to 1959 have generally confirmed early findings regarding the necessity of a phosphate application at time of planting for satisfactory *Pinus pinaster* establishment on sands of the Swan Coastal Plain. This rule holds true for all sites on the Bassendean association. Without superphosphate at time of planting, establishment is a failure.

On limited areas of the Spearwood Dunes system where the sands may have a limestone influence, it has been found that superphosphate is either not required due to relatively high initial P_2O_5 values (as in parts of Somerville and Stirling Plantations) or that zinc replaces P_2O_5 as the initial essential fertilizer to be added (Moore River plots).

(1) *Retention of Applied P_2O_5 in the Soil.*

In 1951 a project was commenced to determine the lasting effect of applied P_2O_5 in the plantation soil.

Sites that had received phosphate applications either at time of planting, or subsequently, were sampled in the 0 to 6 inch and 36 inch soil layers. Residual P_2O_5 values in parts per million were determined for each sample.

Results of the chemical analyses for two major sites are set out in Table 2.

TABLE 2.

Retention of Applied Superphosphate in the Profile under Gnangara Plantation Conditions.

A.—Flat Type.

Date Applied ...	Control		1934–41		1933–37		1933–49		1940		1950	
	P_2O_5 Values in Parts per Million											
Replications ...	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.
1	18	8	34	12	17	9	40	11	24	....	38	5
2	20	10	26	15	22	6	31	20	18	2	42	13
3	14	6	40	13	17	6	34	32	9	2	43	19
Mean P_2O_5 ...	17·3	8·0	33·3	13·3	18·6	7·0	35·0	21·0	17·0	1·3	41·0	12·6
Total super applied	*Nil*		12 oz.		6 oz.		16 oz.		2 oz.		2 oz.	
Date Sampled ...	19/1/51		16/2/52		19/1/51		16/2/52		19/1/51		19/1/51	

B.—Top of Medium Dune.

Date Applied	Control		1933–37		1933–49		1949		1950	
	P_2O_5 Values in Parts per Million									
Replications	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.	0–6 in.	36 in.
1	20	8	27	11	18	8	25	11	57	14
2	28	10	24	15	24	11	29	10	61	14
3	18	7	20	19	23	12	26	16	67	11
Mean P_2O_5	22·0	8·3	23·6	15·0	21·6	10·3	26·6	12·3	61·6	13·0
Total super applied	*Nil*		6 oz.		16 oz.		2 oz.		2 oz.	
Date Sampled	16/2/52		16/2/52		16/2/52		16/2/52		16/2/52	

It can be seen from these results that:—

(i) P_2O_5 values under plantation conditions may be as low as 17 parts per million in the surface six-inch soil layer and reduced to seven parts per million at a depth of 36 inches.

(ii) Applied P_2O_5 is not fixed to any extent in the surface soil layer. In older stands, surface P_2O_5 values return almost to normal within a few years after the cessation of regular superphosphate applications.

Sampling was also carried out in the surface six-inch soil layer to determine the effect of leaching on the 2 oz. basal superphosphate dosage applied at time of planting.

Table 3 sets out the results of monthly sampling on 12 different spots supered in September. August or September is the normal application time for this standard treatment.

TABLE 3.

Residual Effect of a 2 oz. Basal Application of Superphosphate Applied in September at Gnangara.

	P_2O_5 in Surface 6-inch Soil Layer in Parts per Million			
Sample	August	September	November	December
1	33·2	110·5	55·8	21·4
2	57·2	75·2	203·8	20·8
3	56·8	128·5	127·8	43·8
4	34·5	132·2	93·8	16·0
5	41·2	91·7	153·0	17·1
6	66·8	100·8	110·0	41·3
7	61·9	268·2	88·8	50·9
8	53·4	257·3	171·3	42·5
9	63·5	164·5	85·3	59·2
10	54·0	146·3	81·8	29·3
11	89·2	162·8	118·8	38·9
12	43·8	287·9	157·8	40·3
Mean	54·6	160·5	120·6	34·1

It is obvious that leaching alone may remove the applied P_2O_5 from the surface soil within a period of six months after application.

(2) *The Use of Rock Phosphate.*

Rock phosphate has proved superior to superphosphate as a means of applying P_2O_5 to pine plantations in Queensland (Young 1948, Richards 1954). In 1952 a replicated trial was established at Gnangara to determine whether this material could satisfactorily replace superphosphate at time of planting under the heavy leaching conditions of the Swan Coastal Plain.

Three treatments were tested:—

(a) Two ounces of ground rock phosphate (36.6 per cent. P_2O_5) applied basally at time of planting.

(b) One ounce of ground rock phosphate + 1 oz. of superphosphate (30.3 per cent. P_2O_5 for mixture) applied basally at time of planting.

(c) Two ounces of superphosphate (23.0 per cent. P_2O_5) applied basally at time of planting. This is the normal prescription.

Controls for an adjacent hormone trial showed that a P_2O_5 application was necessary on the particular site.

Table 4 sets out the results of the 1959 measurement of the experiment.

TABLE 4.

Mean heights for Phosphate Rock Experiment at Time of Planting.

Block	Mean Heights in Feet (unit 25 trees)		
	Treatment 1	Treatment 2	Treatment 3
1	23·25	22·75	21·25
2	20·0	21·5	22·75
3	22·25	21·75	20·75
4	19·0	22·5	22·0
5	22·0	24·25	24·5
Experiment Mean	21·3	22·6	22·0

Analyses of variance carried out on these results and the previous data for measurements one year after establishment proved—

(i) there was no significant difference between the survival percentages for the three treatments;

(ii) there was no significant difference in the height growth, up to an age of 7 years, for the three treatments.

SECOND OR SUBSEQUENT APPLICATION OF FERTILIZERS

In 1951, a series of disorders in the plantation at Gnangara caused considerable concern and prompted intensified nutrition investigation. The disorders were variable in nature (Stoate and Bednall 1953). The most important, from the nutrition viewpoint, is known as "rapid decline" and is characterised by a general falling off in crown density, needle length, needle colour and general tree vigour on certain areas that initially developed satisfactorily. This condition is also reported by Richards (1954) for certain older stands of *Pinus taeda* in Queensland.

Stand decline or degrade demanded a new approach to the nutrition problem at Gnangara. Past work concentrating on regular supering of sample areas provided no leads as to the identity of the deficient nutrients or the fertilisers that could be employed to ameliorate the condition.

The most important project established at Gnangara to investigate stand decline is commonly referred to as the "1952 Wait and See Series."

(1) *The Wait and See Series.*

This project, as the name implies, is an empirical method designed to widely test the effect of a range of fertilizer treatments on the degraded sites. Relative rather than absolute treatment effects were anticipated at the inception of the project in 1952.

Thirteen standard treatments (see Table 6) were applied over a range of thirteen degraded stands. Treatments were randomly located on each site and plots 0.1 acre in extent were generally established for each treatment. In certain instances, mainly those of the nitrogenous treatments, plots were reduced to 0.05 acres to lower fertilizer costs. Ten sample trees tagged for measurement in each plot were measured in 1953, 1954 and 1959, following establishment in 1952.

Results from the series have been recorded as:

(a) The frequency of individual treatment responses over the range of sites tested. See Table 5.

TABLE 5

Frequency of Response to Standard Treatments for Short and Medium Periods After Application.

Treatment Number	Compartment Response Designated +																				Totals	
	18		26		14		27		20 & 21		29		77		2		16		30			
	1	6	1	6	1	6	1	6	1	6	1	6	1	6	1	6	1	6	1	6	1 yr.	6 yrs.
1	....	+	—	—	....	....	—	—	....	+	—	—	+	+	....	....	—	—	+	0	2/10	3/9
2	....	....	+	+	....	....	....	+	+	+	—	—	+	+	+	+	—	—	....	0	4/10	5/9
3	+	+	....	....	+	+	+	+	+	+	—	+	+	+	+	....	—	+	....	0	6/10	7/9
4	+	+	+	+	....	....	....	+	....	....	....	—	+	+	+	+	—	....	+	0	6/10	5/9
5	....	....	+	....	+	....	+	+	....	....	—	—	+	+	....	....	—	....	+	+	5/10	3/10
6	....	+	+	+	....	....	....	+	+	+	—	—	....	+	....	....	+	+	+	+	4/10	7/10
7	+	+	+	+	+	+	+	+	....	+	—	—	+	+	+	+	—	+	+	0	7/10	8/9
8	+	+	+	+	+	+	....	—	+	+	....	—	....	+	+	—	+	+	+	+	7/10	7/10
9	....	....	....	+	....	....	....	+	—	+	—	+	....	+	+	—	+	+	+	+	3/10	7/10
10	....	....	....	....	....	....	....	—	—	....	—	—	....	....	—	—	—	—	....	....	....	....
11	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	10/10	10/10
12	—	+	+	+	+	+	+	+	—	+	—	—	—	+	—	—	+	0	+	....	5/10	6/9
13	+	+	+	+	+	+	+	+	....	+	+	+	+	+	—	—	—	0	+	....	7/10	7/9
Totals	6	9	9	9	7	6	6	10	5	10	2	4	8	12	7	4	5	6	10	5	65	75
	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	10	12	7	120	113

(b) The relative magnitude of treatment responses averaged over all sites in the six-year period from 1953 to 1959. Basal area increment per cent. was the criteria used to compare growth increments for the various treatments. See Table 6.

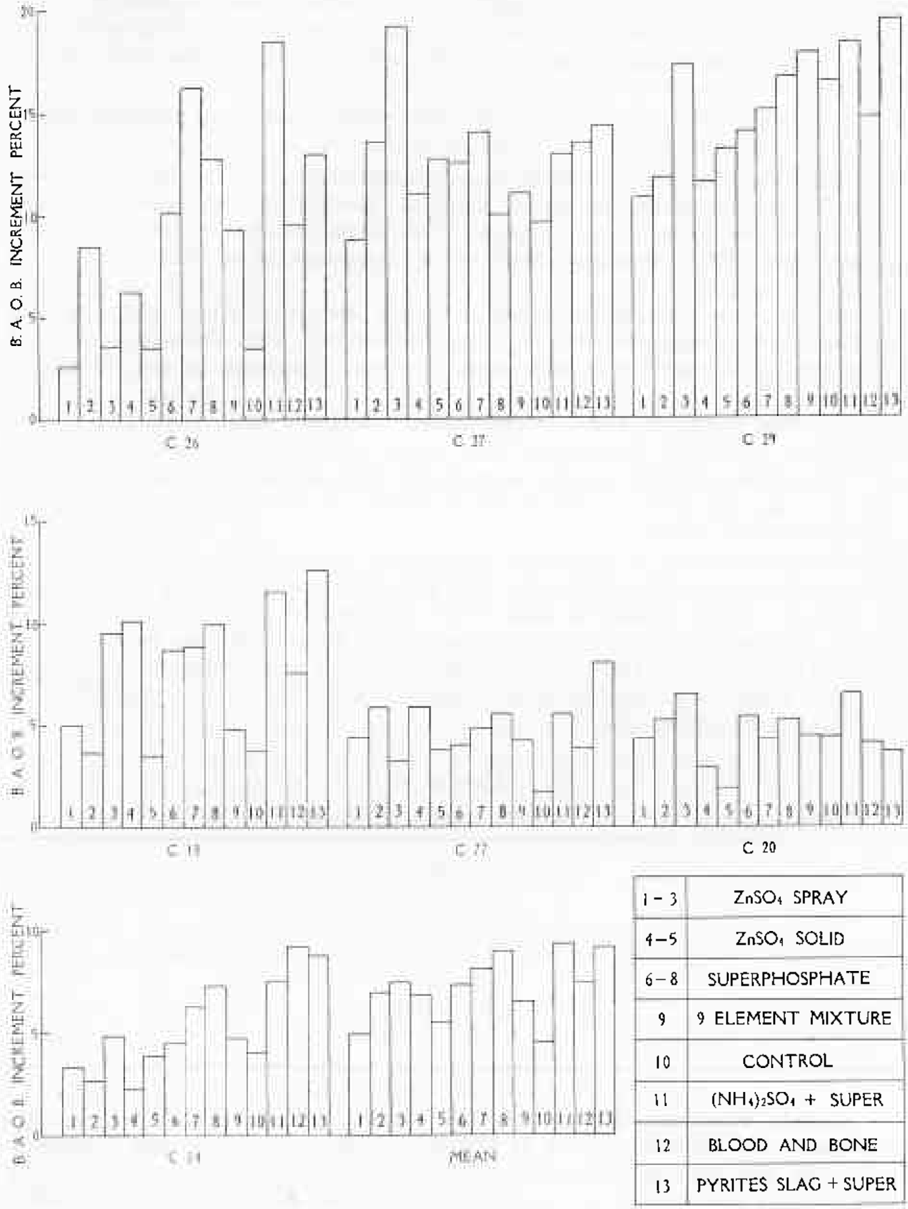

Fig. 1.

Histograms illustrating the relative pine responses to 13 standard fertilizer treatments tested in seven degraded stands at Gnangara plantation. Response is recorded as basal area increment per cent. over a six-year period.

(2) *Broadcast Superphosphate Strips and Plots.*

Further to the "Wait and See Series" designed to determine the most effective fertilizers to use in rehabilitating degraded stands, parallel work was commenced in 1953 with the aim of providing the following information:—

(a) The optimum stand age for fertilizer application and rate of response to treatment.

(b) The area of plantation over which subsequent fertilizer treatments would be applicable.

Since 1953 continuous chain wide broadcast super strips have been laid down to sample most plantation areas at Gnangara. Four cwt. of superphosphate per acre is the standard treatment applied. Broadcasting is carried out with a Ferguson fertilizer spreader operating along outrows at 2 chain intervals.

In the older plantation areas, 0.1 acre broadcast super plots initially replaced the continuous strips. This practice has been discontinued, as it does not adequately cover the range of sites presented in the Wanneroo Division.

(a) The Optimum Time for Subsequent Fertilizer Application and rate of Response:

The critical stand age, for second fertilizer application, varies with the site and can only be diagnosed by the incidence of stand responses to the trial superphosphate strips.

The earliest age at which an appreciable response has been obtained to date, is 10 years. This particular site was poor and subject to waterlogging in winter. Super applied in May, 1958, produced an improvement in crown colour and vigour which was clearly observed in October of that year.

Table 7 sets out the results of needle length measurements carried out on these control and treated areas 11 months after the date of application of 4 cwt. of superphosphate.

TABLE 7.

Superphosphate Effect on Needle Length at North Lane Poole, Gnangara.

	Needle Length in Inches			Number of Samples Measured
	Minimum	Mean	Maximum	
Control	2·5	3·6	5·0	204
Treatment	5·3	7·5	9·5	188

Counts were also carried out with samples taken over a wide area to determine the average number of fascicle bundles laid down since treatment. Although the number of needle bundles on the treated trees was slightly higher than the controls no emphasis is placed on this difference. Immediate crown response is considered to be due solely to an increase in needle length and improvement in needle colour.

It can be stated that—

(i) the optimum time for application of subsequent fertilizer treatments can only be determined, at this stage, by observing stand responses to diagnostic fertilizer strips placed to sample the area.

(ii) no evidence has yet been established to warrant a second application of fertilizer to stands younger than 10 years.

(iii) response to fertilizer treatment on degraded sites is immediate. A definite observable increase in needle length and an improvement in needle colour results within 6 months of early winter fertilizer applications.

(iv) crown response to fertilizers is initially a result of increased needle length and improved needle colour.

(v) Basal area responses occur in the second year after fertilizer application (Table 6) and are maintained at an appreciable level for at least 7 years.

(b) The Area of Plantation Over Which Subsequent Fertilizer Treatment Would Prove Economical:

Broadcast treatment strips have as yet not produced any appreciable observable response over the general healthy area of the plantation. Degraded areas are isolated, readily demarked in older stands, but as yet unidentifiable in younger stands.

Until further time is allowed to examine the long term response to the superposphate diagnostic strips, large scale subsequent fertilizing cannot be considered, excepting in limited older or very poor young stands showing distinct degrade symptoms.

(3) *Broadcast NP Strips.*

In 1958 a large scale trial to determine the economics of degraded stand improvement by NP Fertilizer mixture was commenced in 27 year old, thinned pine in Compartment 19, Gnangara.

The trial embraces 19 acres of treated area and 6 acres of control and comprises three adjacent 4 chain strips covering the whole width of the compartment. The centre strip was left untreated as a control.

Treatment on the two outer strips consists of a broadcast application of 5 cwt. superphosphate and 2 cwt. ammonium sulphate per acre. Sample trees of final crop standard were selected in each strip and measured.

Results for the last 15-month period of the 17 months since treatment are set out in Table 8.

TABLE 8

Increment in the Gnangara C.19 NP Fertilizer Trial

	Number of Trees	Total B.A.o.b.		Current Annual Increment per cent.
		27/11/58	2/3/60	
Treated 25/8/58	15	6·531	7·495	11·5
Control	16	6·839	7·543	8·2

Treatment has resulted in a 3 per cent. increment greater than the control in the 17 months since fertilizing. Since basal area response is small or nil in the first 12 months following application, the result is very promising.

Final assessment of this trial will be on a greater number of samples than indicated. The present sample selection is maintained purely for check purposes.

(4) *Stumpage Returns.*

In certain instances, sufficient replication of trials or confidence in results from single plots has permitted detailed plot analyses which indicate the financial aspects of subsequent fertilizer treatments to be carried out.

TABLE 9.

Stumpage Value Increment from Fertilizer Treatment

A.—Portuguese. Planted 1939. *Treated* 28/8/52

	B.A.o.b. per Acre			Mean Height			Merch. Volume per ac. (cub. ft.)		Stumpage Value (£1 5s. 3d. per load)*		Treatment Value
	1953	1959	Merch. Trees	1953	1959	Merch. Trees	1953	1959	1953	1959	
									£ s. d.	£ s. d.	£ s. d.
Control	102·7	128·8	77·5	31	36	39	....	1,101	....	24 8 5	....
Treatment	100·9	158·4	123·4	30	43	46	....	1,961	....	43 2 5	18 14 0

Gnangara. Compt. 18. Wetherel. Planted 10 ft. x 6 ft. Unthinned. Treatment Value per Annum = £3 2s. 4d. Treatment Cost = £6 6s.

B.—South African. Planted 1939. *Treated* 27/8/52

									£ s. d.	£ s. d.	£ s. d.
Control	57·7	69·0	....	20	25	0	....	0	....	....	....
Treatment	53·7	98·2	30·1	20	29	32	....	327	....	7 3 0	7 3 0

Gnangara. Wetherel Block. Compt. 26. Planted 10 ft. x 6 ft. Unthinned. Treatment Value per Annum = £1 3s. 10d. Treatment Cost = £6 6s.

C.—Portuguese. Planted 1931. *Thinned* 1952. *Treated* 26/9/53

									£ s. d.	£ s. d.	£ s. d.
Control	99·3	120·5	....	53	60	60	2,163	3,108	47 11 9	68 6 2	....
Treated	86·0	138·0	....	51	64	64	1,785	3,675	39 5 5	80 17 0	20 7 2

Gnangara. Wetherel Block. Compt. 19 Planted 10 ft. x 8 ft. Thinned to 210 stems. Treatment Value per Annum = £3 7s. 10d. Treatment Cost = £8

* 1 load = 50 cub. ft.

Table 8 sets out the volume and stumpage returns obtained from fertilizer treatments on three separate sites. Stumpage values are based on a single figure of 22/- per 50 cubic feet volume over bark. This was the average 1958 to 1959 stumpage rate at Gnangara for 7 ft. logs to a minimum under bark diameter of 4 inches. Data is based on three treated and three control plots in the cases of 9A and 9B. Data in 9C is for a single 0.1 acre plot and a surrounding control.

Treatment has proved economical in all three instances.

Approximate treatment costs, calculated on the basis of broadcasting with a Ferguson super spreader in the 1958 to 1959 financial year are as follows:—

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5 cwt. superphosphate/acre = £4 10 0.
8 cwt. superphosphate/acre = £6 12 0.
20 cwt. superphosphate/acre = £16 0 0.
5 cwt. of superphosphate +
2 cwt. of ammonium sulphate = £8 15 0 per acre.

THE PRESENT EXTENT OF THE KNOWLEDGE OF FERTILIZER USE IN PLANTATIONS ON THE SWAN COASTAL PLAIN

THE NEED FOR FERTILIZERS

Successful *Pinus pinaster* plantation esablishment on the sands of the Swan Coastal Plain cannot be accomplished without the use of nutritional amendments at time of planting.

Stand development, following initial treatment, is generally sound up to an age of approximately 20 years. In certain areas, however, stand decline or degrade has been found to arise between the ages of 10 and 25 years. Degrade is a result of soil nutrient deficiencies and recent work has shown that phosphorus, nitrogen and zinc treatments are necessary to restore degraded stands to vigour. One, and in some cases at least two, fertilizer treatments are therefore necessary to manage *Pinus pinaster* plantations successfully up to an age of 30 years on Coastal Plain sands.

An initial phosphate fertilizer dressing is general. The subsequent mixed fertilizer dressing only applies, as far as present research can determine, to degrade areas which occur only on certain soil types.

FERTILIZER REQUIREMENTS

(1) *Phosphate Fertilizers.*

Phosphate treatments are necessary at time of planting to ensure satisfactory pine establishment on the grey sands of the Bassendean association. Basal applications within a 12-inch radius of the transplant provide the optimum effect and concentrations of 2 oz. of either superphosphate or ground rock phosphate per tree are most satisfactory for general use.

In certain areas of the yellow and brown limestone stands of the western, Cottesloe and Karrakatta associations, phosphate is not required at time of planting. Here zinc or original high soil P_2O_5 are the operating factors.

On restricted areas within established plantations the effect of the time of planting fertilizing has been found to fade after a period of early satisfactory growth. Second applications of superphosphate, broadcast, on the resultant degraded stands produce marked growth responses.

Optimum superphosphate concentrations, to rehabilitate degraded stands, appear to be between 4 and 8 cwt. per acre, broadcast. After 4 cwt. the law of diminishing returns operates to excess. Average basal area responses, over the control, for applications of 4, 8 and 20 cwt. of superphosphate per acre tested, were found to be 2.6 per cent., 3.4 per cent. and 4.2 per cent. respectively (Table 6). This represents an 0.7 per cent., 0.4 per cent. and 0.2 per cent. increase per unit cwt. of superphosphate added.

Supering at concentrations greater than 4 to 8 cwt. per acre is not warranted, as at this level superphosphate in mixture with nitrogen or minor elements will produce far greater and more consistent responses than with the continued use of phosphate alone (Tables 5 and 6). To date it appears that 5 cwt. of superphosphate is a satisfactory value to employ in fertilizer mixtures.

Rock phosphate has only recently been proved a substitute for superphosphate at time of planting and further trials are required before it can be considered for general prescription. Rock phosphate has apparent advantages over superphosphate of comparative cost, higher contained P_2O_5 values and greater stability under leaching conditions. It is used in Queensland plantation practice (Richards 1954). There is a trend in Britain, however, after years of trials with mineral phosphate in heathland plantations, away from these materials to the favour of superphosphate (Leyton 1958).

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(2) *Nitrogenous Fertilizers.*

Prior to 1952 there was no indication that nitrogen was an important deficiency element under local pine plantation conditions. Mixed fertilizer trials carried out between 1933 to 1950 generally provided no benefit over phosphatic fertilizers used alone.

Young (1948), working with *Pinus taeda* and *Pinus elliottii* under Queensland conditions, has reported detrimental effects for nitrogen either used alone as ammonium sulphate or in mixture with phosphatic fertilisers. American and British workers report favourable effects of nitrogenous fertilisers in pine nutrition.

On sandy soils in Western Australia, nitrogenous materials have a definite place in plantation fertilising. In conjunction with phosphatic fertilisers, ammonium sulphate gives a degree of improvement in stands of subsequent degrade beyond that obtained with phosphate alone and at more favourable treatment costs. Leyton (1958) reports similar circumstances in heathland pine plantations in Great Britain. Nitrogen deficiencies only show up later in the rotation following initial phosphate treatments.

Average growth responses obtained for fertiliser trials over seven degraded sites, as set out in Table 6, show that a treatment of 2 cwt. of ammonium sulphate plus 5 cwt. of superphosphate produces an average response of 5 per cent. This is superior to all other treatments tested. Table 5, which records the frequencies of treatment responses over a range of 10 different sites, further shows that this NP mixture is more consistent in its increment over the general range of sites tested.

It is obvious that NP mixtures are superior to straight P application in subsequent fertilizer work. The few cost analyses available indicate that the NP treatment is economical from the viewpoint of improved stumpage values.

(3) *Potassium Fertilizers.*

Potassium has only been tested on a limited scale in Western Australian pine nutrition work. Recent trials incorporated 1 cwt. of potassium sulphate with 1 cwt. of superphosphate and seven other elements (Treatment 9, Table 6). Results are not very promising and in certain instances needle burning is attributed to this treatment.

Potassium has been found beneficial in America (Heiberg and White 1951, White 1956), while British workers (Zehetmayr 1954) report detrimental effects for this nutrient. Rossiter (1951) has shown the necessity of potassium to pasture growth on sands of the Swan Coastal Plain and it is considered that potassium sulphate at the 0.5 and 1.0 cwt. per acre level, in mixture with the standard NP treatment, is worthy of future plantation trial.

(4) *Zinc Sulphate.*

Zinc can be a deficient element in *Pinus pinaster* nutrition on all sands of the Swan Coastal Plain tested by plantations or small 0.1 acre sample plots.

On the limestone sands of the coastal Cottesloe and Karrakatta associations, zinc may be deficient at time of planting or within a few years after planting. This deficiency can be corrected by a 2½ per cent. zinc sulphate foliage spray.

Isolated test areas at Pinjar and Moore River on the Limestone associations indicate that zinc may replace the phosphate effect experienced at time of planting elsewhere. Superphosphate with zinc spray treatments on these sites has no effect further than zinc spray alone in the initial establishment stage and, in certain instances, superphosphate treatments had no advantage over the untreated control. Here zinc was the only necessary addition for establishment.

On the typical grey sands of the Bassendean association, zinc is not a deficiency element in the early years of establishment. In areas of subsequent degrade zinc is a deficiency element, and may be remedied with a 5 per cent. zinc sulphate foliage spray.

Of three spray treatments and two soil applications tested in degraded stands at Gnangara (Table 6), the 5 per cent. zinc sulphate spray has given the maximum average stand response. Table 5 further shows that this spray is the most consistent of the five zinc treatments tested.

It is of interest that a soil application of 2 cwt. of zinc sulphate solid broadcast per acre appears to have a toxic effect on pine growth.

Several tests carried out with zinc spray in conjunction with phosphate treatments on degraded sites of the Bassendean association have produced responses far above those of similar zinc or phosphate treatments employed alone. Results obtained in the second year after treatment in two areas tested were 3.5 per cent. for treatments with 1 cwt. of superphosphate plus a 2½ per cent. zinc spray as compared with 0.1 per cent., 2.8 per cent. and 3.6 per cent. responses for the 5 per cent. zinc spray, 8 cwt. of superphosphate and 5 cwt. of superphosphate plus 2 cwt. of ammonium sulphate treatments respectively. Insufficient plots have been established to confidently state what will be the average trend over all degraded sites for this combined, inexpensive treatment.

(5) *Commercial Pyrites Slag.*

Excellent results have been obtained on degraded sites with a treatment of 5 cwt. of superphosphate and 4 cwt. of pyrites slag. In relative trials with other treatments this combination has given a response second only to the combined NP mixture of superphosphate and ammonium sulphate (Tables 5 and 6).

Analysis of the slag reveals several minor elements to which the increased effect could be attributed. Zinc (1.24 per cent. as zinc oxide) has already been discussed. Copper (2.05 per cent. as copper oxide) has been found necessary for pasture growth on these soils (Rossiter 1951) while manganese (0.07 per cent. as manganese dioxide) was an early suspect element in Western Australian pine nutrition work. Sulphur (1.90 per cent. as sulphate and 0.85 per cent. as sulphide) is a further constituent which has been found important in pasture establishment in Australia.

Pyrites slag, containing 90 per cent. of silica and ferric oxide, is a very unwieldy vehicle for adding minor elements, and controlled pot trials are required to define the important constituents for use in more economical fertilizer mixtures.

MODE OF APPLICATION OF NUTRIENTS

Three separate application methods have been found necessary in *Pinus pinaster* fertilizer practice.

At time of planting, basal applications of superphosphate or ground rock phosphate are necesary to initiate growth. Broadcasting is essential for applications in stands older than three years, if fertilizer treatments are to be effective. Zinc is applied most satisfactorily as a foliage spray.

Three separate factors operate on the site to determine the placement of soil fertilizers:

(1) The poor nutrient fixing capacity of the surface sands.

(2) A climate and soil which favour rapid leaching.

(3) The rate of root development of *Pinus pinaster*.

(1) *Nutrient Fixing Capacity.*—The grey surface soils of the Bassendean association have very little fine fraction; in some instances the coarse sand percentage is as high as 96 per cent. Cation exchange capacity of these layers is directly correlated with their organic content, a value which is in the vicinity of 2.0 per cent. in the surface 6 inches and as low as 0.3 per cent. at a depth of 36 inches.

(2) *Leaching.*—The coarse nature of the soils and prevailing climatic conditions favour rapid leaching down the profile. Ploughing prior to planting, to reduce scrub competition, would also tend to aid leaching.

Superphosphate applied at time of planting at the rate of 2 oz. per plant, within a 12 inch radius of the transplant stem, may be leached from the surface 6 inch soil layer within 6 months of the date of application (Table 3) and from the surface 3 foot layer within 12 months of application. Analyses to determine the residual P_2O_5 values resulting from frequent superphosphate dressings within the plantation have shown that within 12 months of the cessation of fertilization, P_2O_5 values in the surface 36 inches soil layer are almost back to normal (Table 2).

(3) *Root Development of Pinus pinaster.*—For the first 6 months after planting, the pine roots are restricted to a soil cube of approximate maximum edge 12 inches. In a 3 year old plantation at 7 foot spacing, roots may, however, extend over a radius of 21 feet from the parent plant (Burbidge 1936).

Fertilizer employed at time of planting must be applied basally within a radius of 12 inches from the transplant if it is to be effective before leaching removes the soluble P_2O_5 out of range of the restricted root system. Two oz. of superphosphate per tree (approx. 1 cwt. per acre at 7 ft. × 7 ft. spacing) is optimum under such conditions (Stoate 1950).

It is not practical to broadcast superphosphate at time of planting under prevailing conditions. Excessively high concentrations of approximately 20 cwt. per acre are required to give the optimum, transitory, surface P_2O_5 values of 150 parts per million. The majority of this broadcast material would be lost through leaching before root extension could utilize it, and the only effect the applied P_2O_5 between the rows may have is to encourage excessive weed growth.

In stands older than 3 years, where the feeding roots are fully utilizing the surface soil layers, basal fertilizer applications are only able to feed the limited root area immediately adjacent to the pine stems. Under these conditions, broadcast dressings, at much reduced concentrations, adequately supply the entire surface root area of the site.

This pattern of fertilizing applies to sites where leaching is an excessive factor. In Queensland plantations where the applied nutrients are fixed in the surface soil layers (Richards 1954) there is possibly no great advantage in utilizing basal treatments. This should also hold true for *Pinus pinaster* and *Pinus radiata* plantations established on the more fertile soils of Western Australia.

Zinc deficiencies can be effectively remedied by foliage sprays, stem injections or soil treatments. The foliage application has proved the most economical and efficient.

TIME OF APPLICATION OF SUBSEQUENT FERTILIZER TREATMENTS

It is not possible, from present research, to set a single figure as the optimum time to fertilize to prevent decline. The value varies with individual sites.

Information obtained from continuous, one chain wide, subsequent superphosphate strips over the plantation area has shown that the earliest stand age at which treatment is warranted is 10 years. No effective response has been obtained from the diagnostic strips located in younger stands.

Until a greater knowledge of the factors of site quality for the plantation areas is available the time to apply subsequent fertilizer treatments can only be determined by trial fertilizer strips.

Other points must be considered. It is not practical to use a mechanical broadcaster until the stands have been pruned and cleaned. Also, it is most desirable that subsequent fertilizer treatments should be in thinned stands, wherever possible, to ensure that the cost of fertilizing is carried only by merchantable trees.

Wright (1957) has shown the effect of thinning in increasing the nutrient supply available to the remaining trees. Fertilizer applications should work in with this principle and, if possible, also be designed to aid litter breakdown.

RATE OF RESPONSE TO FERTILIZERS

All degraded stands treated have produced an immediate and marked fertilizer response within 12 months of application. Within six months of application, a marked increase in needle length (Table 7) and improvement in needle colour is noted.

Basal area increments from treatments are measurable in the second year after application and are maintained at an appreciable level of up to double the control for at least seven years after treatment (Table 6). Limited measurements indicate that on certain areas the maximum basal area increment rate occurs in approximately the fifth year after treatment and decreases gradually in the two further years covered by measurement.

ECONOMICS OF SUBSEQUENT FERTILIZER PROGRAMMES

In the past it has been considered that the most important aspect of any plantation fertilizer research is to determine whether treatments will be economical from the viewpoint of improved stumpage values.

Detailed plot analyses on three separate areas at Ganagara have shown that subsequent fertilizing with either 8 cwt. of superphosphate per acre or 5 cwt. of superphosphate and 2 cwt. of ammonium sulphate is economical in degraded stands of good strain *Pinus pinaster* tested (Table 9). Values for basal area increments over a range of seven degraded sites carrying different aged stands (Fig. 1 and Table 6), when compared with the limited detailed cost analysis available, further indicate that fertilizing with an NP mixture is economical over the general area of subsequent degrade experienced.

With poor strain *Pinus pinaster*, such as the South African provenance which was widely planted in Western Australia in the 1930's, the immediate economics of fertilizing, from the stumpage value viewpoint, is debatable. Here other factors require consideration.

Even though present evidence points to sound economics for the rehabilitation of degraded stands, it is considered that this point is not the whole argument in favour of treatment. It is probable that future cost analyses will not be favourable to warrant treatments of poor strain compartments. These unthrifty areas, however, represent a potential hazard to the remaining healthy plantation through their existence as possible centres of infection for entomological and pathological epidemics.

Data estimating the costs of insect damage to plantations and natural forests is available (Baker 1959, Bendict 1959). It indicates that if sound sustained yield management is to be achieved, unhealthy stands, particularly in single species plantations, should be brought to full vigour as a preventative measure from the entomological viewpoint.

Fertilizing of these poor stands will also guarantee a higher recovery if they are to be clear felled and replanted with Portuguese stock.

THE PRACTICAL EXTENT OF SUBSEQUENT FERTILIZER PROGRAMMES

No evidence is available at present to warrant the application of subsequent fertilizer treatments to the general plantation area. So far it has only been proved that treatment is effective on sites subject to degrade.

It is felt that within the rotation period of 60 years, most areas of sandplain plantations will require at least one subsequent fertilizer treatment to maintain full vigour. Investigations being carried out on the rate of depletion of soil nutrients by the developing pine stand support this statement. These incomplete investigations, however, also show that after a period of approximately 20 years under plantation, there is a trend towards the gradual build up of nutrients in the surface soil as a result of litter decomposition (Hatch 1959). Heavier thinning practice may also offset the nutrient drain on the site by eliminating useless stems from the crop, building up the soil organic content and returning litter nutrients early in the rotation (Wright 1957).

The question of the practical extent of subsequent fertilizing practice may be at present summed up by stating that second applications of fertilizers are only warranted on areas of known degrade. This can be accomplished satisfactorily with a mechanical fertilizer spreader working along outrows.

LINES OF RESEARCH

Major lines of research established or being considered with the species under local conditions may be summarised as follows:—

(i) Larger and more confident field trials to determine the incidence of degrade in existing stands.

(ii) Trials to test cheaper and more effective fertilizer materials. Phosphate rock is an immediate possibility at present under trial. Potassium and calcium materials will be tested wherever present field plots do not cover them.

(iii) Pot trials and foliar analysis, coupled with detailed soil chemical analysis are avenues of research which will assist to explain the basic nutrition pattern of the species on the site.

(iv) The factors which decide the numerous and unexplainable site quality variations within established plantations are at present being investigated. Soil moisture studies and surface sand fractionation tests may be important in this direction.

(v) The effect of thinning and pruning treatments in building up the soil organic content and returning nutrients to the site through accelerated litter decomposition is considered important. Present trials will determine the optimum spacing for site utilization throughout a rotation. Work is also planned to determine the feasibility of utilising pasture or a green crop to build up soil structure and fertility before planting.

CONCLUSION

It is necessary when writing a paper on nutrition to outline the problems involved rather than to discuss relative advantages of crop management on a particular site. This paper may have adequately outlined nutrition work carried out to date in the *Pinus pinaster* plantations of the Swan Coastal Plain. In doing so, it has probably not encouraged the external reader to view pine establishment on these areas with confidence.

Experience to date indicates that fertilizer programmes must play an important part in the management of sandplain *Pinus pinaster* plantations. This has always been realized. It is sufficient to say that research indicates that such treatment will be practical over large areas of plantation.

Coastal Plain plantation sites have the advantages of being close to key markets, clearing and establishment costs are at a minimum, and the use of these neglected, infertile soils, wherever possible, is of benefit to the State economy as a whole.

Average growth rates for the plantations, although poor when compared to *Pinus radiata*, are quite reasonable when viewed from the world standard. With tree breeding attention, *Pinus pinaster* will become a much more favourable species for plantation use.

The Coastal Plain plantations are necessary if the future softwood requirements for the State are to be met. Reasonably good soil for *Pinus radiata* establishment is scarce in Western Australia and agriculture has first priority on its use. Forestry, as is normal, has had to turn to the problem areas to fulfil its obligations. All present indications are that it will do so effectively.

To close, it is worthy to stress that nutrition has now become as integral a part of forestry as the traditional practices of thinning, pruning and fire protection. It can no longer be considered within the profession as a hobby for officers working in marginal forests or on afforestation schemes, but must become a consideration of every forester working in producing forests. Rennie (1957) states the situation as follows ". . . the only alternative to diminishing timber productivity is the development of silvicultural methods which have, at least, as their basis the replenishment from extraneous sources of the nutrients removed via timber crops; and although to the forester this may seem a novel, revolutionary and perhaps impossible principle, it must be remembered that it is the one which for centuries has been the basis of sound husbandry and all lasting systems of agriculture."

In forestry, particularly on sites described for the Swan Coastal Plain, thinning practices and the addition of soil fertilizers have the same function. They must be considered in conjunction with each other. There is a limit to the extent to which satisfactory stand growth may be maintained through progressive thinning. There is also a limit to which nutrition amendments can be added to the site to support vigorous growth. The desirable balance between the two practices can only be determined from further investigation into the nutrient requirements, nutrient uptake and nutrient removal in managed forests. Studies into the economics of thinning and fertilizing schedules will determine our future forest practice in accordance with the nutrition findings.

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Most measurement, statements of results and assumptions based on results and relevant literature are those of the author.

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